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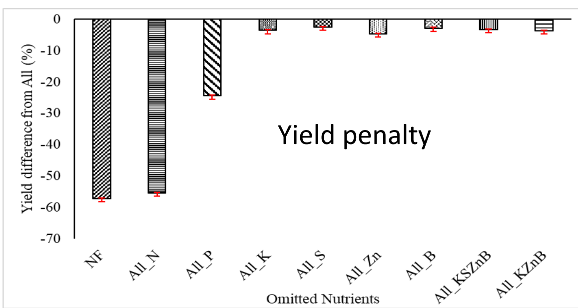

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1. Yield-Limiting Nutrients for Bread Wheat Production on the Vertisols of Central Highlands of Ethiopia.

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Abstract

Wheat production and productivity in Ethiopia are influenced by various factors, with nutrient availability being one of the most critical in the central highlands. An experiment was conducted in the Moretina Jiru and Mojana Wodera districts on 13 farmers' fields to identify the most important yield-limiting nutrients for bread wheat production. The treatments were designed to quantify the contribution of individual nutrients to yield increase. The study included ten treatments: NPKSZnB (All), NPKSZn (All-B), NPKSB (All-Zn), NPKZnB (All-S), NPSZnB (All-K), NKSZnB (All-P), PKSZnB (All-N), NP (Recommended NP), and a control (without nutrients). The treatments were arranged in a randomized complete block design with three replications at each field. Composite soil samples were collected before planting from each site at a depth of 0–20 cm for analysis of soil physicochemical properties. The results indicated deficits in Nitrogen (N), Sulphur (S), and Phosphorus (P) across all study sites. The study found significant differences in all measured parameters, including plant height, spike length, fertile tillers, biomass yield, grain yield, and harvest index, between treatments. In the Moretina Jiru district, the highest biomass (11,474 kg/ha) and grain yield (5,073 kg/ha) were achieved with the combined application of 30 kg S and recommended NP. This treatment increased biomass and grain yield by 333% (8,827 kg/ha) and 350% (3,945 kg/ha) compared to the control (without nutrient application). The lowest biomass and grain yield were observed in the control plot, which was statistically similar to the N-omitted plot. Nitrogen, Sulphur, and Phosphorus were identified as the limiting nutrients for biomass and grain yield of wheat. In the Mojana Wodera district, the highest biomass and grain yield were observed with the application of all treatments, which increased biomass yield by 240% (7,020 kg/ha), 184% (6,446 kg/ha), and 18% (1,540 kg/ha) compared to the control, N-omitted, and recommended NP treatments, respectively. The highest biomass yield (9,464 kg/ha) was observed in the Zn-omitted plot, followed by the application of all treatments. Zn omission increased biomass yield by 240% (7,020 kg/ha), 184% (6,446 kg/ha), and 18% (1,540 kg/ha) compared to the N-omitted treatment, control treatment, and recommended NP, respectively. The highest grain yield (4,009.6 kg/ha) and lowest grain yield (945.3 kg/ha) were obtained from the application of all nutrients *and the control treatment, respectively. Concerning agronomic efficiency, the highest (71 kg/ha) was recorded from the application of micronutrients (B and Zn), followed by P application. Nitrogen, Phosphorus, and Sulphur were the most yield-limiting nutrients for this district as well. Therefore, N, P, and S are the most yield-limiting nutrients for the production of bread wheat in the study areas. The application of NPS-containing fertilizers at biologically and economically optimal rates is recommended for the optimum production of bread wheat in the study areas.*

Keywords: Bread wheat, nutrient omission, yield limiting nutrients, Vertisols

Introduction

Wheat (*Triticum aestivum* L.) is a globally produced and sold cereal crop that accounts for 15% of total cereal crops area coverage globally (Kiss, 2011). It ranks second among the world's most important cereal crops after rice (Asadallah, 2014; Falola *et al*., 2017). Wheat accounts for around 17% of total grain production in Ethiopia, ranking it third after tef and maize (CSA 2021). Ethiopia's yearly production of wheat is about 5.8 million tons, with a mean productivity of 3 tha^{-1} (CSA 2021), which is significantly lower than the crop's possible yield of up to 5 tha^{-1} (Zegeye *et al*., 2020). Wheat is one of the most widely adapted crops, growing in a variety of altitudes (Tadesse, 2019) and produced in rain fed and irrigated production system. Wheat production and productivity in Ethiopia are influenced by different factors. Understanding and prioritizing the most important factors is the first steps in increasing wheat productivity and production. Lack of accurate information about soil nutrient requirements coupled with limited access to appropriate fertilizers could lead to mismatch between soil nutrient requirements and fertilizer applications (Kibrom *et al*., 2021).

Fertilizer research in Ethiopia began in the 1960s, after a soil survey expedition in the late 1950s revealed widespread deficiency of Nitrogen (N) and Phosphorus (P) in the soils. The initial research focused on the response of cereals, such as tef, wheat, and maize, to the application of N and P fertilizers. In the early 1970s, a blanket recommendation of 64 $Kgha^{-1}$ N and 20 $Kgha^{-1}$ P was made for all crops and soil types, which was applied in the form of di-ammonium phosphate and urea (Teklu *et al*., 2022; Abdulkadir *et al*., 2017). However, this recommendation was not effective, as only 30-40% of the farmers used fertilizers at a rate less than recommended, and the cereal yields increased only 10% despite a five-fold increase in fertilizer application since the 1980s. This was due to limited supply, high prices, and low and declining crop response to fertilizers. Moreover, the blanket recommendation did not account for the variability in soil types, climate, and crops ((Teklu *et al*., 2022). Therefore, in the 1980s, more comprehensive and site-specific research was conducted across agro-ecological and edaphic spectrum, which recommended 30-138 Kgha^{-1} N and 0-50 Kgha^{-1} P, depending on the crop and soil type. In the 1990s, research on the integrated use of inorganic and organic sources of fertilizers was initiated, which resulted in increased yield and better economic benefits. However, these recommendations were not widely adopted or disseminated by the national agricultural extension system (Teklu *et al*., 2022). In 2011, a new soil survey expedition was launched, which mapped the soil nutrient status using literature-based critical limits. The maps showed the deficiency of N, P, Potassium, Sulphur, Zinc, and Boron across the surveyed areas. The recent soil fertility map of the Amhara national regional state developed by MoANR and ATA indicates that in addition to the conventional N and P containing fertilizers and 96% of the soil are deficient in macro (N, P, K and S) and micro nutrients (Zn, B, Cu and Fe) (EthioSIS, 2016). Thereafter, the interest in applying other nutrients other than NP nutrient substantially increased. For this purpose, on station and on farm trial were established to evaluate different blend fertilizers across different parts of Ethiopia (Teklu *et al.*, 2022; Bizuwork and Yibekal, 2020; Hiwot, 2012; Abdurahman *et al*., 2021; Ishete and Tana, 2019; Tilahun and Tamado, 2019; Bizuwork and Yibekal, 2020; Tadele *et al*., 2018). However, this trial ends up with a range of outcomes. Some research report indicated that application of other nutrients for instance S nutrient increase crop yield (Shawel *et al.*, 2021, Assefa, 2016, Almaz 2021, Ayele *et al*., 2020; Sofonyas *et al*., 2022). In contrary, other report indicated that the non-significant impact of this nutrient (K, Zn and B) on wheat yield (Tadele *et al*., 2018, Liben *et al*., 2020). There is also a controversy result on nutrient like K. Some report indicated that application of K increased crop yield (Hagos *et al*., 2017; Yohannes *et al*.,2018; Abiye *et al*., 2004; Hailu *et al*., 2017; Gebrehawariyat *et al*., 2018).

Nutrient omission trial is a technique that is used to estimate fertilizer requirements and identify nutrient limitations for crops. It involves applying adequate amounts of all nutrients except for the nutrient of interest, which is omitted. The yield gap between the target yield and the yield in the omission plot is then used to calculate fertilizer requirements (YESHIBIR, 2023; Abebe *et al*., 2018; Kumar *et al*., 2018). Nutrient omission trial is important for wheat crop because it can help to: determine the optimal rate and time of Nitrogen, Phosphorus, and Potassium fertilizer application for wheat, which are the three key nutrients that primarily limit crop productivity, identify the variability in soil fertility and crop response to fertilizers across different fields and regions, and develop site-specific fertilizer recommendations that can suit the local conditions, enhance the efficiency and profitability of fertilizer use, and reduce the environmental and economic costs of over- or under-fertilization (Kumar *et al.*, 2012*)*. Therefore, the objective of this experiment was to determine and prioritize the most important yield limiting nutrients and to investigate the indigenous soil supply of macro- and micronutrients for wheat production in the study area.

Material and Methods

Description of the Study Area: The experiment was conducted on farmers' field of Moretina Jiru district (8 farmer's field) and Mojana Wodera district (5 farmers field) during the main cropping season in 2021. Moretina Jiru is located in North Shewa Zone of the Amhara Regional State. The area is located 195 km North East of Addis Abeba. Vertisols are the dominant soil type in the areas. The farming system is characterized by mixed crop-livestock. Wheat, tef and sorghum are the most important cereals produced in the districts. The rainfall in the growth period was 1042.76mm. The temperature varies from 5.2°C in November to 28.8°C in June.

Mojana Wodera district is located in the Amhara regional state, North Showa zone, central Ethiopia. The district is located 202 kilometers north of, Addis Abeba, and 72 kilometers north of Debere Brehan town. Ithas an elevation range of 1459-3172 m above sea level and is traditionally separated into three agricultural zones: Dega (28%), Woyna Dega (69%), and kola (3%). Specifically, our experiment was conducted in the Dega agro-ecological zone. The district's yearly rainfall ranges between 800-1000 mm, and the annual temperature ranges from 10-18^{0}C

Treatments Set up and Experimental Design: The experiment was conducted in a randomized complete block design (RCBD) with three replications on total of eight farmers' fields in Moretina Jiru district and five farmers field in Mojana Wodera districts. The experiment is designed in such a way that the effect of each individual nutrient is quantified and should be compared with the recommended NP (167 Kgha^{-1} N and 103.5 Kgha^{-1} P_2O_5) and control (with no fertilizer). While omitting a nutrient, all other nutrients were applied. The rates were: 167 Kgha^{-1} N, 103.5 Kgha^{-1} P_2O_5, 60 Kgha^{-1} K_2O, 10.5 Kgha^{-1} S, 5 Kgha^{-1} Zn and 1 Kgha^{-1} B. The effect of S nutrient further looked with one more nutrient (30 Kgha^{-1}) with recommended NP rate. The total treatment was 10 (Table 1).

Crop Management: Bread wheat var. Dendea used at the rate of 150 $Kgha^{-1}$. Planting was by broadcast in July (23-29/2021) in Moretina Jiru and from July 17 to August 6/2021 in Mojana Woderadistrict. The wider gap for planting in Mojana Wodera district is because of planting date difference of distinct soil types (Vertisols and Cambisols). A gross plot size was 12.24m^2 and BBF (broad and bed furrow) with a bed and furrow width of 80 and 40 cm used. The whole amounts of TSP (0–46 P_2O_5-0), KCL (0-0-60 K_2O), $MgS0_4$ (12.9%S), ZnEDTA (10% Zinc), $Na_2B_4O_7.10H_2O$ (11% Boron), and half split of Nitrogen (46 N-0-0) fertilizer were applied at planting. The remaining half split of Nitrogen was topdressed at tillering stage of the crop. Harvesting was made at physical maturity of the crop.

Table 1. Treatment set up, description and nutrient application rate

Treatment		Description	Applied Nutrients ($Kgha^{-1}$) N	P_2O_5	K_2O	S	Zn	B
NPKSZnB	All	Application of all nutrients to determine the attainable yield with application of balanced nutrient	167	103.5	60	10.5	5	1
NPKSZn	All - B	Application of all nutrient except B to identify the soil indigenous supply capacity of B	167	103.5	60	10.5	5	0
NPKSB	All - Zn	Application of all nutrient except Zn to identify the soil indigenous supply capacity of Zn	167	103.5	60	10.5	0	1
NPKZnB	All -S1	Application of all nutrient except S (10.5 Kg) to identify the soil indigenous supply capacity of S	167	103.5	60	0	5	1
NPSZnB	All - K	Application of all nutrient except K to identify the soil indigenous supply capacity of K	167	103.5	0	10.5	5	1
NKSZnB	All - P	Application of all nutrient except P to identify the soil indigenous supply capacity of P	167	0	60	10.5	5	1
PKSZnB	All-N	Application of all nutrient except N to identify the soil indigenous supply capacity of N	0	103.5	60	10.5	5	1
NP	NP	Application Recommended N and P only for comparison with those treatments.	167	103.5	0	0	0	0
Control	Control	without any nutrient application	0	0	0	0	0	0
NP+30 Kg S	RNP + S2	Application of recommended N, P and S (30 $Kgha^{-1}$) to identify the response of S over the recommended NP	167	103.5	0	30	0	0

Data Collection: All agronomic data were collected following standard procedures. Effective/fertile tiller were recorded per plant base at maturity stage of the test crop by counting all fertile tiller having head from 10 randomly selected plants in each plots. Plant height (cm) was measured at maturity from the ground to the tip of the spike excluding the awns from 10 randomly selected main tillers from each plot. Spike length (cm) also determined from randomly selected 10 plants at maturity stage of the crop by measuring the spike of effective tiller from the bottom of the spike to the tip of the spike by excluding the awns. Above ground biomass from leaves, systems and seeds from the net plot area was harvested from the ground level and sun dried until constant weight achieved and then expressed in $Kgha^{-1}$. Grain yield ($Kgha^{-1}$) was determined after threshing the above ground biomass manually. The grain yield was adjusted to 12.5% moisture content after measuring the grain moisture using moisture tester.

Harvest index (HI) was calculated as the ratio of grain yield to the above ground biomass yield, expressed as a percentage and calculated with the following formula

$$HI = \frac{\text{Grain yield}}{\text{above ground biomass}}$$

Where; HI = harvest index

Agronomic efficiency of the applied nutrient was also determined by subtracting the yield of all minus nutrient in target from the yield of all and then divide this result by nutrient application rate. For instance, for determining the N agronomic efficiency, we can subtract the yield of All-N from the yield of all. Then divide this by the N application rate. To determine P agronomic efficiency, the yield from All-P was subtracted from all and then the result is divided by the P application rate. To determine the K agronomic efficiently, the yield from All-K was subtracted from the yield of all and then the result is divided by K application rate. To determine the S agronomic efficiently, the yield from All-S was subtracted from the yield of all and then the result is divided by S application rate. The same procedure was applied for Zn and B agronomic efficiency.

$$AE = \frac{GYf - GYc}{\text{Applied nutrient } Kgha-1}$$

Where AE= agronomic efficiency

GYf= grain yield of fertilized plot

GYc = grain yield of unfertilized plot

Soil sample Collection and Analysis: Composite soil samples from a depth of 0-20cm from each site were collected before planting for analysis of soil physicochemical parameters using an augur from 10 spots by walking in a zigzag fashion. After thoroughly mixing the composite samples, 1 kilogram of sub-sample was taken for the analysis. Soil samples were air dried under shed conditions and crushed to pass through a 2 mm mesh sized sieve. The texture of the samples was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was tested using the pH-water method with 1:2.5 soils to water suspension and measured with pH meter. Wet digestion method was used to determine the OC content of the soil (Walkley and Black, 1934). Total Nitrogen (TN) was determined using the modified micro Kjeldhal method, available P was determined using the Olsen *et al.*, (1954) method, and exchangeable K in the soil was extracted with 1 N NH_4OAc and determined using a flame photometer (Jones, 2001). A spectrophotometer was used to assess soil available Sulphur. CEC was measured after the soil was saturated with 1 N NH_4OAc and displaced with 1 N NaOAc (Chapman, 1965).

Data Analysis: The collected data were subjected to analysis using statistical analysis software (SAS) 9.3 (SAS, 2012). Analysis of variance (ANOVA) was carried out to determine the presence of significant differences among and between treatments. Mean separation of was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels.

Results and Discussion

Based on the soil analysis of before planting, the soil textural class the study sites were clay. The soil pH of both districts was 6.5. Based on the rating developed by Tekalign (1991), it was rated as slightly acidic (Table 2). The total Nitrogen, organic carbon and available S content of both site also rated as low to very low (Table 2). The soils of both experimental sites of the districts are rated as high in K, Mg. the Cation exchange capacity of (CEC) of both districts are also rated as high. The soil analysis result also indicated that the soil available Phosphorus (P) content was found to be ranged from low to optimum. The available P content of Moretina Jiru are even higher than the P critical developed for the same crops in Vertisols (Beza *et al*., 2020). The Boron (B) content of both districts is rated as low.

Table 2. Mean Soil-Physico chemical properties of the experimental soil

Parameters	Mean Value MW	MJ*	Rating	References
pH 1:2.5 (H_2O)	6.9	6.5	Slightly acidic	Tekalign (1991)
Total N (%)	0.09	0.1	low	Tekalign (1991)
Avail. P (ppm)	11.3	17.9	Low-optimum	Olsen (1954)
Excha. K ($cmolKg^{-1}$)	1.15	1	High	FAO (2006)
S (ppm)	0.52	0.5	Very low	Bashour and Sayegh (2007)
B (ppm)	0.62	0.7	Low	Jones and Benton (2003)
Excha. Na ($cmolKg^{-1}$)	0.43	0.4	Moderate	FAO(2006)
Ca ($cmolKg^{-1}$)	19.46	17.9	high - very high	FAO(2006)
Mg ($cmolKg^{-1}$)	5.48	3.6	High	FAO(2006)
CEC ($cmolKg^{-1}$)	26.53	22.9	High	Landon (1991)
EC (1:2.5 suspension) ($dS\ m^{-1}$)	0.12	0.1	Non saline	Horneck *et al.*, (2011)
Organic carbon (%)	0.96	0.7	low	Tekalign (1991)
Sand (%)	18		8.8	
Silt (%)	15.2		17	
Clay (%)	66.8		74.3	
Textural class	Clay			

**MJ: Moretina Jiru, MW= Mojana Wodera.*

Biomass: The analysis of variance showed that biomass yield was significantly influenced by nutrient treatments and across different sites in both locations (Table 3). The highest mean biomass yield (9053.5 $Kgha^{-1}$) was recorded in Moretina Jiru district, which increased its biomass yield by 14.9% (1,171 $Kgha^{-1}$) compared to the yield recorded in Mojana Wodera district. This variation can be attributed to the interaction of several factors, including climate and soil conditions. In Moretina Jiru district, the highest biomass yield (11474 $Kgha^{-1}$) was observed with the combined application of 30 Kg S and recommended NP for the test crop (Table 3). This treatment increased biomass yield by 333% (8827 $Kgha^{-1}$), 280% (8458 $Kgha^{-1}$), and 11% (1131 $Kgha^{-1}$) compared to

N omitted, control treatment, and recommended NP, respectively. In the order of importance, 85%, 8%, and 7% of biomass yield improvement were recorded from the application of N, S, and P nutrients, respectively. In the Mojana Wodera district, the highest biomass (9949.4 $Kgha^{-1}$) was observed from application of all nutrients followed by the application of all treatments (9593$Kgha^{-1}$). K omission increased biomass yield by 240% (7020 $Kgha^{-1}$), 184% (6446 $Kgha^{-1}$), and 18% (1540 $Kgha^{-1}$) compared to the Control, N omitted treatment, and recommended NP, respectively (Table 4). In order of importance, 56%, 19%, 13%, 5%, 4%, and 3% of the biomass yield improvement were recorded with application of N, P, S, B, Zn, and K nutrients, respectively. The biomass yield observed from the N-omitted treatment and the control treatment is statistically similar in both locations. Indicating addition of other nutrients in the absence of Nitrogen has no significant effect on biomass yield. Application of 30 $Kgha^{-1}$ S increased biomass yield in both locations compared with the recommended NP rate by 11% (1131 $Kgha^{-1}$) and 12% (985 $Kgha^{-1}$) in Moretina Jiru and Mojana Wodera districts, respectively. In both locations, the N-omitted treatment significantly reduced the biomass yield. Nevertheless, in Moretina Jiru district, the biomass yield observed from N omitted plot was found to be even lower than the control.

*Grain Yield***:** The analysis of variance showed that grain yield significantly influenced by nutrients omission and within site in both locations (Table 3). The highest mean grain yield (3990.5 $Kgha^{-1}$) observed from Moretina Jiru district increased grain yield by 25.7% (815 $Kgha^{-1}$) compared to the yield observed from Mojana Wodera district. In both locations, yield variability across site also found significant. This difference caused by the combined effect of variability across different farms. This includes; soil fertility difference, difference in precursor crops and others factor. In Moretina Jiru, application of 30 Kg S with recommended NP increased grain yield by 350% (3945 $Kgha^{-1}$) and by 311% (3599 $Kgha^{-1}$) compared to control and N omitted treatment, respectively. The yield observed from control plot and N omitted plot was statistically non-significant (Table 3). In Moretina Jiru district the yield difference between the control treatments and other treatment was nearly similar across different farms and the difference is large. Indicating that without fertilizer, production of wheat remained very low. The same is true for omitting Nitrogen. The relative importance of nutrients also determined by subtracting the yield observed from nutrient in question from the yield observed from application of all nutrients. This is important to prioritize nutrients based on their response in determining wheat yield. Accordingly, 84% of the yield of wheat was limited by Nitrogen application followed by 9%, 6% and 1% of S, P and K, respectively.

Therefore, N, S and P nutrient were identified as the major yield limiting nutrients for bread wheat productivity in the study areas. Of course, the response of wheat to N and P nutrient application is well documented for this crop (Adamu, 2018; Melesse, 2017; Getachew *et al*., 2015; Fresew *et al*., 2018).

The result indicated that, grain yield decreased with S omitted treatment and dramatically increased with application of 30 Kg S with recommended NP. Application of recommended NP with 30 Kgha^{-1} S was superior over other treatment in four farmers field (Figure 2). This treatment increase yield from 13% (595 Kgha^{-1}) to 27% (1107 Kgha^{-1}), from 2% (83 Kgha^{-1}) to 19% (1043 Kgha^{-1}), from 267% (3695 Kgha^{-1}) to 485% (4371 Kgha^{-1}) and from 226% (3519 Kgha^{-1}) to 511% (4410 Kgha^{-1}) compared to recommended NP, application of all nutrients with 10.5 Kgha^{-1} of Sulphur, control and N omitted treatment, respectively. Indicating that application of S nutrient is highly required in this district. The increase in grain yield with application of S nutrient was associated with a high N uptake rate and the positive interaction between both nutrients (Fernando *et al*., 2009). Similarly, different authors reported that application of S increased wheat yield (Aulakh, 2003; Kiros and Singh, 2009; Shawel *et al*., 2021; Assefa., 2022; Almaz 2021, Ayele *et al*., 2020; Assefa, 2016)

In Mojana Wodera district the highest (4009.6 Kgha^{-1}) and lowest (945.3 Kgha^{-1}) grain yield were observed from application of all nutrient and control treatment, respectively. The yield difference between the control treatments with other treatment was not consistent across different field and the difference was small in some of the sites (Figure 1). This is also because of the different variability across different farms. In some of the sites, the yield observed with the highest yielding treatment is even lower than the mean yield of all farms. Compared with the control, application of 30 Kg S with recommended NP resulted in the highest yield in two farms followed by application of all nutrients, K omitted and S omitted plot. In this district, 61% of the grain yield of wheat was limited by N followed by P application (26%), Zn application (7%), S application (4%), and B application (Table 6). Similarly, Limin *et al*. (2013) also reported that N was the first nutrient limiting for wheat yield in China, followed by P, and then K. Addition of K nutrient did not bring any significant yield improvement indicating indigenous soil supply of this nutrient is sufficient to at least the current situation.

Table 3. Effect of Nutrient omission treatment on biomass and grain yield of wheat

Treatment	Biomass yield ($Kgha^{-1}$)		Grain yield ($Kgha^{-1}$)	
	MJ	MW	MJ	MW
Control	3016.7^{d*}	2929.7^{c}	1127.9^{d}	945.3^{c}
All-N	2647.6^{d}	3503.3^{c}	1158.7^{d}	1113.6^{c}
All-P	9923.9^{c}	7723.8^{b}	4510.8^{bc}	2771.7^{b}
All-K	10868.6^{ba}	9593.1^{ab}	4716.9^{b}	4000.8^{a}
All-S1	9808.5^{c}	8450.2^{ab}	4372.1^{c}	3815.4^{a}
All-Zn	10924.7^{ba}	9464.1^{ab}	4749^{b}	3656.9^{ab}
All-B	10961.8^{ba}	9408.5^{ab}	4793.4^{ba}	3938.6^{a}
NP	10343.1^{bc}	8409.3^{ab}	4645.4^{bc}	3627.9^{ab}
NP+S2	11474.2^{a}	9393.8^{ab}	5073.1^{a}	3871.3^{a}
All	10565.8^{b}	9949.4^{a}	4757.6^{b}	4009.6^{a}
LSD(0.05)	638.33	1037	305.88	527.7
CV (%)	12.4	20.1	13.5	21.6

[*a, b, c] Mean value with different letters of superscript with in the column are significantly different ($P<0.05$), MJ= Moretina Jiru, MW= Mojana Wodera,

Table 4. Relative importance of Nutrient for biomass and grain yield of wheat (Kgha^{-1})

	Biomass yield		Grain yield		Relative importance of Nutrients	Increase (Kgha^{-1})				% Increase			
						BY		GY		BY		GY	
Nutrients	MJ*	MW	MJ	MW		MJ	MW	MJ	MW	MJ	MW	MJ	MW
Control	3017	2930	1128	945									
RNP	10343	8409	4645	3628									
RNP+S2	11474	9394	5073	3871									
All	10566	9949	4758	4010	All=(All-Control)	7549	7020	3630	3064				
All-N	2648	3503	1159	1114	N=(All-All-N)	7918	6446	3599	2896	85	56	84	61
All-P	9924	7724	4511	2772	P=(All-All-P)	642	2225	247	1238	7	19	6	26
All-K	10869	9593	4717	4001	K=(All-All-K)	-303	356	41	9		3	1	
All-S1	9809	8450	4372	3815	S1=(All-All-S1)	757	1499	386	194	8	13	9	4
All-Zn	10925	9464	4749	3657	Zn=(All-All-Zn)	-359	485	9	353		4	0	7
All-B	10962	9409	4793	3939	B=(All-All-B)	-396	541	-36	71		5		1

*MJ= Moretina Jiru district, MW= Mojana Wodera district, BY= biomass yield (Kgha-1), GY= grain yield (Kgha^{-1})

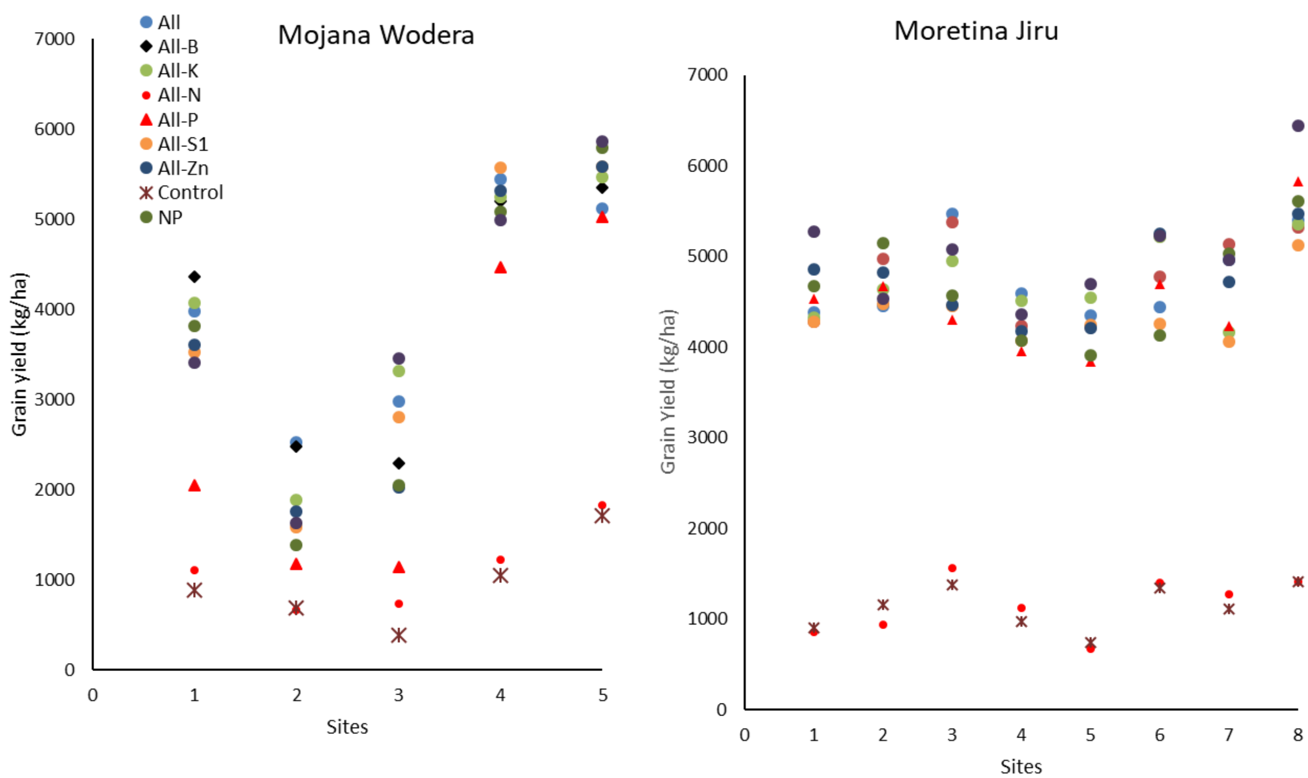

Figure 1. Effect of different nutrient omission treatment compared with the control

Agronomic and Yield Related Parameters: The effect of nutrients omission significantly influenced plant height in both locations (Table 5). In Moretina Jiru district the highest plant height of wheat was recorded from application of 30 Kgha^{-1} S with recommended NP rates. The lowest plant height was recorded from the control. The control treatment was found statistically non-significant with N omitted treatment. Indicating N is the most important nutrient in increasing the plant height. This increase in plant height could be attributed to the fact that N improves plant height by influencing the synthesis of macromolecules (proteins, enzymes, pigments, hormones, and so on) as well as the rate of processes such as photosynthesis on cell division and cell elongation, and ultimately internode length. Boosted N rates in the soil results in greater internode length that increase plant height. N application also improved the total vegetative growth of bread wheat (Saeed *et al*., 2012). In Mojana Wodera district, the highest and lowest plant height was recorded from K omitted and control treatments, respectively. Indicating that the soil K status of the experimental site were found to be sufficient in K. Spike length of wheat also significantly influenced by nutrient omission treatment in both locations (Table 5). The highest spike length in Moretina Jiru district was recorded from application of the recommended NP with 30 Kgha^{-1} S. In Mojana Wodera district, the highest spike length was recorded from K omitted treatment. In both locations, the lowest spike length was recorded from the control treatment and this treatment was found statistically as par with N omitted treatment. Fertile tiller were also counted in each treatment by considering all wheat planthaving head during maturity time. The analysis of variance showed that number of fertile tiller per plant showed significant variation with nutrient omission treatment (Table 3). In both locations, the highest number of fertile spike was recorded from K omitted treatment and the lowest was from the control treatment (Table 5). Indicating that application of this nutrients is not required in this district. This is actually because the experimental sites had high soil P content (Table 2). In Mojana Wodera district the highest yield observed from K omitted treatment was found statically similar with other treatments except the control (Table 5).

Table 5. Effect of nutrient omission on agronomic and yield related parameters of wheat

	Plant height		Spike length		Fertile tiller		Harvest Index	
Nutrient	MJ	MW	MJ	MW	MJ	MW	MJ	MW
Control	54.6^{d*}	62.9^{d}	5.57^{d}	5.09^{c}	2.66^{c}	2.57^{b}	0.4^{b}	0.2^{e}
All-N	54.8^{d}	63.8^{d}	5.43^{d}	5.13^{c}	2.48^{c}	2.73^{b}	0.44^{a}	0.24^{e}
All-P	85.6^{c}	81.7^{c}	8.2^{bac}	7.13^{b}	3.11^{b}	3.65^{a}	0.45^{a}	0.5^{bdc}
All-K	87.1^{bac}	88.4^{a}	8.5^{bac}	7.51^{a}	3.51^{a}	3.87^{a}	0.44^{a}	0.56^{bac}
All-S1	86.3^{bc}	85.2^{b}	8.21^{bac}	7.17^{b}	3.25^{ba}	3.83^{a}	0.45^{a}	0.46^{d}
All-Zn	88^{ba}	86^{ba}	8.05^{c}	7^{b}	3.13^{b}	3.6^{a}	0.44^{a}	0.58^{ba}
All-B	87.4^{bac}	85.8^{ba}	8.12^{bc}	7.14^{b}	3.36^{ba}	3.71^{a}	0.44^{a}	0.55^{bdac}
NP	86.3^{bc}	84.1^{bc}	8.13^{bc}	6.96^{b}	3.28^{ba}	3.57^{a}	0.45^{a}	0.48^{dc}
NP+S2	89.1^{a}	86.6^{ba}	8.64^{a}	7.15^{b}	3.36^{ba}	3.88^{a}	0.44^{a}	0.55^{bdac}
All	87.6^{bac}	86^{ba}	8.54^{ba}	7.1^{b}	3.32^{ba}	3.64^{a}	0.45^{a}	0.59^{a}
LSD (0.05)	2.4	2.92	0.48	0.34	0.31	0.34	0.0257	0.094
CV(%	5.21	4.99	11	6.9	17.18	13.4	10.3	27.5

[*a, b, c] Mean value with different letters of superscript with in the column are significantly different ($P<0.05$), MJ= Moretina Jiru, MW= Mojana Wodera,

Agronomic Efficiency: Agronomic efficiency is the amount of additional yield obtained for each additional Kg of nutrient applied (Fageria and Baligar, 2001). Agronomic efficiency could be used to characterize the nutrient effect (Dobermann, 2007). In Moretina Jiru district the highest (26 Kgha^{-1}) and lowest (-36 KgKg^{-1}) agronomic efficiency were recorded with application of S and B nutrient respectively. Application of N, P, Zn and K nutrient also resulted in agronomic efficiency of 22 KgKg^{-1}, 5 KgKg^{-1}, and 2 KgKg^{-1}, and 1 KgKg^{-1}, respectively. Application of K fertilizer resulted in agronomic efficiency of 0 KgKg^{-1} in this district (Figure 2). Indicating that the application of this nutrient does not increase wheat yield and the indigenous soil supply of this nutrient is the highest and external application of this nutrient is not required (Congreves *et al.*, 2021). In Mojana Wodera district, the highest (71 KgKg^{-1}) agronomic efficiency was recorded with application of Zn and B nutrients. The lowest agronomic efficiency (0Kgha^{-1}) was recorded from application of K nutrient. In between, application of P, N, and S nutrient resulted in agronomic efficiency of 28 KgKg^{-1}, 137KgKg^{-1}, and 13 KgKg^{-1}, respectively (Figure 2)

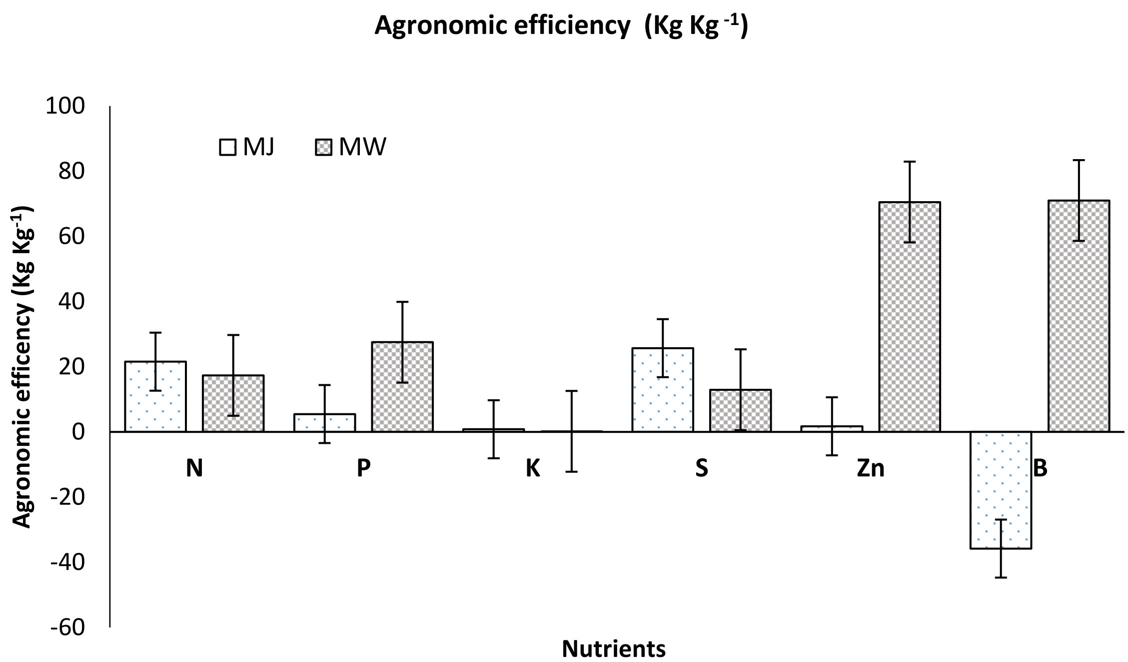

Figure 2. Agronomic efficiency of wheat for application of different nutrient in Moretina Jiru district (MJ) and Mojana Wodera district (MJ)

Conclusion and Recommendation

Appropriate fertilization based on actual limiting nutrients and crop requirements is economic and judicious for sustainable crop production. Nutrient omission trial is an excellent tool for nutrient assessment because it can indicate the most limiting nutrient and the order of limitation. The result indicated that all the measured parameters were responded for nutrient omission treatment in both locations. Higher mean grain yield of 5073 $Kgha^{-1}$ and biomass yield of 11474 $Kgha^{-1}$ wheat were recorded with application of 30 $Kgha^{-1}$ with recommended NP rate in Moretina Jiru district. In this district the lower grain and biomass yield were observed from the control (without nutrient application) and N omitted treatments indicating that N was the most yield limiting nutrient for wheat production. In this district, Nitrogen, Sulphur and Phosphorus nutrients were identified as the most yield-limiting nutrients for the study area and soils type and the application of Potassium, Zinc, and Boron nutrients didn'thave a significant wheat grain yield advantage over the applied Nitrogen and Phosphorus nutrients. Therefore, agronomic and economic optimum rates of N, S and P should be done for wheat in this district. In Mojana Wodera district, higher mean grain 4009 $Kgha^{-1}$ and biomass yield of 9949 $Kgha^{-1}$ was recorded from application of all nutrientsy. In this district, Nitrogen, Phosphorus and Sulphur nutrients identified as the most yield-limiting nutrients for the study area and soils type. Therefore, agronomic and economic optimum rates of N, P and S should be studied for wheat in these districts.

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2. Yield-Limiting Nutrients for Tef on Vertisols of the Central Highlands of Ethiopia

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Abstract

Tef production and productivity in Ethiopia are influenced by different factors. Understanding and prioritizing the most important factors is the first step in increasing tef production. One of the most important factors affecting tef yield is the application of suboptimal and unbalanced nutrients to the crop. The experiment was conducted in 2021 in Siyadebrna Wayu on 8 farmers' field with the objective of determining and prioritizing the most important yield limiting nutrients for tef and to investigate the indigenous soil supply of macro- and micronutrients for tef production. The experiment consists of ten treatments including: NPKSZnB (All), NPKSZn (All-B), NPKSB (All-Zn), NPKZnB (All-S), NPSZnB (All-K), NKSZnB (All-P), PKSZnB (All-N), NP (Recommended NP), NP+S2 and control (without nutrient). The treatments were laid out in a randomized complete block design with three replications. Composite soil samples were collected from each site before planting from a depth of 0–20 cm for the analysis of selected soil properties. The analysis of variance showed that plant height, panicle length, biomass yield, grain yield, and harvest index, were significantly influenced by nutrient omission. While total number of tillers and fertile tillers were not influenced by the nutrient omission. The highest biomass yield (7289 Kgha^{-1}) was obtained from the application of 30 Kgha^{-1} S with recommended NP) whereas the lowest (3316 Kgha^{-1}) biomass yield was obtained from the control. The highest grain yield (2001.9 Kgha^{-1}) was recorded from the recommended NP (120 and 68.7 P_2O_5 Kgha^{-1}) with the grain yield increment by 97% compared to N omitted treatment and by 97.3% compared with the control. But application of all nutrients has resulted in grain yield penalty of 9% compared with recommended NP. The result indicated that N and P are the major yield limiting nutrients and their application can sufficiently increase tef yield in the study area. This was justified by the fact that 89.6% of the yield increment was recorded from the application of N nutrients followed by 6.6% yield increment from the application of P and 2.5% yield increment from the application of S respectively. The Additive Main effect and Multiplicative Interaction (AMMI) analysis also indicated that; S omitted, application of S at 30 Kgha^{-1} with recommended NP, and P omitted treatment were the most stable treatment and showed wider adaptation over the tested sites. Whereas, B omitted, N omitted and control treatment were identified as the non-stable treatment and need further investigation. The result also indicated that NP>All-K > All-S >NP+S2 > All-B >All and All-Zn were identified as highest performing treatments across eight environments. Therefore, N and P are the major yield limiting nutrients for tef production in the study area.

Key words: *balanced, nutrient, omission, trial, wheat*

Introduction

Tef is a cereal crop and the local people's principal food crop in Ethiopia, while tef straw is favored as livestock fodder (Assefa *et al*., 2011). Tef is originated and extensively cultivated in Ethiopia (Assefa, 2003; Vavilov, 1951; CSA, 2019). It is a key cereal crop that provides a living for the majority of smallholder farmers, as well as a strategic crop with the potential to boost smallholder agricultural commercialization and food security in Ethiopia (Gidelew *et al*., 2022). The majority of small-scale farmers in Ethiopia prefers tef because it is the most adaptable to a wide range of environmental conditions (Gelaw and Qureshi, 2020). In comparison to other grains, the crop well grows in marginal locations and is drought tolerant. The national productivity of tef is very low 1.8 t/ hectare (CSA, 2019).

Tef production in Ethiopia faces several challenges, such as low yield, poor quality, pest and disease infestation, climate change, lack of improved varieties, inadequate input supply, and limited market access (Hailu *et al*., 2017; Tadele and Tewabe, 2021) all contributed to low productivity of tef. The low tef productivity in Ethiopia's are primarily due to continuous cropping, repeated tillage, insufficient organic fertilizer addition, complete removal of crop residues, and little or no compensation for removal through the application of external inputs (Karltun *et al*., 2013). There are also wide variations in grain yields among tef farms as a result of differences in the practices used to manage crops and in soil fertility (Fikadu *et al*., 2019). Even when traditional plant husbandry farmers used superior tef cultivars, yields were significantly lower than potential due to inadequate crop and soil management methods. In most cases, farmers that plant improved cultivars and adopt enhanced management approaches such as row sowing versus spreading and proper N and P fertilizer treatment earn the highest yields. Differences in planting rate, N and P application rates, and weed control strategies are all key contributors to tef output variability among farms and locales in Ethiopia (Vandercasteelen *et al*., 2014; Fekremariam *et al*., 2020).

Low fertilizer application by Ethiopian farmers is a challenge that affects the agricultural productivity and food security of the country. This is mainly because of lack of knowledge and extension services on the optimal type, rate, and timing of fertilizer application for different crops and soils. Therefore, Developing and disseminating location-specific fertilizer recommendations based on soil testing and crop response, and providing training and extension services to farmers on the best practices of fertilizer use is very important to increase tef productivity in Ethiopia. In this regard, nutrient omission trials are conducted to identify the nutrient deficiencies and imbalances that limit crop production in different soils and regions (Nziguheba *et al*., 2009). By omitting one or more nutrients from the fertilizer application, the trials can reveal the effects of each nutrient on the crop growth, yield, and quality. The results of the trials can help to develop and disseminate location-specific fertilizer recommendations based on soil testing and crop response, and to improve the efficiency and profitability of fertilizer use (Epée and Paul, 2018; Nziguheba *et al*., 2009; Singh *et al*., 2020; YADAV *et al*., 2020; Rawal *et al*., 2017).

Nutrient omission trial is a technique that is used to estimate fertilizer requirements and identify nutrient limitations for crops. It involves applying adequate amounts of all nutrients except for the nutrient of interest, which is omitted. The yield gap between the target yield and the yield in the omission plot is then used to calculate fertilizer requirements (YESHIBIR, 2023; Abebe *et al*., 2018; Kumar *et a* ., 2018). Nutrient omission trial is important for wheat crop because it can help to: determine the optimal rate and time of Nitrogen, Phosphorus, and Potassium fertilizer application for wheat, which are the three key nutrients that primarily limit crop productivity, identify the variability in soil fertility and crop response to fertilizers across different fields and regions, and develop site-specific fertilizer recommendations that can suit the local conditions, enhance the efficiency and profitability of fertilizer use, and reduce the environmental and economic costs of over- or under-fertilization (Kumar *et al*., 2012)

Therefore, the objective of this experiment was to determine and prioritize the most important yield limiting nutrients and to investigate the indigenous soil supply of macro- and micronutrients for tef production in the study area.

Materials and Methods

Description of the study area: Siyadebrina Wayu district is located in the North Shewa zone of Amhara National Regional State (ANRS), Ethiopia. The district is located 175 kilometers from Addis Ababa, the capital city of Ethiopia. It is precisely placed between 90 42′ and 90 53′ N and 390 08′ and 390 17′ E with an elevation ranging from 2705 to 1260 masl Siyadebrina Wayu district is characterized by the highland (Dega) agro-ecological zone. It receives rainfall ranging from 735 to 1187 mm and experiences average annual minimum and maximum annual temperatures of e 10 ◦C to 22 ◦C respectively. The population is mostly dependent on mixed farming systems. The, major crops grown in the district include: wheat (*Triticum Aestivum),* tef (*Eragrostis tef),* faba bean (*vicia faba*), and lentil (*Lens culinaris)*. However, the district faces several production challenges, such as: climate variability and change, which affect the rainfall patterns, temperature, and evapotranspiration, and cause droughts, floods, pests, and diseases, land degradation and soil erosion, which reduce the soil fertility, water holding capacity, and crop productivity, low adoption of improved agricultural technologies and practices, such as improved seeds, fertilizers, irrigation, and climate-smart agriculture, due to lack of access, awareness, skills, and resources, and poor market access and infrastructure, which limit the farmers' ability to sell their products and obtain inputs and services (Kifle *et al*., 2023). The irregular nature of rainfall has been a severe challenge in the farming community's livelihood in recent decades. According to a research paper by Tekeste Kifle *et al*., 2022, the major soil types in Siyadebrina Wayu district are Vertisols, Nitosols, and Cambisols. Farmer's practice drainage of excess water using BBF (broad bed and furrow) for most crops except tef.

Treatments and Experimental Design: The experiment was conducted in Siyadebirna Wayu district on a total of eight farmers' field in 2021. The treatments were arranged in a randomized complete block design (RCBD) with three replications. The experiment was designed in such a way that the effect of each independent nutrient is quantified and should be compared with the recommended NP (120 Kgha^{-1} N and 68.7 Kgha^{-1} P_2O_5) and control with no fertilizer. In the omission of one nutrient, all other nutrients were applied at the rate of 120 Kgha^{-1} N, 68.7 Kgha^{-1} P_2O_5, 60 Kgha^{-1} K_2O, 10.5 Kgha^{-1} S, 5 Kgha^{-1} Zn and 1 Kgha^{-1} B. The effect of S nutrient application also was quantified by two ways; by omitting the S (10 Kgha^{-1} S) and by increasing the S level (to 30 Kgha^{-1}) with recommended NP rate. The treatment includes 10 treatments (Table 1).

Table 1. Treatment set up, description and nutrient application rate

Treatment		Description	Applied nutrients ($Kgha^{-1}$)					
			N	$P_2 0_5$	$K_2 0$	S	Zn	B
NPKS ZnB	All	Application of all nutrients to determine the attainable yield with application of balanced nutrient	120	68.7	60	10.5	5	1
NPKS Zn	All - B	Application of all nutrient except B to identify the soil indigenous supply capacity of B	120	68.7	60	10.5	5	0
NPKS B	All - Zn	Application of all nutrient except Zn to identify the soil indigenous supply capacity of Zn	120	68.7	60	10.5	0	1
NPK ZnB	All - S1	Application of all nutrient except S (10.5 Kg) to identify the soil indigenous supply capacity of S	120	68.7	60	0	5	1
NPSZnB	All - K	Application of all nutrient except K to identify the soil indigenous supply capacity of K	120	68.7	0	10.5	5	1
NKS ZnB	All - P	Application of all nutrient except P to identify the soil indigenous supply capacity of P	120	0	60	10.5	5	1
PKSZnB	All-N	Application of all nutrient except N to identify the soil indigenous supply capacity of N	0	68.7	60	10.5	5	1
NP	NP	Application Recommended N and P only for comparison with those treatments.	120	68.7	0	0	0	0
Control	Control	without any nutrient application	0	0	0	0	0	0
NP+30 Kg S	RNP + S2	Application of recommended N, P and S (30 $Kgha^{-1}$) to identify the response of S over the recommended NP	120	68.7	0	30	0	0

Crop Management: Tef dega variety was sown by broadcasting at the recommended rate of 30 $Kgha^{-1}$. Planting was done starting from July 31 to August, 6/2021. The whole amounts of TSP (0–46 P_2O_5-0), KC1 (0-0-60 K_2O), $MgSO_4$ (12.9%S), ZnEDTA (10% Zinc), $Na_2B_4O_7.10H_2O$ (11% Boron), and half of Nitrogen (46 N-0-0) were applied at planting. The remaining half

Nitrogen was applied at tillering stage of the crop. Two weeding's were performed. Harvesting was done manually starting from the second week of December to end of December 2022.

Data Collection: All agronomic data were collected following the standard procedures. Effective/fertile tillers were recorded per plant at maturity by counting all fertile tiller having head from 10 randomly selected plants in each plots. Plant height (cm) was measured at maturity from the ground to the tip of the spike excluding the awns from 10 randomly selected main tillers from each plot. Spike length (cm) was also determined from randomly selected 10 plants at maturity stage by measuring the spike of effective tiller from the bottom of the spike to the tip of the spike by excluding the awns. In addition, above ground biomass from the net plot area was harvested from the ground level and sun dried until constant weight was achieved and then expressed in $Kgha^{-1}$. While grain yield ($Kgha^{-1}$) was determined after separating the grains from the straws by threshing manually.

Harvest index (HI) (%) was calculated as the ratio of grain yield to the above ground biomass yield, expressed as a percentage and calculated with the following formula

$$HI= \frac{\text{Grain yield}}{\text{above ground biomass}}*100$$

Where; HI = harvest index

Agronomic efficiency of the applied nutrient was also determined by subtracting the yield of all minus nutrient in target from the yield of all and then divide this result by nutrient application rate. For instance, for determining the N agronomic efficiency, we can subtract the yield of All-N from the yield of All. Then divide this by the N application rate. To determine P agronomic efficiency, the yield from All-P was subtracted from All and then the result is divided by the P application rate. To determine the K agronomic efficiently, the yield from All-K was subtracted from the yield of All and then the result is divided by K application rate. To determine the S agronomic efficiently, the yield from All-S was subtracted from the yield of All and then the result is divided by S application rate. The same procedure was applied for Zn and B agronomic efficiency.

$$AE= \frac{GYf - GY\ c}{\text{Applied nutrient Kgha}-1}$$

Where AE= agronomic efficiency

GY f= grain yield of all nutrient fertilized plot

GY c = grain yield of all nutrient minus grain yield of all nutrient minus the nutrient in target

Soil Sample Collection, Preparation and Analysis: Before planting, composite soil samples were collected from 0-20cm depth using augur from each site from 10 random spots by walking in a zigzag fashion for the analysis of soil physicochemical parameters. After completely combining the composite samples, 1 kilogram of sub-sample was taken, packed, labeled and sent to the soil laboratory of Debre Birhan Agricultural Research Center, where it was air dried and crushed and passed through 2 mm mesh sized sieve. The texture of the samples was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was tested using the pH-water method with 1:2.5 soils to water suspension and measured with pH meter (van Reeuwijk, 1986).). The wet digestion method was used to determine the OC content of the soil (Walkley and Black, 1934). Total Nitrogen (TN) was determined using the modified micro Kjeldhal method; available P was determined using the Olsen's calorimetric method as described by Olsen *et al.*, (1954), and exchangeable K in the soil was extracted with 1 N NH_4OAc and the amount was calculated using a flame photometer (Jones, 2001) and Mg was calculated using Atomic Absorption Spectrophotometer. A spectrophotometer was used to assess soil available Sulphur. CEC was measured after the soil was saturated with 1 N NH_4OAc and displaced with 1 N NaOAc (Chapman, 1965).

Data Analysis: The collected data were analyzed using statistical software (SAS) 9.3 (SAS, 2012) Analysis of variance (ANOVA) was carried out to determine the significant differences among the treatments. Mean separation of significant treatment means was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels.

Results and Discussion

Based on the pre planting soil analysis, the soil textural class of both districts was clay. The soil pH was found to be 6.5. Based on the ratings developed by Tekalign (1991), the pH was rated as slightly acidic and favorable for most crops including tef. The mean value of total Nitrogen, organic carbon and available S contents of experimental sites were rated as low to very low (Table 2). The soils of both experimental sites of the districts are rated as high in ex. K and ex. Mg. The

Cation exchange capacity of (CEC) of both districts is also rated as high. The soil analysis result also indicated that the soil available Phosphorus (P) and Boron (B) contents of the experimental sites were rated as low.

Table 2. Soil-physico-chemical properties of the soils of the experimental sites (mean of 8 sites)

Parameters	Range	Mean Value	Rating	References
pH 1:2.5 (H_2O)	5.88-7.2	6.5	Slightly acidic	Tekalign (1991)
Total N (%)	0.05-0.12	0.08	low	Tekalign (1991)
Avail. P (ppm)	8.9-21.6	13.40	Moderate	Olsen (1954)
Excha. K (cmol Kg^{-1})	1.07-1.32	1.19	High	FAO (2006)
S(ppm)	0.25-0.77	0.47	Very low	Bashour and Sayegh (200
B(ppm)	0.5-1	0.75	Low	Jones and Benton (2003)
Excha. Na (cmol Kg^{-1})	0.25-0.67	0.42	Moderate	FAO(2006)
Ca(cmol Kg^{-1})	19.36-24.2	21.76	high to very high	FAO(2006)
Mg(cmol Kg^{-1})	3.1-8.94	4.68	High	FAO(2006)
CEC(cmol Kg^{-1})	20-44	28.06	High	Landon (1991)
EC (1:2.5 suspension) (dS m^{-1})	0.04-0.09	0.07	Non saline	Horneck *et al.*, (2011)
Organic carbon (%)	0.52-1.5	0.96	low	Tekalign (1991)
Sand (%)	10-32	13.00	8.8	
Silt (%)	11-21	13.75	17	
Clay (%)	54-78	73.25	74.3	
Textural class		Clay		

Plant Height: The analysis of variance (ANOVA) showed that tef plant height significantly responded to nutrient omission (Table 3). On average, application of 30 Kg S with recommended NP had the tallest plant height (82.6 cm) while N omitted treatmenthad significantly the shortest plant height (40.5 cm). The lowest plant height observed from the N omitted plot was found statistically similar with the control without any nutrient application. Indicating that application of other nutrient irrespective of N does not bring any improvement in plant height (Table 4). This mainly because N application can increase plant height in tef by stimulating the production of cell division and elongation hormones, such as auxins and cytokinins, and enhancing the photosynthetic capacity and biomass accumulation of the plant. The result indicated that application of N nutrienthad only influence plant height. Similar result were reported by different authors for the same crops in Ethiopia (Beamlaku *et al*., 2022; Tamirat; 2019; Haftamu *et al*., 2009; Desta *et al*., 2021; Okubay *et al*., 2014). This might be attributed to the fact that N normally promotes vegetative development in tef, resulting in taller plants with longer panicles. Nevertheless, omission of P, K, S, Zn and B didn't show any role in determining plant height of tef. Plant height of tef recorded from application of all nutrients was even lower than the recommended NP rate.

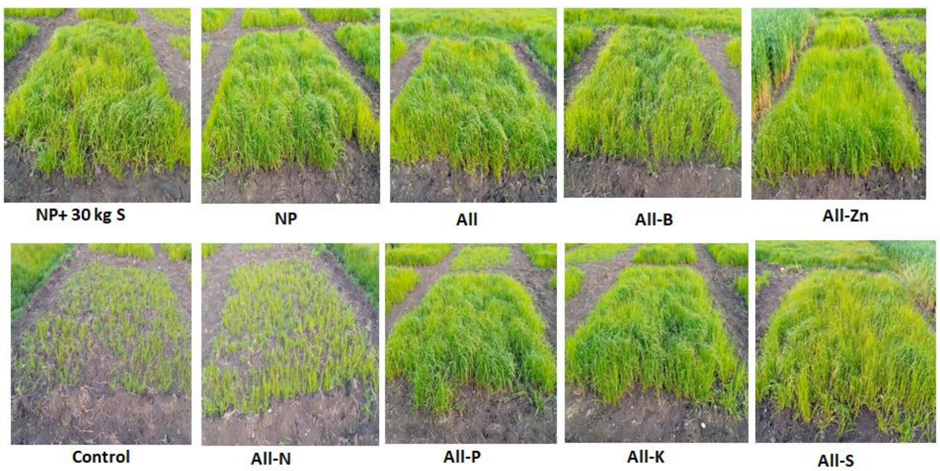

Figure 1. Treatment performance during Vegetative growth

Figure 2. Treatment performance during heading

Table 3. ANOVA for the effect nutrient omission on wheat yield and yield related parameters

Source	DF	Mean square value						
		PH *	PL	TT	FT	BY	GY	HI
Site	7	1467.2***	137.8***	32***	11.8***	57052809.7***	4350869***	0.019***
Rep	2	145.2*	11.8ns	2.89ns	1.2ns	239439.7ns	80608.6ns	0.0031*
Nutrient	9	5978.4***	493.1***	0.7ns	0.3ns	51907625.0***	3300193***	0.0034***
Error	221	40.01	4.559	0.402	0.33	752067	74038.96	0.00083
Total	239							
R-Square		0.88	0.84	0.52	0.54	0.84	0.79	0.48
CV		8.9	7.8	14.7	13.5	14.2	16	10.1
Root MSE		6.33	2.14	0.63	0.58	867.22	272.1	0.029
Mean Value		71.5	27.4	4.3	4.3	6102.2	1705.5	0.28
LSD (0.05)		3.60	1.21	ns	ns	493.4	154.8	0.016

**PH= plant height (cm), PL= panicle length (cm), TT= total tiller, FT= Fertile tiller, BY= biomass yield (Kgha^{-1}), GY= grain yield (Kgha^{-1}), HI= harvest index,*

****, **, * and NS = significant at >1, 1%, 5%*

Table 4. Effect of Nutrient omission treatment on yield related parameters of tef

Nutrient	Plant height (cm)	Panicle length (cm)	Total tiller	Fertile tiller	Harvest Index
NP+S2	82.6[a]	30.8[a]	4.4	4.4	0.26[d]
All-K	80.9[ba]	30[ba]	4.4	4.4	0.29[bac]
NP	79.6[bac]	29[b]	4.3	4.3	0.29[bac]
All-P	78.4[bc]	29.6[ba]	4.4	4.4	0.27[dc]
All-Zn	78.1[bc]	29.1[b]	4.4	4.4	0.28[dc]
All-B	77.7[bc]	29.3[b]	4.3	4.3	0.28[dc]
All-S1	77.2[c]	29.7[ba]	4.2	4.2	0.29[ba]
All	76.4[c]	28.9[b]	4.3	4.2	0.28[bdc]
Control	43[d]	19.5[c]	4.2	4.2	0.30[a]
All-N	40.5[d]	18.3[c]	4.1	4.1	0.30[a]
LSD* (0.05)	3.6	1.21	ns	ns	0.016

**LSD= Least significance difference; [a, b, c] Mean value with different letters of superscript with in the column are significantly different (P<0.05)*

Panicle Length: Panicle length was significantly (P<.0001) affected by the nutrient omission (Table 3). The longest (30.8 cm) panicle length was obtained from the application of 30 Kg S with recommended NP followed by All-K while the shortest (18.3 cm) was obtained from N omission. The panicle length recorded from the control was at par with that recorded from the N omission (Table 4). The result also indicated that 96% of the increase in panicle length was attributed from application of N nutrient. Similar to the result observed in plant height, application of other nutrient does not bring any improvement in panicle length. Indicating that application of other nutrient irrespective of N does not bring any improvement in panicle length. This mainly because Nitrogen is an essential nutrient for plant growth and development, and it affects various aspect tef physiology and morphology including panicle length (Tamirat and Tilahun, 2020). The highest panicle length observed from application of 30 Kg S with recommended NP might because application of Nitrogen, Phosphorus and Sulphur increased tef panicle length by enhancing the vegetative growth of the plants, resulting in taller plants with more tillers and longer panicles. Nitrogen also increased the post-anthesis Nitrogen uptake and translocation from the vegetative organs to the grains, which improved the seed set and grain yield. Phosphorus and Sulphur also improved the nutrient availability and the soil fertility, which supported the growth and development of tef plants (Ketema and Abdisa, 2021; Tamirat and Tilahun, 2020).

Number of Tiller per Plant: The analysis of variance (ANOVA) showed that neither total number of tillers nor number of fertile tillers wasn't significantly influenced by nutrient omission (Table 3). The result indicates that, irrespective of the nutrient applied the entire tillers were found fertile.

Biomass Yield: The analysis of variance (ANOVA) showed that biomass yield significantly influenced by nutrient omission treatment and across sites (Table 3). The highest biomass yield (7289 $Kgha^{-1}$) was obtained from the application of 30 $Kgha^{-1}$ S with recommended NP whereas the lowest biomass yield (3316 $Kgha^{-1}$) was from the control plot (Table 5). The biomass yield advantage of this treatment over the recommended NP was 4.1% (285 $Kgha^{-1}$) and 119.8% (3973 $Kgha^{-1}$) over the control. While the biomass yield from this treatment was at par with omission of P, S, Zn and B. Indicating that omission of P, S, Zn and B were equal importance in determining biomass yield. Compared with recommended NP, S omitted treatment, and application of all nutrients, application of 30 $Kgha^{-1}$ S with recommended NP increased biomass yield by 4.1% (285 $Kgha^{-1}$), 10.1% (671 $Kgha^{-1}$), and by 8.6% (577 $Kgha^{-1}$) (Table 5). The result indicated that irrespective of N nutrient, application of other nutrient does not bring any significant biomass improvement. This was justified by the fact that only 1.8% (60 $Kgha^{-1}$) yield improvement with application of 68.7 $Kgha^{-1}$ P_2O_5, 60 $Kgha^{-1}$ K_2O, 10.5 $Kgha^{-1}$ S, 5 $Kgha^{-1}$ Zn and 1 $Kgha^{-1}$ B.

Grain Yield: Grain yield is the outcome of several complex morphological and physiological processes that occur throughout crop growth and development (Khan *et al*., 2008). The analysis of variance revealed that tef grain yield was significantly influenced by nutrient omission (Table 3). The highest grain yield (2001.9 $Kgha^{-1}$) was recorded from the application of recommended NP and ithad 97% yield advantage compared with N omitted treatment and 97.3% yield advantage compared with the control (Table 5). The grain yield obtained from the other treatments was at par with the yield obtained from recommended NP. However, application of all nutrients has resulted in grain yield penalty by 9% (168 $Kgha^{-1}$) compared with application of RNP indicating that application of N and P nutrients was sufficient for this crop in the study area. This was justified by the fact that 89.6% of the yield increment was recorded from the application of N nutrients (Table 7). This was followed by 6.6% and 2.5% yield increment with application of P and Zn nutrients (Table 5).

Application of Nitrogen and Phosphorus fertilizer increased tef yield by enhancing the vegetative growth of the plants, resulting in taller plants with more tillers and longer panicles. It also increased the post-anthesis Nitrogen uptake and translocation from the vegetative organs to the grains, which improved the seed set and grain filling (Chala *et al*., 2022). Similarly, Beamlaku *et al*., (2022) reported that omission of N reduced tef grain yield by 81.6%, 96.5%, and 58.0% on-station, on-farm, and pot experiments, respectively as compared to the applied NP nutrients. The positive effect of N and P nutrients in increasing crop yield was reported by different authors (Fekremariam *et al*., 2022; Mirutse *et al.,* 2009; Beamlaku *et al*., 2022; Kumar *et al*., 2018; Rawal *et al*., 2018; Tadele *et al*., 2018; Tesfaye *et al*., 2019, Getahun *et al*., 2018; Kefyalew *et al*., 2012; Abay *et al*., 2011; Giday *et al.,* 2014; Bekalu and Tenaw, 2015). The result also indicated that application of other nutrients doesn't bring any significant yield improvement on tef. Nevertheless, Bereket *et al*. (2011), reported that On-farm application of Zn fertilizer at a rate of 8 Kgha^{-1} Zn increased tef grain and straw yields by 14% and 15% on average, respectively, which could be economically profitable. Eyasu *et al*., (2022) also reported that application of K fertilizer increase tef yield by 20% compared with the control from the on-farm experiment conducted in four districts of the central highlands of Ethiopia (Suluta, Mulo, Moretina Jiru, and Bereh). Similarly, Demiss *et al*., 2019 and Mulugeta *et al*., (2020) reported that K fertilizer application significantly affected tef grain and straw yield in 67% of the researched 18 locations in central Ethiopia.

Grain yield data were subjected to Additive Main effect and Multiplicative Interaction (AMMI) analysis to determine the stability of the nutrient across different environment (sites). This is actually, because the mean grain yield obtained in the normal analysis of variance (ANOVA) procedure might be skewed because of the highest yield observed from some sites. Based on the result obtained, S omitted, application of S at 30 Kgha^{-1} with recommended NP, and P omitted treatment were the most stable treatments and showed wider adaptation over the tested sites (Figure 3). Zn omitted, recommended NP, K omitted and application of all nutrients were moderately stable across the tested environment (Figure 3). Whereas, B omitted, N omitted and control treatment were identified as the non-stable treatment and need further investigation (Figure 6). The highest yielding treatments based on AMMI selection were also performed for the eight sites (Table 6). Based on this ranking, treatments having highest performance were found to be; NP>All-K > All-S >NP+S2 > All-B >All and All-Zn (Table 4).

Table 5. Effect of nutrient omission treatment on biomass and grain yield of tef

Nutrient	Biomass yield ($Kgha^{-1}$)	Grain yield ($Kgha^{-1}$)
NP+S2	7288.9^{a}	1906.9^{bac}
All-K	6938.3^{ba}	1969.3^{ba}
NP	7004^{ba}	2001.9^{a}
All-P	6574.5^{b}	1773.8^{c}
All-Zn	6573.1^{b}	1810.6^{c}
All-B	6621.1^{b}	1813^{c}
All-S1	6617.8^{b}	1914.9^{bac}
All	6711.6^{b}	1833.7^{bc}
Control	3316^{c}	1014.8^{d}
All-N	3376.3^{c}	1016.3^{d}
LSD (0.05)	493.37	154.8

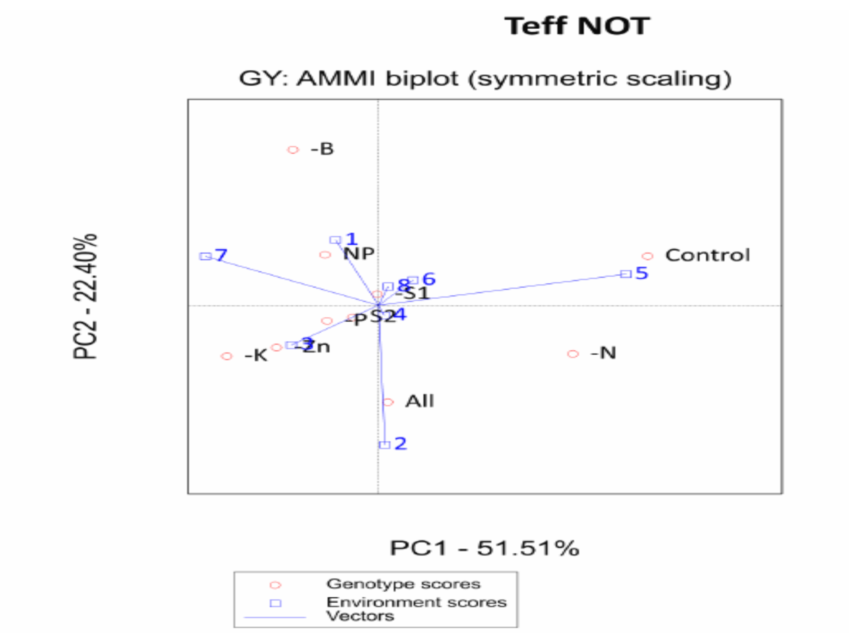

Figure 3. Stability of nutrient omission treatment

Table 6. AMMI Selections for the Highest Four Yielding Treatment across Eight Sites

			Treatment ranking			
Site	MeanGY*($Kgha^{-1}$)	IPC score	1^{st}	2^{nd}	3^{rd}	4^{th}
1	1998	4.132	NP	All-B	All-K	All-S1
2	1837	-0.603	All-K	All	S2	All-Zn
3	2206	8.406	All-K	NP	S2	All-S1
4	1960	-0.526	NP	All-K	All-S1	S2
5	1160	-23.888	NP	All-S1	S2	All
6	1250	-3.326	NP	All-S1	All-K	S2
7	1811	16.731	All-K	NP	All-B	S2
8	1422	-0.925	NP	All-K	All-S1	S2

**GY= grain yield*

Table 7. Relative importance of nutrient for biomass and grain yield of wheat

			Relative importance of	Increase ($Kgha^{-1}$)		Relative increase (%)	
Treatment	GY($Kgha^{-1}$)	BY($Kgha^{-1}$)	nutrients	GY*	BY	GY	BY
Control	1014.8	3316.0					
RNP	2001.9	7004.0					
RNP+S2	1906.9	7288.9					
All	1833.7	6711.6	All=(All-Control)	818.9	3396		
All-N	1016.3	3376.3	N=(All-All-N)	817.4	3335	89.6	88
All-P	1773.8	6574.5	P=(All-All-P)	59.9	137	6.6	4
All-K	1969.3	6938.3	K=(All-All-K)	-135.6	-227		
All-S1	1914.9	6617.8	S1=(All-All-S1)	-81.2	94		2
All-Zn	1810.6	6573.1	Zn=(All-All-Zn)	23.1	139	2.5	4
All-B	1813	6621.1	B=(All-All-B)	20.7	91		2

**GY= grain yield; SY= straw yield*

Agronomic Efficiency: Agronomic efficiency is the amount of additional yield obtained for each additional Kg of nutrient applied (Fageria and Baligar, 2001). Agronomic efficiency could be used to characterize the nutrient effect (Dobermann, 2007). The highest (21 $KgKgha^{-1}$) and lowest (-5 $KgKg^{-1}$) agronomic efficiency were recorded with application of B and S nutrient respectively. Application of N, P, Zn and K nutrient also resulted in agronomic efficiency of 7 $KgKgha^{-1}$, 2 $KgKg^{-1}$, and 5 $KgKg^{-1}$, and -3 $KgKg^{-1}$, respectively (Figure 4). Indicating that B, N, Zn and P were the most important nutrient in increasing agronomic efficiency of wheat. Nevertheless, application of K and S resulted in a negative agronomic efficiency (Figure 8). Negative agronomic efficiency for the applied nutrient is an indication that the nutrient application rate under consideration is too high, too low, or not suitable for the crop or soil conditions (Vanlauwe *et al*., 2011). It can also indicate that the fertilizer is lost to the environment due to leaching, runoff, volatilization, or denitrification (Brentrup & Pallière, 2010). Negative agronomic efficiency of applied fertilizer is undesirable for both economic and environmental reasons, as it implies a waste of resources and a potential source of pollution (Awada & Phillips, 2021). To avoid negative agronomic efficiency of applied fertilizer, it is important to apply the right type, amount, and timing of fertilizer for the specific crop and soil situation.

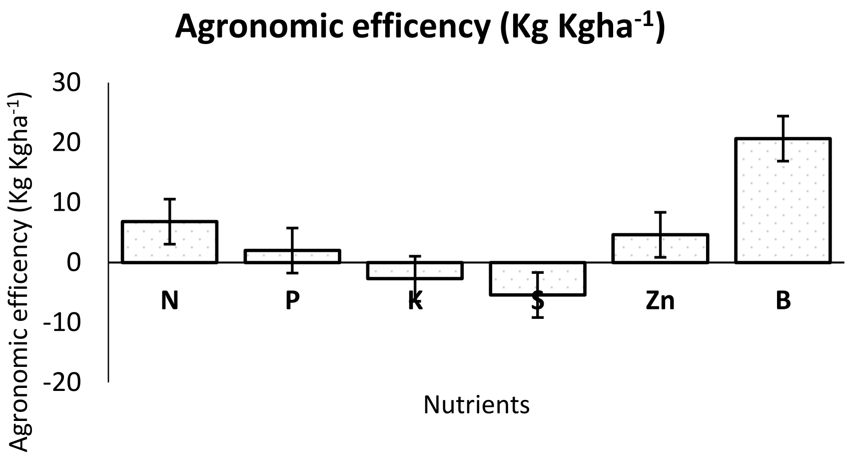

Figure 4. Agronomic efficiency of wheat for application of different nutrient

Correlation analysis: The correlation analysis result depicted that, grain yield was positively and significantly correlated with plant height (R^2=0.77***). It means that there is a strong and reliable relationship between the two traits, and that higher plants tend to produce more grains. This could be because taller plants have more biomass, more tillers, and longer panicles, which are all associated with higher grain yield (Jifar *et al*., 2015; Teklu and Hailu, 2005). Grain yield also positively and significantly correlated with biomass yield (R^2=0.92***). This is because plants that produce more biomass tend to produce more grains. This could be because higher biomass indicates higher photosynthesis, which provides more carbohydrates for grain filling. It could also be because higher biomass reflects higher tillering, which increases the number of panicles and grains per plant (Bayable *et al*., 2021; Teklu and Hailu, 2005). This means there is a strong and reliable relationship between the two traits, and that plants thathave longer panicles tend to produce more grains. This could be because longer panicles have more spikelets and grains, and also because longer panicles indicate higher vegetative growth and biomass, which provide more carbohydrates for grain filling (Woldeyohannes *et al*., 2022; Merchuk-Ovnat *et al.*, 2020). Similarly, grain yield of tef significantly and positively correlated with fertile tiller (R^2=0.18**), and total tiller (R^2=0.18**). Similarly, biomass yield were positively and significantly correlated with panicle length (R^2=0.85***) and plant height (R^2=0.87***) (Figure 5). Beamlaku et *al.*, (2022) reported that grain yield of tef positively and significantly correlated with plant height, panicle length and biomass yield (Figure 5).

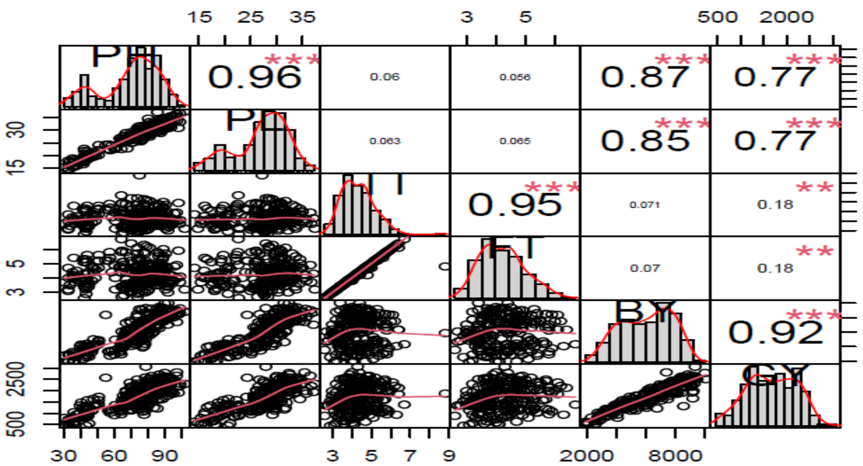

Figure5. Correlation among agronomic, yield related and yield data

Conclusion and Recommendation

Appropriate fertilization based on actual limiting nutrients and crop requirements is economic and judicious for sustainable crop production. Nutrient omission trial is an excellent tool for nutrient assessment because it can indicate the most limiting nutrient and the order of limitation. The result indicated that most of the measured parameters were responded for nutrient omission treatment. Higher mean grain yield of 2001.9 Kgha^{-1} and biomass yield of 7289 Kgha^{-1} tef were recorded with application of recommended NP and from application of 30 Kgha^{-1} S with recommended NP, respectively. The lowest mean grain (1014.8 Kgha^{-1}) and biomass (3316 Kgha^{-1}) yield observed from the control plot without any nutrient applications. The result also indicated that 89.6% and 88% of the grain and biomass yield improvement of tef was determined by N nutrient applications. This was followed by 6.6% and 4% yield improvement with P applications. Therefore, only N and P nutrients were identified as the most yield limiting nutrients for the test crop.

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3. Identifying Major Yield-Limiting Nutrients for Potato (*Solanum tuberosum* L.) Yield in Major Potato Growing Areas of North Western Amhara, Ethiopia

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Abstract

In Ethiopia, fertilizer consumption has shown a linear increment. One year on-farm research was conducted in Western Amhara, Ethiopia with the objective of identifying major yield-limiting nutrients for potato yield (Solanum tuberosum L.) productivity. The experiment was conducted in 2021 under rain feed cropping season on eight farm's field which are located at three major potato growing domains (Quarit-Yilmana Densa, Debecha and Baja-Sekela). A total of ten treatments [NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, NPS, NP and control (no input)] were evaluated in the experiment. The treatments were arranged in randomized complete block design (RCBD) with three replications. Improved potato variety "Gudenie **(***CIP-386423-13***)***" was also used as test crop. Urea, TSP (triple super phosphate), KCl (muriate of potash), $MgSO_4$ (magnesium sulphate), EDTA and Borax was used for the sources of N, P, K, S, Zn and B nutrients, respectively. Except urea, all fertilizer types were applied at planting using basal application. While, Urea fertilizer was applied in three equal splits at different crop stages (planting, flowering and tuber initiation). Before plating, one composite soil sample from each experimental site was taken at 0-20 cm depth and subjected to analysis for some selected soil physic-chemical properties. Both potato yield components and biological yield (tuber yield) were taken using standard procedure. Marketable and total tuber yields of potato showed highly significant differences (pr< 0.0001) among treatment means at each individual experimental site as well as from combined analysis in the domains. The main driving force for the occurrence of significant difference among treatment means in the ANOVA was due to omitting of N and P nutrients. In the ANOVA result, both marketable and total potato tuber yields showed quick and automatic responses for N followed by P nutrient. However, both marketable and total tuber yields didn't show any significant differences either due to adding or omitting of sulphur (S), Zinc (Zn), Boron (B) and Potassium (K) nutrients. This showed that, Nitrogen (N) and Phosphorus (P) nutrients are still the major potato yield-limiting nutrients, respectively at major potato growing areas in North West Amhara.*

Keywords: Potato, nutrient, omission, marketable yield

Introduction

Agriculture in Ethiopia contributes over 35%, 80% and 75% to the annual GDP, export income and job opportunity, respectively (CSA, 2018). Of the agricultural GDP, crop production contributed about 70% and over. Due to increased use of agricultural inputs (improved seeds, fertilizers and pesticides), agriculture showed a dramatic progress with the annual growth rate of 8% and over (CSA, 2018).

In Ethiopia, potato (*Solanum tuberosum* L.*)* is an excellent smallholder farmers' crop in the highlands with a short cropping cycle (3-4 months) which serves as cash and food security crop. It is an important crop to fill food supply gap during 'serious food shortage months' (October to December) which is before small grain crops are being harvested. Potato has high potential for improving food security, increasing household income and provides important nutrients such as carbohydrates, proteins and vitamins (vitamin C) (FAOSTAT, 2008). Ethiopia is among the top potato producers in Africa, with 70% of area coverage at and above 1500 m a.s.l altitude (Yilma, 1991).

The annual production of this crop in 2013 was 1.62 million tons from 0.18 million ha (CSA, 2014). The national average yield was 9 tha^{-1} (CSA, 2014) which was very low compared to the world average yield (16.4 tha^{-1}) (Husna and Eliakira, 2014). As Yazie *et al.,* (2017) mentioned by referring (ANRS, 2007 and 2008) report, potato is the widely grown crop for food and income generating sources in Amhara National Regional State (ANRS). ANRS takes the largest area (71,000 ha) for potato production which accounted 43.25% of arable land and produce 338,781 tons of potato (CACC, 2003a). Both nationally and regionally potato production is constrained due to poor soil fertility, fluctuated climatic condition, inadequate seed supply, poor post-harvest management and storage, high input costs lack of disease tolerant varieties, appropriate cultural practices and market access (Gebremedhin *et al.*, 2001; Yazie *et al.*, 2017).

In Ethiopia, fertilizer consumption has shown a linear increment Endale (2010). Following Plan for Accelerated and Sustained Development to End Poverty (PASDEP) for consecutive five-years, from 1995-2009, fertilizer consumption was increased by 10 tons every year for 16 years. After the development of soil fertility map by Ethiopian Soil Information System (EthioSIS, 2015) and the second growth and transformation plan (GTP II, 2016-2020), the country has increased the fertilizer types used from two to five and more. Due to this, annual import and consumption of fertilizers raised to >100,000 $tyear^{-1}$. Currently, the country imports about 1.4 million tons of multi nutrient fertilizers and projected to use over 2 million tons by the end of 2025.

In targeting the right fertilizers to the right places, EthioSIS project team has mapped the soil nutrient status of agricultural lands in Ethiopia (EthioSIS, 2016). Based on the developed map by the project, N, P, K, S, B, Zn, Fe and Cu are the deficient nutrients identified and recommended for enhancing crop productivity in most of Ethiopian agricultural soils. Even though the newly formulated fertilizer types needed a validation work, Agricultural Transformation Agency (ATA) and Ministry of agriculture (MoA) in collaboration conducted a direct demonstration trial on over 60,000 trial sites within the country. However, the developed soil fertility map was not validated by the response of crops under field experiment and had a major limitation from different aspects. With those limitations, the Ethiopian government is already customized the use of the above mentioned nutrients and made available as fertilizer form on the fertilizer market. Although the new formulated fertilizers were available on the fertilizer market, still there is no national/regional conscience on the importance of those newly formulated fertilizer types. Therefore, this activity was conducted with the objective of identifying the major yield-limiting nutrients for potato productivity in North West Amhara Region, Ethiopia.

Materials and Methods

Study Area Description: The experiment was conducted at three major potato growing domains (belts) (Quarit-Yilmana Densa, Debecha and Baja-Sekela) which are found in Amhara regional state and located in North West direction from the capital city of Ethiopia (Fig 1). All the testing domains or districts grouped under optimum potato producer agro-ecology range.

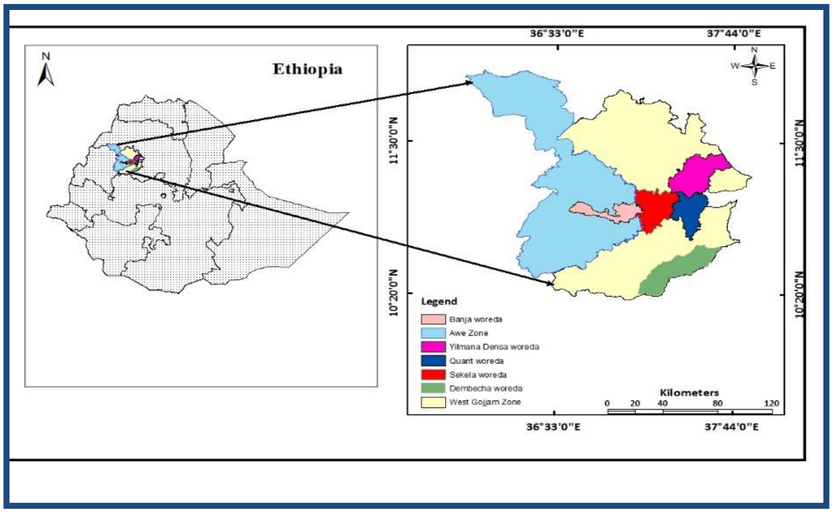

Fig 3 Map of the study districts

Soil sampling, Preparation and Analysis: From each experimental site, one composite soil sample was taken from five points following X- pattern sampling technique at the depth of 0-20 cm before planting. The sampled soils were air dried and sieved by (≤2 mm) sieve for the analysis of the required parameters. Soil pH, organic carbon (OC), cation exchange capacity (CEC), available Phosphorus (AP) and total Nitrogen (TN) were analysed using standard laboratory procedure. All the mentioned parameters were analysed at Adet agricultural research centre's (AARC) soil laboratory. Soil pH was determined using 1:2.5 soil-water suspensions according to (Taye *et al.*, 2002). Olsen (1954) was used for AP analysis. While, TN was analysed following Kjeldahl method (Bremner and Mulvaney, 1982). Soil OC was determined using wet oxidation. The CEC was determined using ammonium acetate method.

As indicated in Table 2, soil pH values of the experimental sites found from strongly (4.5-5.2) to moderately acidic (5.3-5.9) ranges Tekalign (1991) which is optimum for potato production (4.5-5.5). Available Phosphorus (AP) values were rated from medium (5-10) to high ranges (>10) based on Olsen (1954) nutrient rating scale. Except at one trial site in Banja-Sekela domain (site 2), OC and TN were in medium to high (1.5-3%) to >3% and (0.12-0.25%) to >0.25% range according to Tekalign (1991). According to Hazelton and Murphy (2007), CEC readings of the experimental sites were medium (12-25) to high (25-40) $Cmol_cKg^{-1}$ range in nutrient rating scale.

Table 1. Before planting selected soil properties of the experimental sites

Parameter	Denbecha		Banja-sekela			Quarit-Yilmana				
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Rating level	References
pH(H2O)	5.4	5.2	5.8	4.8	Na*	5.0	4.9	5.3	Strong-moderate	Tekalign (1991)
SOC (%)	1.798	2.176	1.065	3.631	Na	3.549	1.619	1.665	Low-High	Tekalign (1991)
AP (Ppm)	8.56	5.80	12.04	11.71	Na	5.74	8.67	5.8	Medium-High	Olsen (1954)
CEC	23.7	28.5	33.2	37.7	Na	32.8	33.7	33.0	Medium-High	Murphy (2007)
N (%)	0.182	0.162	0.083	0.273	Na	0.144	0.150	0.132	Low-High	Tekalign (1991)

*****Na=Not available*

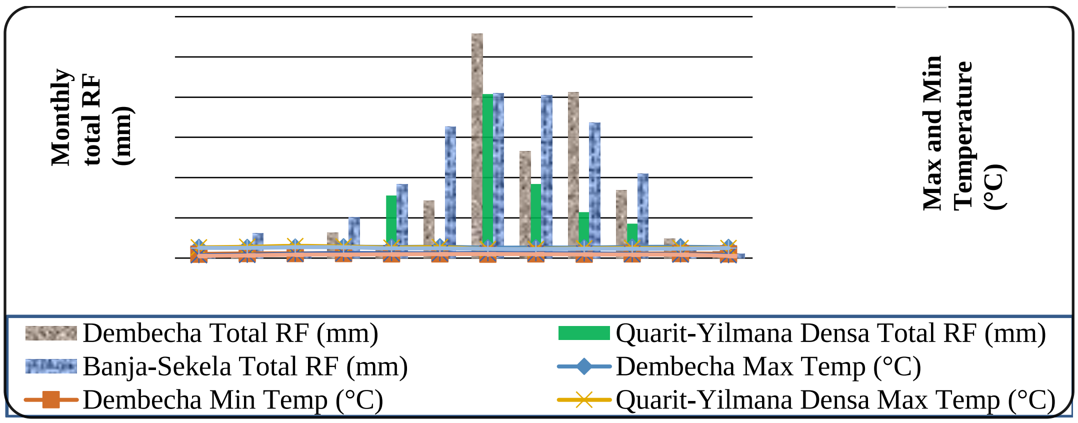

Fig 4. Climate data at study domains during the cropping season (2021) based on Ethiopian Meteorological Service Agency (EMSA), North West branch, Bahir Dar

Experimental Materials: Improved potato variety [Gudenie (CIP-386423-13)] was used as seed source. Urea, TSP, KCl, MgSO4, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Soil auger and core-sampler was used to collect soil samples. Ridomil fungicide chemical was also used for controlling late blight diseases.

Experimental Methods and Design: The experiment was conducted in 2021 at eight (8) farmers' field. Randomized complete block design (RCBD) with three replications was used as experimental design. Spacing between plants, rows, plots and blocks was 0.3m, 0.75m, 1m and 1.5m, respectively. The gross and netharvestable areas were (4.5x3=13.5), 7.2 m^2 areas, respectively. The experimenthad a total of ten treatments as indicated in Table 1. Except Urea, all fertilizers were applied at planting in basal application. While, Urea fertilizer was applied in three equal splits at different crop stages (planting, flowering and tuber initiation).

Table 2. Treatment setup for the on-farm experiment

No	Treatment	Description	Nutrient application rates (Kgha^{-1})					
			N	P_2O_5	K_2O	S	Zn	B
1	NPSZnBK	All	138	69	60	10.5	5	1
2	NPSZnK-B	B-omitted	138	69	60	10.5	5	-
3	NPSBK-Zn	Zn-omitted	138	69	60	10.5	-	1
4	NPBZnK-S	S-omitted	138	69	60	-	5	1
5	NPSZnB-K	K-omitted	138	69	-	10.5	5	1
6	NSZnBK-P	P-omitted	138	-	60	10.5	5	1
7	PSZnBK-N	N-omitted	-	69	60	10.5	5	1
8	NPS	NPS alone	138	69	-	10.5	-	-
9	NP	NP alone	138	69	-	-	-	-
10	Control	No fertilizer	-	-	-	-	-	-

Data Collection and Analysis: Yield component data like plant height, steam number, tuber number, dry matter content, specific gravity, starch level and all biological yields (marketable and total yield weight) were collected using standard procedure. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). The least significant difference (LSD) was used for mean comparison at 5% probability.

Results and Discussion

Dry matter content, specific gravity and starch content: Dry matter content (DMC), specific gravity (SG) and starch content (SC) of potato showed significant difference (p-value) among treatment means at Dembecha district (domain) (Table 3). Even though the statistically significant differences observed at the district mentioned above, the response of the treatments on the parameters greatly vary from district to district without regular trend (Table 3). This inconsistence may be due to insignificant contribution of the nutrients on the parameters which is supported by Niguse *et al.*, (2016) finding. Even on the control treatment higher DMC, SG and SC values were recorded at some of the experimental domain. However, the result of this study was in contrary to the findings reported by Nebiyu *et al.*, (2019). As his report said, the highest DMC was obtained with no P application while the lowest was obtained from application of 60 Kgha^{-1} P. Unlike P, increased level of K application from 0 to 110 Kgha^{-1} increased the DMC from 21.1 to 24.4%. Similarly, increasing the application of P from 0 to 60 Kgha^{-1} significantly decreased SG of the tuber while increasing K levels from 0 to 110 Kgha^{-1} increased the tuber SG. Furthermore, higher levels of P and K increased the SC of potato tuber (Nebiyu *et al.*, 2019). But in our study, the application of all type of nutrients (N, P, K, S, Zn and B) showed insignificant on DMC, SG and SC of potato.

Table 3. Dry matter content, specific gravity and starch content

Treatments	Dray matter content (%)			Specific gravity			Starch content (%)		
	Denbecha	Banja-sekela	Quarit-Yilmana	Dembecha	Banja-sekela	Quarit-Yilmana	Dembecha	Banja-sekela	Quarit-Yilmana
NPSZnBK	20.86	22.18	21.89	1.081	1.087	1.085	14.59	15.76	15.51
NPZnBK-B	20.88	21.93	21.85	1.081	1.086	1.085	14.61	15.54	15.48
NPSBK-Zn	21.36	22.26	22.08	1.083	1.087	1.086	15.04	15.84	15.68
NPSZnK-S	20.11	22.17	22.07	1.077	1.087	1.086	13.92	15.75	15.67
NPSZnB-K	22.23	21.81	22.44	1.087	1.085	1.088	15.81	15.44	16.00
NSZnBK-P	21.40	22.27	21.67	1.083	1.087	1.084	15.07	15.84	15.31
PSZnBK-N	21.35	22.55	21.51	1.083	1.088	1.084	15.02	16.10	15.17
NPS	21.86	22.24	21.92	1.085	1.087	1.086	15.48	15.82	15.54
NP	21.23	22.93	22.15	1.082	1.090	1.087	14.92	16.44	15.74
Control	21.97	22.67	21.75	1.086	1.089	1.085	15.58	16.21	15.38
LSD (0.05)	0.99	0.95	1.54	0.005	0.005	0.008	0.88	0.85	1.37
Sign	**	NS	NS	**	NS	NS	**	NS	NS
CV	4.0	4.53	7.48	0.36	0.53	0.77	5.06	5.68	9.41

***=Highly significant, *= Significant, NS= Non significant*

Potato Tuber Yields: At each experimental site in study domains, marketable tuber yield of potato showed a highly significant difference among treatment means (Table 4). Most of the observed significant differences among treatment means of the tuber yield in the study domains were derived due to control and N omitting treatments, respectively. The minimum marketable yield values were recorded either on the control treatment or N omitting treatment interchangeably. This showed that, the contribution of N was highest on potato yield across the study sites. However, the maximum values observed at any one of the treatments at least it contains N and P nutrients together. In all testing sites, high and significant responses on potato marketable yields were observed when both N and P nutrients were added. This confirmed that, N and P nutrients were still yield-limiting nutrients which is in line with the finding of (Tadele *et al.,* 2022). Tadele *et al*., (2022) stated that the yield-limiting nutrients to produce maize and wheat in major growing areas in Amhara region were N and P nutrients, respectively. However, no significant difference were observed among potato marketable tuber yield means due to adding or omitting of S, Zn, B and K in the study domains which is in line with the report of Tadele *et al.,(* 2018).

Table 4. Total marketable tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	26.0	30.5	29.1	23.7	24.3	17.2	14.0	18.9
NPSZnK-B	28.3	30.1	28.5	22.0	23.4	16.9	15.7	22.0
NPSBK-Zn	23.1	31.4	25.7	26.4	24.9	16.3	16.9	21.5
NPBZnK-S	26.4	26.1	26.1	25.6	23.3	17.6	14.7	19.1
NPSZnB-K	26.0	32.0	27.8	19.6	22.8	12.6	11.7	19.8
NSZnBK-P	21.7	26.1	18.9	16.4	18.1	10.6	8.3	19.4
PSZnBK-N	16.6	10.4	7.6	9.1	9.4	10.1	5.3	5.4
NPS	23.0	29.1	28.6	21.8	20.2	13.1	12.5	23.2
NP	25.5	27.3	27.2	22.9	19.0	11.9	13.1	23.9
Control	13.8	15.2	8.9	7.4	8.7	6.8	4.9	5.4
LSD (0.05)	6.0	6.9	5.1	4.7	6.5	3.7	3.2	4.5
Sign	**	**	**	**	**	**	**	**
CV (%)	15.3	15.8	13.2	14.0	19.8	16.5	15.9	14.6

At all experimental sites, unmarketable potato tuber yield didn't show any statistical significant difference among treatment means (Table 5). This may not tell us, the treatments had no significant difference on potato total yield production. But it indicated that, the parameter we took (unmarketable tuber yield) could not determine significantly by the treatments we used. For this reason, all the observed trends on marketable potato tuber yield also replicated on total potato tuber yield weight at all experimental sites of the study domains (see Table 4 and 6).

Table 5. Total unmarketable tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	0.15	0.31	0.35	0.21	0.28	0.48	0.23	0.55
NPSZnK-B	0.44	0.57	0.33	0.28	0.36	0.46	0.17	0.34
NPSBK-Zn	0.21	0.25	0.40	0.23	0.31	0.66	0.14	0.46
NPBZnK-S	0.38	0.27	0.31	0.25	0.86	0.59	0.12	0.60
NPSZnB-K	0.40	0.55	0.29	0.19	0.34	0.54	0.34	0.62
NSZnBK-P	0.34	0.51	0.30	0.37	0.44	0.42	0.17	0.30
PSZnBK-N	0.22	0.37	0.26	0.24	0.98	0.28	0.19	0.32
NPS	0.28	0.81	0.22	0.27	0.51	0.36	0.29	0.70
NP	0.23	0.28	0.26	0.26	0.86	0.32	0.18	0.56
Control	0.24	0.18	0.26	0.33	0.31	0.56	0.13	0.27
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sign	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	53.3	93.2	61.2	41.5	73.5	35.5	61.4	48.4

Table6.Total tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	26.2	30.8	29.5	23.9	24.6	17.7	14.2	19.5
NPSZnK-B	28.8	30.7	28.8	22.3	23.7	17.3	15.8	22.4
NPSBK-Zn	23.4	31.6	26.1	26.7	25.2	16.9	17.0	22.0
NPBZnK-S	26.7	26.4	26.4	25.8	24.2	18.1	14.8	19.7
NPSZnB-K	26.0	32.6	28.1	19.8	23.1	13.2	12.0	20.4
NSZnBK-P	22.1	26.6	19.2	16.8	18.6	11.0	8.5	19.7
PSZnBK-N	16.8	10.8	7.9	9.4	10.4	10.4	5.5	5.7
NPS	23.3	29.9	28.8	22.1	20.7	13.5	12.8	23.9
NP	25.7	27.6	27.5	23.2	19.8	12.2	13.3	24.5
Control	14.0	15.4	9.1	7.7	9.0	7.4	5.0	5.7
LSD (0.05)	6.1	7.2	5.2	4.6	6.6	3.8	3.2	4.5
Sign	**	**	**	**	**	**	**	**
CV (%)	15.3	16.1	13.2	13.8	19.5	16.4	15.5	14.5

Similar to the individual experimental sites, both marketable and total tuber yields of potato showed highly significant difference among treatment means in each study domain (Table 7). Next to the control treatment, highly significant responses (yield penalty) on potato marketable and total tuber yields occurred when N and P nutrients were omitted, respectively. This finding confirmed by Tadele *et al.*, (2022) finding who mentioned, N and P nutrients are the yield-limiting nutrients to produce maize in Amhara region, respectively. However, similar to the individual testing site results, any significant difference didn'thappen among potato marketable and total tuber yields due to S, Zn, B and K nutrients application in the study domains (Table 7).

Table7. Combined result of marketable and total tuber yield weight at each domain (tha^{-1})

Treatments	Denbecha		Banja-sekela		Quarit-Yilmana Densa	
	MTY*	TTY	MTY	TTY	MTY	TTY
NPSZnBK	28.23	28.46	25.71	25.99	16.69	17.11
NPSZnK-B	29.22	29.72	24.63	24.95	18.18	18.50
NPSBK-Zn	27.26	27.49	25.66	25.97	18.20	18.62
NPBZnK-S	26.23	26.55	25.00	25.47	17.11	17.54
NPSZnB-K	28.80	29.27	23.39	23.67	14.69	15.19
NSZnBK-P	23.93	24.36	17.82	18.19	12.79	13.09
PSZnBK-N	13.51	13.81	8.729	9.22	6.914	7.18
NPS	26.06	26.61	22.99	23.32	15.10	15.55
NP	26.37	26.63	22.58	23.04	15.13	15.48
Control	14.51	14.72	8.32	8.62	5.70	6.02
LSD (0.05)	5.00	5.11	3.57	3.57	4.14	4.24
Sign	**	**	**	**	**	**
CV (%)	17.67	17.81	18.61	18.26	31.51	31.35

**MTY= Marketable tuber yield and TTY= Total tuber yield*

In most of the study domains, omitting of each nutrient contributed non-significant yield penalty in comparison from the bench mark treatment (treatment which received all type of nutrients). However, the contribution of each nutrient on potato yield penalties didn't show similar magnitudes. Even omitting some nutrients (like B and Zn) provided a yield advantage from the benchmark treatment. With these remarks, omitting of K, S, B and Zn nutrients contributed too low and insignificant impact on potato total tuber yield. However, impact of omitting N and P nutrients showed too high and significant total tuber yield of potato, (Figure 3). Especially omitting N provided equivalent yield as compared to without fertilizer treatment (Fig.3).

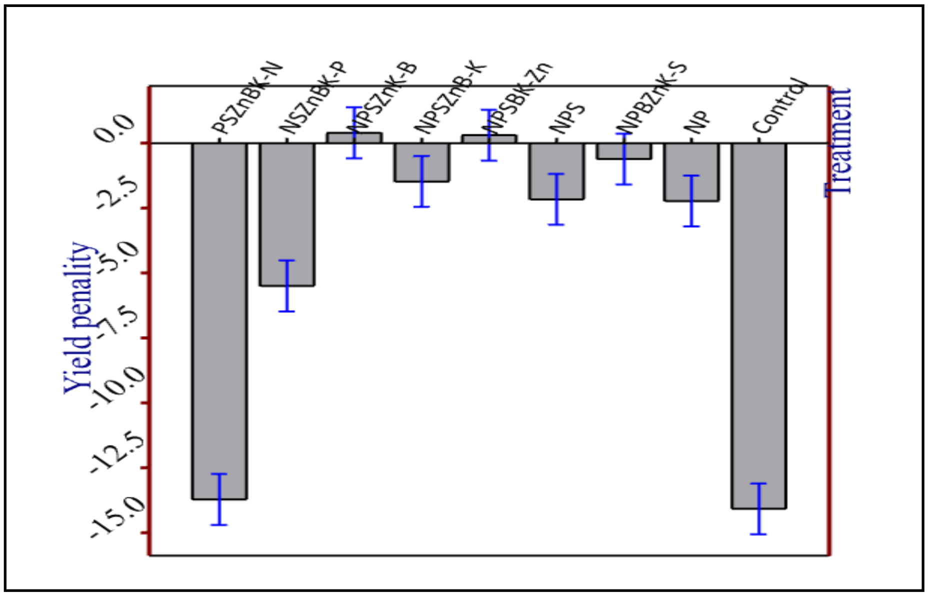

Figure 5. Yield penalty /advantage of potato tuber yield due to nutrient omitting

*__Note__: All stands for treatment containing **NPSZnBK** nutrients.

In all study domains, total tuber yield of potato showed strong and positive significant correlation with yield components like plant height, total tuber number and total marketable yield except with steam number. Similarly, most potato yield components by themselves also showed highly and positive significant correlation with each other (Table 8).

Table8. Correlation of some yield components with of potato yield at each study domains

Parameters	Dembecha				Banja-Sekela			
	PH*	SN/hill	TN	TMY	PH	SN/hill	TN/plant	TMY
PH	-				-			
SN/hill	0.18^{ns}	-			0.20^{ns}	-		
TN/plant	0.29*	0.26*	-		0.50**	0.38**	-	
TMY	0.84**	0.09^{ns}	0.28*	-	0.76**	0.41**	0.70**	-
TYW	0.84**	0.09^{ns}	0.28*	0.99**	0.76**	0.40**	0.70**	0.99**

Quarit-Yilmana Densa		
	TN/plant	TMY
TN/plant	-	
TMY	0.37**	-
TYW	0.36**	0.99**

***PH=plant height, SN=steam number, TN=tuber number, TMTY=total marketable tuber yield, TTY=total tuber yield, **=Correlation is significant at p<0.01; *=Correlation is significant at p<0.05 & ns=Correlation is non-significant (p≥0.05).

Conclusion

Both marketable and total tuber yields of potato showed a highly statistically significant difference among treatment means at each site as well as at all study domains. The study confirmed that N is the primary potato yield-limiting nutrient followed by P nutrient. However, the remaining four nutrient types (S, Zn, B, and K) didn'thave any statistically significant role in the enhancement of potato tuber yield. Therefore, it is still possible to enhance potato productivity using sole N and P fertilizer sources including other improved potato production technologies. However, frequent revision of the soil fertility status is too important for updating nutrient type requirements for enhancing potato productivity and production in the Amhara region, Ethiopia

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4. Evaluation of the Nutrient Content of Vermicompost Prepared from Different Proportions of Lantana Camera and Other Organic Wastes at Efratanagdem District, Ethiopia

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Abstract

Lantana camara is a noxious weed which is widely distributed in eastern Amhara and disturbing the day to day life of the smallholder farmers. Wise utilization of this weed as organic waste or vermicomposting is an environmentally sound and economically feasible technology resulting in the production of alternative organic fertilizer source. Hence, the experiment was conducted at Efratanagidem district to determine the nutrients content of vermicompost prepared from different proportions of lantana camara and other organic wastes for two consecutive years (2017/18-2018/19). Lantana camara biomass and other organic wastes (Jatropha, Banana pseudo stem and weed from cultivated land) were mixed at different levels (w/w basis) to give five different ratios (0:100%; 25:75%; 50:50%; 75:25). The experiment was laid out in a completely randomized design with four replications. Plastic pots of 10 litre capacity were used for vermicompost production. Composting materials were chopped and mixed in different ratio for all treatments and allowed for about 30 days to partially decompose and create suitable condition for the composing worms. Then 200 red worms (Eisenia fetida) were introduced in to each treatment. The analysis of variance revealed that mixture of lantana camara with different feeding materials of produced vermicasthad a highly significant ($p<0.05$) influence on all tested parameters of vermicompost. The result indicates that the highest total Nitrogen (1.70%), organic carbon (17.79%), lowest carbon to Nitrogen ratio, (10.57) available Phosphorus (1083.87 ppm) and available Potassium and (1.91%) were recorded from the vermicompost prepared from a mixture of 75% lantana camara with other green wastes. Generally, it is possible to conclude and recommend that among the substrate used for the experiment the highest values of total Nitrogen and the highest values almost all tested parameters were recorded by higher proportion of lantana camara substrate. Therefore, lantana camara biomass alone or mixed with other green wastes is suitable for the production of quality vermicompost and recommended for farmers around Efratagedim district and similar agro-ecologies for vermicompost preparation and manage invasive weed in useable manner.

Keywords*: *Eisenia fetida, Green wastes, Lantana camara, organic waste, Vermicomposting

Introduction

Lantana camara is one of the most commonly known noxious weed distributed worldwide (Rakesh *et al*., 2016). The red flower variety (*L. camara* var. aculeata) of this weed is mainly toxic and usually prevalent in tropical and sub-tropical countries (Pereira *et al*., 2003; Mello *et al*., 2005). Lantana affects grazing land and disturbs the ecology. It releases inhibiting chemicals in the soil to prevent other plants from germination (https://en.wikipedia.org/wiki/Lantana_camara). L.camara is good example on the impact of introduction and invasion on biodiversity of the Ethiopia (Rezene *et al*., 2012). It found in cultivated and non-cultivated lands of Ethiopia.

Extensive efforts have been made with billions of dollars invested, to control invasive weed species like lantana by physical, chemical or biological means (McFadyen, 1998; Day *et al.,* 2003; Zalucki*et al.,* 2007). However, these attempts have not succeeded in even controlling, let alone eradicating, any of the major weeds. Some research reports indicated that other controlling mechanize were appeared and developed for advantageously utilizing the invasive, it may not only offset the costs of mechanically removing them but also exercise some control over their spread. According to Tessema (2012) “Eradication by Utilization” is believed that economic exploitation of invasive species as a means of harnessing their economic potentials for meeting basic human needs and at the same time controls its spread and possibly eradicate them. In the form of biodegradation, a possible option is conversion of weeds into vermicompost and utilizing the latter as a soil fertilizer. Vermicomposting of a substrate is believed to convert some of its nutrients into more bioavailable forms and bestow upon the substrate micro flora that is beneficial for soil health (Gajalakshmi and Abbasi, 2008; Edward *et al.*, 2011).

Suthar and Singh, (2008) also reported that different weed or plant residues commonly available in any agricultural land can be converted to a potential plant-nutrient enriched resource - compost and vermicompost that can be utilized for sustainable land restoration practices. The biomass of lantana camara is huge that could be utilized by the farmers to prepare compost and vermicompost that could be utilized as an organic manure. Animal dung serves as a good source of inoculants in composting medium to increase the microbial population (Singh and Angira 2011). Proper utilization of Lantana biomass through appropriate technologies like composting and mulch etc. may help in supplementing chemical fertilizer besides adding organic matter to the soil. The macro nutrients were also found to be improved in all the vermicomposts. Laboratory analysis result of Lantana camara Nitrogen Phosphorus and Potassium content is 27, 1.6-2.4 and 21-27 $Kgton^{-1}$ comparable to manure which is 7-23, 1-11 and 6-8 $Kgton^{-1}$ (Tamene *et al*., 2017; Zingore *et al*., 2014 and Kaizzi and Wortmann 2001). Studies by Singh and Angiras (2011) have also reported that the macronutrients were improved by the decomposition of Lantana with animal manures and earthworms. Banta and Dev (2009) have also reported that the Nitrogen enriched Phosphorus compost prepared from Lantana was found to be beneficial for the improved yield and nutrient uptake in wheat.

The laboratory analysis result of vermicompost produced from Lantana camara revealed that the phenols and the sesquiterpene lactones that are responsible for the allelopathic impact of Lantana were largely destroyed in the course of vermicomposting and there is also an indication that lignin content of Lantana was reduced during its vermicomposting (Hussain *et al.*, 2015). In addition to this, to confirm the reduction of allelophatic effects of vermicomposted lanta materials used to see the germination index of seed bioassay test indicated beneficial and useful for the growth of agricultural crops (Sharma *et. al*., 2016). Such type research findings help to open up the possibility that the billions tons of biomass that is generated annually by Lantana can be gainfully utilized in producing organic fertilizer via vermicomposting.

Vermicomposting is a mesophilic process and is the process of ingestion, digestion, and absorption of organic wastes by earthworms followed by excretion of castings through their metabolic systems during which the biological activity of earthworms enhances plant-nutrients of organic waste (Venkatesh and Eevera, 2008). Vermicompost possesses higher and more soluble levels of major nutrients - Nitrogen, Phosphorus, Potassium and magnesium (Bansal and Kapoor, 2000; Singh and Sharma, 2002; Reddy and Okhura, 2004) compared to the soil, and the normal compost. During the process, the nutrients locked up in the original substrate organic waste are changed to simple and more readily available and absorbable forms such as nitrate or ammonium Nitrogen, exchangeable Phosphorus and soluble Potassium, calcium, magnesium in the worm's gut (Lee, 1985 and Atiyeh *et al***.,** 2002).

Among the 8000 known species of earthworm only seven are suitable for use in composting, all belonging to the epigeic category. Throughout the world the most commonly employed species is the Tiger Worm, sometimes referred to as the Red Wiggler or Californian Red (*Eisenia fetida*). Native to Europe the Tiger Worm has exceptional adaptability and tolerance to a range of food sources, temperature variation (12-35°) and moisture content (60-90%). This species also has the capacity to double its population every 60 days and consumed up to half their body weight a day, particularly suitable for the application in the management of organic waste. Therefore, this research aimed at technology development and evaluation of the nutrient contents of vermicompost prepared from the different combination of lantana camara and other organic wastes for the production of quality vermicompost from locally available organic waste materials using composting earthworm.

Materials and Methods

Description of Study Area: The experiment was carried out at farmers training centre (FTC) Ferede weha kebele Efratanagedem district, North Shewa Zone, Eastern Ethiopia for two consecutive years (2018/19-2019/20). Geographically, the experimental sites were located at 10°17'20" to 10° 24‘ 22" N and 39°54‘ 26" to 39° 55‘ 23“ with the altitude ranges of 1488-1586 m.a.s.l. Long term climate of the study areas are characterized by a unimodal rainfall pattern and receive an average annual rainfall of 762.5mm. The long term annual mean minimum and maximum air temperatures were 14.61 and 30.01 respectively.

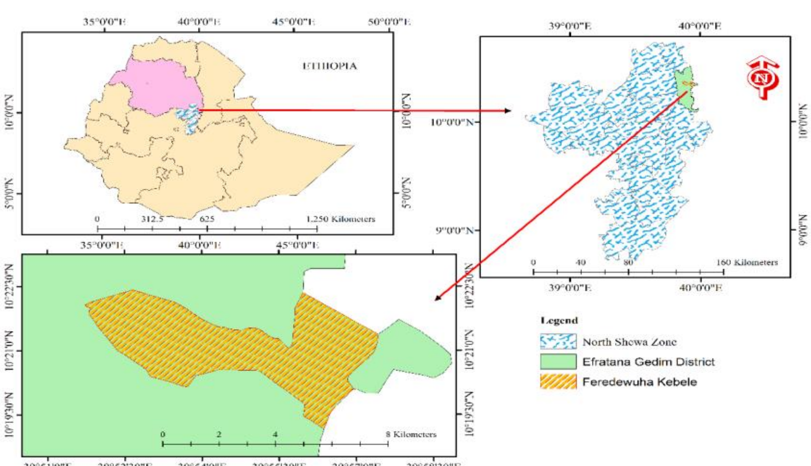

Figure 1. Map of the study area

Treatments and Experimental Design: The experiment was conducted in a shaded area. The Lantana camera weed biomass was collected from the roadside and hillsides of nearby farmlands and then chopped to a smaller size. In order to create a representative sample, manure was gathered from nearby households and mixed in. Lantana camara biomass and other agricultural green wastes (jatropha and weed from cultivated land) were mixed at different levels (w/w basis) to give five different combinations. The mixtures were left with moisture for 21 days in order to semi compost the feed to become more palatable and softer for the worms. Eisenia foetida was used for vermicomposting by introducing equal number/weight on different treatment combination. The moisture and temperature was maintained by sprinkling water and turning the mixture.

The experiment was laid in a completely randomized design replicated four replicates. These different ratio combinations were then evaluated for different physical properties, pH and C/N ratio of vermicompost and major nutrients NPK analyzed. This process was repeated at least 3 to 4 times to see the performance of earth worm's vermicomposting capacity at different seasonal condition. The details of the treatments are shown in here

1. 0:100% Lantana camara (0 Kg) + other organic wastes (5 Kg)
2. 25:75% Lantana camara (1.75 Kg) + other organic wastes (3.25 Kg)
3. 50:50% Lantana camara (2.5 Kg) + other organic wastes (2.5Kg)
4. 75:25% Lantana camara (3.25 Kg) + other organic wastes (1.75Kg)
5. 100:0% Lantana camara (5 Kg) + other organic wastes (0 Kg)

To carry out the experiment under shade and create uniform climate condition for vermicomposting process, Site was selected with collaboration of Efrata gedim district Agricultural office experts. The organic waste (manure) was collected from local house hold and goat ranch mixed together to get representative sample. Lantana camera twigs and leaves of regenerated after cutting were collected from hillsides of closed areas, and road sides of the farm lands and chopped in to pieces. In addition, other green organic materials like pseudo stem and its leafy parts of banana, Jatropha carcass and weed biomass were collected and chopped. Furthermore, weed material were also collected from farm lands, mostly grassy type locally called *ingicha dominated.* Pots of a size of about 10 litre capacity were prepared for Vermicompost preparation. Then the pots were filled with different ratios of lantana camara and other organic wastes. Composting materials were chopped and mixed with liquid manure as slinking purpose with a 1:1 manure water ratio for all treatments in equal amount and allowed for about 30 days to partially decomposed to create suitable condition for composing worms and substrate become more palatable. All pots were placed on raised bed made from wooden materials to protect earthworms from their enemies like ant and termites. In addition, liquid soap foam and kerosene were sprayed under the shade to prevent the aforementioned pests. After 30 days, the earthworm (n=200) (Eisenia foetida) was inoculated to each treatment for vermicomposting. The moisture and temperature were maintained by sprinkling water on fiber bag used as cover a pot and under shade and above pots there was plastic shade to protect an unexpected rain occurrence. Proper aeration in the vermicomposting unit was maintained by regular turning using wooden pigs that were already prepared for each composting pots. After vermicomposting, the number of earthworms in the finished vermicompost from each pot was counted by hand sorting and vermicompost yield was measured using weighing balance. The produced vermicomposts from different feeding materials were then packed in bags, labelled, transported to Debrebirhan Agricultural Research Center's soil laboratory and air dried at room temperature.

Chemical Analyses: The homogenized sub-samples of each substrate material and their respective vermicompost samples (on the basis dry weight) were collected destructively at 0 (i.e., from each plot and which were processed for analyses of organic carbon (OC) and total Nitrogen (TN), available Phosphorus (P), and exchangeable Potassium. The pH, and electrical conductivity (EC) were recorded for the vermicomposting. The pH and EC of samples were recorded by a digital pH meter and conductivity meter, respectively (Reeuwijk V, LP, 1993). The OC of the samples was measured by Walkey-Black method (Walkley and Black, 1934). The TN was estimated by the Kjeldahl method (Jackson, 1968), and the P and K contents of the samples were analysed by spctrophpotometer (Oleson, *et al.*, 1954) and flame photometric method (Jackson, 1958), respectively. The ratio was calculated from the measured values of C and N. Total vermicompost productivity (VP %) was determined from the total harvested vermicompost divide by initial vermicompost in Kg used and multiplied by 100 (Goswami and Kalita, 2000).

$$VP\% = \frac{\textbf{Total harvested vermicompost amount (Kg)}}{\textbf{Total weight of organic substrate used (Kg)}} \times 100$$

Data Analysis: Statistical Analysis. One-way analysis of variance (ANOVA) was computed using SAS software (version No. 9.1) to test the level of significance of difference between the vermicomposts produced by the three combinations of substrate with lantana camara and vermicompost samples with respect to nutrient parameters.

Results and Discussion

Some Chemical Characteristics of Initial Raw Materials: Table 1 lists the chemical properties of manure, weed biomass, bananas, Jatropha carcasses, and lantana camara used as raw materials for vermicomposting. The raw materials had the following total organic carbon (TOC) contents: manure (31.17%), weed biomass (26.96%), banana (23.35%), Jatropha carcass (28.74%), and lantana camara (29.350%). Comparably, the lantana camara had a total Nitrogen (TN) content of 2.02%, bananas 0.49%, Jatropha carcasses 1.89%, weed biomass 1.36%, and manure 1.60%, indicating variations in the initial substrate used (Table 1). Table 1. Some chemical characteristics of Initial raw materials

Table 1. chemical properties of raw materials

Parameter	Lantana camara	Banana	Jatropha carcass	Weed biomass	Manure
P (ppm)	13.25	6.89	12.72	10.07	685.67
K (%)	2.23	-	1.08	-	0.94
OC (%)	29.35	23.35	28.74	26.96	31.17
TN (%)	2.05	0.49	1.89	1.36	1.60
C:N	9.62	47.65	15.21	19.82	20.56

pH and EC of Vermicompost: A significant difference ($P<0.05$) was observed among treatments in pH and electrical conductivity (Table 2). The pH is important parameters for the evaluation of vermicompost maturity and quality. The decomposition of organic matter into organic acids causes a pH decrease as the lantana ratio increases. Vermicomposts with a pH range of 6–8.5 are ideal for applying soil fertilizer sources (Hogg *et al*., 2002). Plants have a maximum EC tolerance limit of 4.0 dS/m. Hence, manure with EC below this value can be applied to soil for plant growth and development (Lasaridi *et al*., 2006). The EC that was obtained from lantana vermicompost was higher than that of other lower and sole proportions. This could have been caused by the initial substrate material releasing more mineral ions during the vermicomposting process, such as phosphate, ammonium, and Potassium (Suthar, 2007). Table 2 shows pH (H_2O 1:2.5) and EC (dS/m) of vermicompost made from different mixture of lantana camara with other green waste (Banana pseudo stem, Jatropha carcass and weeds)

Table 2. pH and EC of vermicompost made from different mixture of lantana camara with other green waste

Lantana ratio	Lantana:Banana		Lantana:Jatropha		Lantana:Weed		Mean	
	pH	EC	pH	EC	pH	EC	pH	EC
0:100	8.34[b]	2.34[c]	8.39[b]	1.43[d]	8.64[ab]	2.78[c]	8.46[b]	2.18[c]
25:75	8.63[a]	1.52[d]	8.29[b]	1.91[c]	8.69[ab]	2.88[c]	8.54[ab]	2.10[c]
50:50	8.55[a]	2.85[b]	8.66[a]	2.39[b]	8.77[b]	3.23[bc]	8.66[a]	2.82[b]
75:25	8.35[b]	2.54[c]	7.95[c]	2.92[a]	8.66[ab]	3.74[ab]	8.32[c]	3.07[b]
100:0	8.00[c]	3.91[a]	7.94[c]	2.70[ab]	8.54[b]	4.01[a]	8.16[c]	3.54[a]
CV (%)	1.43	11.12	2.34	15.28	1.84	18.27	2.60	19.57
LSD (5%)	0.12	0.30	0.20	0.35	0.16	0.62	0.13	0.31

Substrate Mix type	pH	EC
Lantana: Banana	8.37[b]	2.63[b]
Lantana: Jatropha	8.24[c]	2.27[c]
Lantana: Weed	8.66[a]	3.33[a]

Available Phosphorus: The analysis of variance indicated that the available Phosphorus was highly significantly ($p < 0.05$) influenced by the treatments (Table 4). The highest (1083.87 ppm) mean available Phosphorus content was registered by feeding of 75% of lantana camara with 25% other feed socks. While the lowest (954.57 ppm) mean available P was recorded by feeding of 100% of other green wastes. This result is in line with the finding of Zarei *et al*., (2011) whom reported that available Phosphorus in vermicompost ranges 1056-1643 $mgKg^{-1}$ respectively.

According to Pramanik *et al*., (2007), maximum Phosphorus in the final feed stocks of vermicompost is mainly due to acid formation during organic waste decomposition is responsible for solubilisation of insoluble Phosphorus. The net loss of dry mass which concentrates the Phosphorus in the final feed stocks of vermicomposting also increases the Phosphorus content (Ravindran and Sekaran 2010).

Table 3. Av. Phosphorus (ppm) of vermicompost made from different mixtures of lantana camara with other green waste (banana pseudo stem and weeds)

Treatment	Lantana:Banana	Lantana:Jatropha	Lantana:Weed	Mean
0%:100%	1025.60[a]	1048.64[b]	789.45[b]	954.57[b]
25%:75%	1147.51[b]	1069.82[b]	798.05[b]	1005.13[b]
50%:50%	1071.03[b]	1049.41[b]	789.76[b]	970.06[b]
75%:25%	1062.16[b]	1051.69[b]	1137.76[a]	1083.87[a]
100%:0%	1056.73[b]	1225.66[a]	781.07[b]	1021.15[ab]
CV (%)				13.65
LSD (5%)				78.55

Substrate Mix type	Mean (n=120)
Lantana: Banana	1072.60[a]
Lantana: Jatropha	1089.04[a]
Lantana: Weed	859.22[b]

Exchangeable Potassium and CEC: The analysis results of of variance showed that treatments had a highly significant ($p < 0.05$) effect on exchangeable bases K^+ (Table 5). Table 5 shows that the mixture of 75% lantana and 25% banana substrate had the highest exchangeable Potassium (2.61%). Additionally, cation exchange capacity was significantly affected by treatments ($p < 0.05$). A mixture of lantana and Jatropha produced the lowest CEC (52.84 meq/100 gm), while lantana camara mixed with banana produced the highest CEC (56.66 meq/100 gm) (Table 5). This result is consistent with Tadele *et al*., (2018)'s finding that the CEC in vermicompost varies from 57 to 68.70 mg/Kg.

Table 4. Ex. K (%) and CEC (meq/100 gm) of vermicompost made from different mixture of lantana camara with other green waste (banana pseudo stem and weeds)

	Lantana:Banana		Lantana:Jatropha		Lantana:Weed		Mean	
Treatment	Ex. K (%)	CEC	Ex. K (%)	CEC	. Ex. K (%)	CEC	Ex. K (%)	CEC
0:100%	2.17[c]	54.36[b]	0.94[c]	53.91[a]	1.46[b]	55.35[b]	1.52[c]	54.54[b]
25:75%	2.46[b]	59.99[a]	1.09[ab]	53.65[a]	1.85[a]	59.68[a]	1.80[ab]	57.77[a]
50:50%	2.42[b]	53.64[b]	1.04[bc]	51.26[b]	1.77[a]	50.95[c]	1.74[ab]	51.95[c]
75:25%	2.61[a]	55.03[b]	1.22[a]	50.55[b]	1.84[a]	55.07[b]	1.91[a]	53.55[b]
100:0%	2.36[b]	58.80[a]	0.97[bc]	54.83[a]	1.60[b]	56.98[ab]	1.64[bc]	56.87[a]
CV (%)	4.37	3.74	13.08	3.33	9.12	4.78	16.38	5.04
LSD (5%)	0.11	2.15	0.14	1.80	0.16	2.71	0.16	2.64
Substrate Mix type	Ex. K (%)		CEC					
Lantana: Banana	2.41[a]		56.66[a]					
Lantana: Jatropha	1.00[c]		52.84[b]					
Lantana: Weed	1.71[b]		55.61[a]					

Organic carbon, Total Nitrogen and Carbon to Nitrogen ratio: The analysis of variance indicated that mean organic carbon content was highly significantly ($p < 0.05$) influenced by the treatments. The highest OC (17.79%) was registered by 100% lantana camara substrate, while the lowest (16.00%) was recorded by 100% or sole lantana, Jatropha and weed feeding ratio (Table 6). Over the course of the vermicomposting and composting processes, organic carbon decreased for all of the substrates used. When compared to its initial value, the organic carbon (OC) in the full dose of lanata camara significantly decreased. During vermicomposting, Elvira *et al.*, (1998) and Kaushik and Garg (2003) have reported losing 20–45% of the organic carbon (OC) in the form of CO_2 from various organic substrates. The analysis of variance indicated that total Nitrogen (TN) was highly significantly ($p < 0.05$) influenced by the substrate mix tpye and ratio of lanatana camara. As compared to other mixes, the highest total Nitrogen content was obtained from sole lantana camara (1.90%) followed by 75%:25% lantana:Jatropha (1.73%) and 50%:50% lantana:jatropha (1.71%) while the lowest TN wasobtained from 100% weed (0.83%) (Table 6). Research result indicated that, total Nitrogen content in vermicomposts can range quite widely from 0.1% to 4% or more (Ibrahim *et al.*, 2013). In genera, lanatana camara and jatropha carcas substrate mixture showed highest mean Nitrogen (1.72%) content compared from banana pseudo stem and weed biomass (Table 6). This might be due to the high nitrification rate in which ammonium ions are converted into nitrates (Dominguez, 2004). The Nitrogen content of vermicomposts produced varies from substrate to substrates and hence the standard total Nitrogen content of compost ranges from 1.5-3.5 % (Katheem Kiyasudeen *et al*., 2016). Study report also indicated thate compost fertilizing capacity and used as source orgnic fertilizer that total Nitrogen content must be over 1% (Kefyalew and Tilahun, 2018).

The mean C/N ratios of vermicomposts of three substrates ranges from 10.1:1-16.37:1; such ratios make nutrients easily available to the plants (Table 6). Plants cannot assimilate mineral N unless the C/N ratio is about equal or less than 20:1, and this ratio is also an indicative of acceptable maturity of compost (Morais andand Queda, 2003). In the present study, all organic substrate mixed with lantana camara in different proportion had a C:N ratio below 20 which indicated the higher N mineralization upon their incorporation in the soil. The C/N ratio of the substrate material reflects the mineralization and stabilization of the organic wastes during the process of composting or vermicomposting. The carbon/Nitrogen ratio decreases due to the rapid decomposition of organic waste, as well as mineralization and stabilization during the vermicomposting process. According to Senesi (1989), a decrease in C:N to less than 20 indicates an advanced degree of maturity in organic waste.

Table 5. Mean OC (%),TN (%) and C: N of vermicompost made from different mixture of lantana camara with other green waste (banana pseudo stem, jatropha carcass and weeds)

Treatment	Lantana:Banana			Lantana:Jatropha			Lantana:Weed			Mean		
	OC	TN	C:N	OC	TN	C:N	OC	TN	C:N	OC	TN	C:N
0%:100%	14.15^{b}	0.87^{b}	16.55^{a}	17.48^{b}	1.59^{c}	10.98^{a}	16.34^{c}	0.83^{c}	20.22^{a}	16.00^{b}	1.10^{d}	15.92^{a}
25%:75%	15.28^{a}	0.87^{b}	18.34^{a}	16.85^{c}	1.65^{bc}	10.15^{b}	17.53^{b}	1.38^{b}	12.89^{bc}	16.55^{ab}	1.30^{c}	13.79^{b}
50%:50%	15.74^{a}	0.91^{b}	17.72^{a}	17.47^{b}	1.71^{b}	10.12^{b}	17.37^{bc}	1.31^{b}	13.30^{b}	16.86^{ab}	1.31^{bc}	13.71^{b}
75%:25%	15.47^{a}	0.91^{b}	17.60^{a}	17.01^{bc}	1.73^{b}	9.76^{bc}	18.95^{a}	1.65^{a}	11.91^{bc}	17.14^{ab}	1.42^{b}	13.09^{b}
100%:0%	16.02^{a}	1.40^{a}	11.62^{b}	18.17^{a}	1.90^{a}	9.48^{c}	19.19^{a}	1.81^{a}	10.61^{c}	17.79^{a}	1.70^{a}	10.57^{c}
CV (%)	5.09	10.55	11.92	2.84	6.35	5.94	6.10	13.92	16.33	17.49	16.50	20.42
LSD (5%)	0.80	0.11	1.99	0.50	0.11	0.61	1.11	0.20	2.30	1.69	0.13	1.57

Substrate Mix	OC (%)	TN (%)	C:N
Lantana: Banana	15.33^{b}	0.99^{c}	16.37^{a}
Lantana:Jatropha	17.39^{a}	1.72^{a}	10.10^{c}
Lantana: Weed	17.88^{a}	1.39^{b}	13.79^{b}

Number of Alive Worms: Table 3 shows that the vermicompost made from 100% lantana camara substrate had the highest mean earthworm number (215) among the three combinations, while the lowest number of worm population (151) was found in the vermicompost made from 50% lantana camara substrate along with other green vermicompost, which was also lower from lantana camara alone. This could be because the mixture included leaf biomass, which encouraged earthworm growth. In a related study, using tree leaves as the only food source resulted in a greater increase in the E. foetida population than using cow dung alone (Nagavallemma *et al*., 2004).

Table 6. Mean number of alive earthworms

Lantana ratio	Lantana:Banana	Lantana:Jatropha	Lantana:Weed	Mean
0:100	189[c]	64[c]	244[b]	165[bc]
25:75	215[bc]	76[b]	211[c]	167[bc]
50:50	218[b]	54[c]	182[c]	151[c]
75:25	207[bc]	60[c]	253[b]	173[b]
100:0	248[a]	105[a]	292[a]	215[a]
CV (%)	12.32	13.02	9.80	17.72
LSD (5%)	27.04	9.54	23.59	17.68

Substrate Mix type	Number of worms
Lantana: Banana	215[b]
Lantana: Jatropha	72[c]
Lantana: Weed	236[a]

Total Harvested Vermicast and Productivity: The analysis of variance indicated that total harvest vermicompost was highly significantly ($p < 0.05$) influenced by with the treatments. The vermicompost yield of 100% lantana camara substrate recorded the largest the value of 1.71 Kg, while the lowest value of 1.33 Kg was recorded by 100% or sole lantana, Jatropha, and weed feeding ratio (Table 7). Alternatively, vermicompost productivity increased in proportion to the lantana camara ratio; higher productivity was observed in 100% lantana camara, while the lowest productivity was observed in mixtures of weeds, jatropha, and bananas alone. Reducing the amount of lantana camara in the mixture resulted in a lower percentage of vermicompost, indicating that other green wastes have not yet reached the point of complete vermicomposting.

Table 7: Amount of vermicast (Kg) produced from different mixtures of lantana camara and other organic wastes

Treatment	Lantana:Banana	Lantana:Jatropha	Lantana:Weed	VC productivity %
0%:100%	1.17[c]	1.17[c]	1.66[ab]	33.28[c]
25%:75%	1.29[bc]	1.33[bc]	1.61[b]	35.31[bc]
50%:50%	1.31[b]	1.44[ab]	1.77[ab]	37.66[b]
75%:25%	1.71[a]	1.50[a]	1.84[ab]	42.05[a]
100%:0%	1.79[a]	1.47[ab]	1.88[a]	42.86[a]
CV (%)	8.55	11.98	13.80	17.45
LSD (5%)	0.13	0.17	0.25	3.82

Substrate Mix type	Mean	VP%
Lantana: Banana	1.45[b]	36.36[b]
Lantana: Jatropha	1.38[b]	34.35[b]
Lantana: Weed	1.75[a]	43.79[a]

Conclusion and Recommendation

The research reveals that lantana camara mixtures with different ratios of other organic wastes differ in their nutrient composition and the amount of nutrient released from their combinations. Based on the amount of nutrients released from the combinations, the sole or 50%:50% combination of lanatan camara with jatropha provided more total Nitrogen and was suitable for vermicomposting by earth worms. As a result, vermicompost production from Latana camara using effective vermicompost worms should be verified and demonstrated on farmers' fields in order to eradicate this noxious weed from all land use types through utilization.

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5. Refining Nitrogen Rate for Yield and Quality of Malt Barley under Balanced Fertilization at Basona Warana District, North Shewa Zone, Ethiopia

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Abstract

The present experiment was conducted at Basona warana district during the main rainy season of 2017/18-2018/19 to determine the effect of different doses of N on yield and quality attributes of malt barley (var. Sabine). The treatment consists: control (0), 23, 46, 69, 92, 115, 138 and 161 Kgha^{-1} N with combination of 46 P_20_5, 30 S, 0.5 B, 2 Kgha^{-1} Zn and 2 Kgha^{-1} Cu. The design was completely randomized block with three replications. Every year the 8 treatments of Nitrogen levels were assigned to plots of each block randomly. The result indicated that Nitrogen rates significantly affected growth, yield and quality component of malt barley as compared to the control treatment with balanced fertilization. The effect of N rate was consistently and positively increasing plant height. Application of Nitrogen at a rate of 161 Kgha^{-1} gave significantly higher grain and straw yields compared to all other rates. Even though the economic analysis result revealed that the highest net return of 64,173.5 ETBha^{-1} and the marginal rate of return 1258.5% was obtained from 138 Kgha^{-1} N, lower friability percentage of malt barley was recorded from 138 Kgha^{-1} which was lower than Ethiopian malt quality standards. Hence, application of 115 Kgha^{-1} N under balanced fertilization is recommended for cultivating malt barley in the study area with minimum acceptable malt quality parameter.

Keywords*: **balanced fertilization, food barley, growth, Nitrogen, yield***

Introduction

Barely (*Hordeum vulgare* L.) is one of the most important food crops produced in the world (Meints, B. & Hayes, 2019). It assumes the fourth position in total cereal production in the world after wheat, rice and maize (FAO, 2011). Russia, Canada, Germany, Ukraine and France are the major barley producers, accounting for nearly half of the total world production (FAOSTAT 2016). Ethiopia is also considered to be the origin and center of diversity for barley (source?). Barley is one of the most important staple food crops produced in the highland areas of Ethiopia (Zemede, 2000). Its grain is used for the preparation of different foodstuffs, such as *injera, kolo, bread, porridge and* local drinks, such as *tela, borde* and beer. The straw is used as animal feed, especially during the dry season. Barley has various useful functions in addition to being used as food, feed, and beverage. According to Emebiri *et al.*, (2003), malted barley is also added to the food process of the biscuit factory and has also sufficient protein content for animal feed.

Malt barley is adapted to wide environmental condition, matures early and has high yield market potential (Hailu and Luer Joop, (1996); Getachew *et al*., (2006)). In Ethiopia, malting process was started by St. Georgis Brewery factory in 1974 ((Legese *et al*., 2007). ORDA (2008) reported that estimated annual production of malt barley is 15,945 tonnes but the annual consumptions of six brewery factories is 48,330 tonnes. Hence, 69% of the demand of malt barley is fulfilled from imports. Recently, the production of malt barley met only 35% of the demand and the remaining imported at a cost of $38 million (Lakew, 2016). The potential of malt barely production in Ethiopia covers about 150,000 ha with an estimated yield of 375,000 tons (ICARDA, 2017). Based on the information of Ethiopian standard authority, the protein level of standard quality for malt should be between 9–12% (EQSA, 2006). The protein content below 9% and above 12% is not accepted for processing because there is strong inverse correlation between protein and carbohydrate content; this may lead to low malt extract level (Fox *et al*., 2003) so that acceptable grain N content of malt barely should not be greater than 1.6–1.8% (Zhao *et al.*, 2006)

Despite, the importance of barely and its many useful characteristics, there are several factors affecting its production. The most important factors that reduce yield of barley in Ethiopia are poor soil fertility, water logging, drought, frost, soil acidity, diseases and insects, and weed competition (ICARDA, 2008). Poor soil fertility and low pH are among the most important constraints that threaten barley production in Ethiopia. Since the major barley producing areas of the country are mainly located in the highlands, severe soil erosion and lack of appropriate soil conservation practices in the pasthave resulted in soils with low fertility and pH particularly deficiency of Nitrogen and Phosphorus is the main factor that severely reduces the yield of barely (Taye *et al.*, 1996).

Fertilizers constitute an integral part of improved crop production technology and their proper management to crops is important for maximum yield and minimum contamination to environment (Corbeels *et al.,* 1999). In Ethiopia, commercial fertilizer mainly in the form of urea and DAP was introduced in the 60s by higher learning institutions through limited laboratory and research activities (Murphy, 1968). Results of several studies also have shown that Nitrogen fertilizer increases grain yield and its protein. Asadi *et al*., (2013) investigated the effects of different levels of Nitrogen and competition on grain yield and reported that with increase of Nitrogen grain yield increased.

No systematic attempthas been made so far with regard to N with balanced fertilization of malt barley in the soils of the study areas. Thus, field research was imitated to determine the optimum N rate for yield and quality parameters of malt barley under balanced fertilization

Materials and Methods

Description of Study Area: The field trial was conducted in Basona warana district, North Shewa Zone of the Amhara Regional State during the main seasons of 2017/18-2018/19. Geographically, the experimental sites were located at a range of 09^{0} 36' to 09^{0} 48'N and 39^{0} 39' to 39^{0} 50'E with a mean altitude of 2650-2868m. According to the climatic records by Ethiopian National Meteorological Agency from 1985 to 20118, the study area has a unimodal rainfall which starts in June and ends in December and received the average long term annual rainfall of 1539.1 mm. The long term mean annual minimum and maximum air temperatures were 9.13 and 19.49 respectively. The total amount of rainfall for 2017 and 2018 were 1469.0 mm and 1621.8 mm respectively (Figure 1).

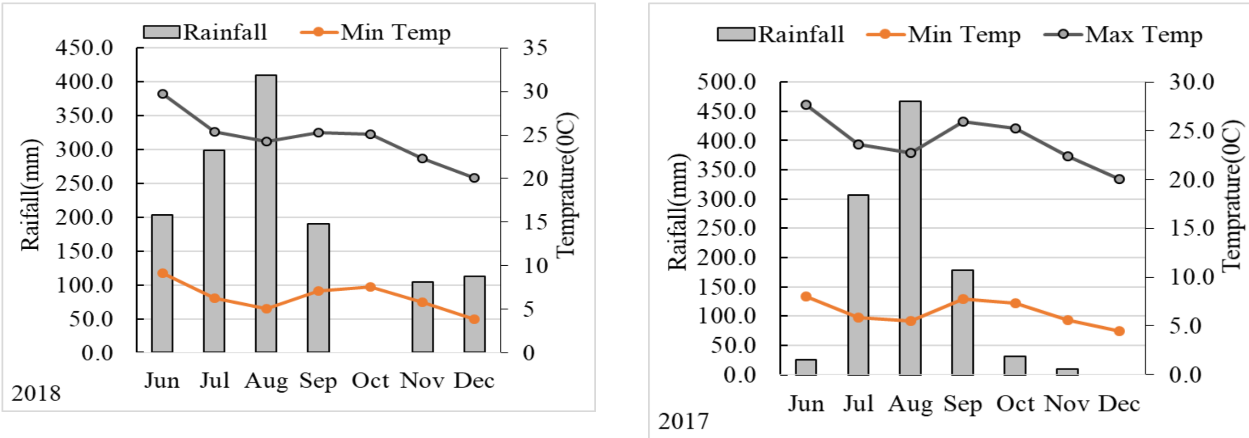

Figure 1 Rainfall minimum and maximum temperature for the growing seasons DBARC- Andit tid meteorological station)

Experimental Design and Procedures: The treatment consisted of eight levels of N (0, 23, 46, 69, 92, 115, 138, and 161 Kgha^{-1} N for with combination of 69 P_2O_5, 30S, 0.5B, 2 Zn and 2 Cu. The experiment was laid out in randomized complete block design with three replications. The experimental field was prepared with oxen power tiller according to farmers' conventional plowing practice. Nitrogen was applied as per each treatment level specification. The full amount of P, S, Micronutrients (Zn, B, and Cu) and half of N from each level were applied at the time of planting in the forms of triple superphosphate (TSP), muriate of potash (KCl), gypsum ($CaS0_4$), ZnS04, Borax and CuS04 and urea respectively. Remaining half urea for N was applied as top dress at 45 days after sowing (at tillering stage). The variety (Sabine) used seed was drilled in line (20 cm apart between raw) at the rate of 100 Kgha^{-1}.The seeds were treated with fungicides (Apron star) to prevent disease with recommended rates labeled on the product. The plot size was 3.6mx3.4 m while the net plot size was 2x3.4 m^2 (ten central rows) and was used for data collection. The spacing between the plots and adjacent replication (blocks) were 0.5 m and 1 m respectively.

Initially composite soil samples (0-20 cm depth) were collected from the experimental plots, air dried, labeled and passed through 0.5 mm for the analysis of TN and OC through 2 mm sieve for the analysis of other parameters. Soil pH was measured with a glass electrode; samples were diluted in water (the ratio of soil to water was 1:2.5) (Van Reeuwijk 1992). Total Nitrogen was determined using the micro Kjeldahl procedure as described by Bremmer and Mulvaney (1982). Soil organic carbon was determined using the Wet Oxidation Method of Walkley and Black described by Nelson and Sommers (1982). Available Phosphorus was determined following Olson and exchangeable Potassium by extraction with 1 N ammonium acetate (method of Morgan) and determined by reading with a fame photometer (Knudsen *et al.*, 1982).

Data collection and Analysis: Agronomic data: such as Growth (plant height, Spike length, fertile tiller, total tiller, kernels per spike), yield (grain, straw and harvest index and thousands kernel were collected and malt quality analyses were performed (grain protein content, malt extractable, friability and ß-Glucan content) with a near infrared reflectance spectrometer (Foss NIRS-500, Foss GmbH, Rellingen, Germany) at Holeta Agricultural Research Center Malt barley quality analysis laboratory. Moisture content of the grain yield was adjusted to 12.5% and converted to kilogram per hectare. The collected data were subjected to the analysis of variances and significant treatment means were separated by Least Significant Difference (LSD) by using Statistical Analysis System (SAS) package (2002).

Partial Budget Analysis: Partial budget analysis with dominance and marginal rate of return was carried out (CIMMYT, 1988). To estimate the economic value of the output (grain and straw yield), the average market price during the two consecutive years for malt barley was 13 ETB (Ethiopian ETB) per Kg. Average input price and labor force applying the nutrients including: N, P_2O_5, S, were 26, 30.4 and 40 respectively. And also micro nutrients (B + Zn + CU) was 200 ETB per ha.

Results and Discussion

Selected Physical and Chemical Soil Properties: Analysis of soil physico-chemical properties prior to planting is presented in Table 1. The lab analysis result indicated that the texture was loam and clay loam. Soil pH (H_2O) was ranged from slightly acidic to acidic which is optimum pH range (6.0 to 7.0) for barley production (CLDB, 2001).

The available Phosphorus content of the experimental soil was rated as medium to low (Olsen *et al.*, 1954) while the exchangeable Potassium content was rated as high to very high (Landon, 1991). Likewise, the mean soil organic carbon and total Nitrogen contents of the experimental soil were rated as low to very low based on Landon's classification (Landon, 1991).

Table 1. Selected physical and chemical properties of the experimental soil at Basona Warana District, 2017/18 and 2018/19

Year	Site	pH (1:2.5)	OC (%)	TN (%)	Av.P (ppm)	Exch.K ($CmolKg^{-1}$)	C	Si	S	Textural Class
2017/18	Mush	6.40	1.54	0.17	6.40	0.31	24	34	42	Loam
	Abamotie	6.70	1.68	0.20	6.70	1.84	44	34	22	Clay
2018/19	Mush	5.70	1.67	0.16	3.74	0.60	52	34	14	Clay loam
	Andit tid	6.32	1.34	0.17	2.02	0.64	38	40	22	Clay loam

Effect of Nitrogen on Malt Barley Growth, Yield and Quality: Since growth parameters are the major yield contributing characters, in the present study, plant height, spike length, total tiller, fertile tiller and number of seeds per spike increased by increasing Nitrogen level (Table 2). The highest mean plant height (87.4 cm), spike length (7.94 cm), total tiller number per 1m^2 (873), number of fertile tillers per 1 m^2 (814), number of seeds per spike (26.6) were obtained from the application of the highest N rate (161 $Kgha^{-1}$ N). This result is in line with the findings of Amare and Adane (2015) and Haftom *et al.,* (2009) with the possible reason of application of Nitrogen have played an essential role in plant growth and development.

Table2. Mean response of malt barley growth parameters for different rates of N fertilizer under balanced fertilization over years at Basona Warana District

N ($Kgha^{-1}$)	PH (cm)	SPL (cm)	Total Tiller (m^2)	Fertile Tiller (m^2)	Number of Kernels ($Spike^{-1}$)
0	61.0^{f}	5.91^{ce}	496^{d}	455^{e}	22.9^{e}
23	65.9^{ef}	6.16^{e}	585^{cd}	535^{de}	22.7^{e}
46	71.9^{de}	6.56^{cd}	610^{c}	565^{cd}	23.8^{de}
69	76.1^{cd}	7.11^{c}	631^{c}	600^{cd}	25.3^{bc}
92	77.2^{bcd}	7.03^{c}	679^{bc}	653^{c}	25.0^{cd}
115	81.8^{abc}	7.36^{bc}	679^{bc}	631^{cd}	25.5^{abc}
138	84.0^{ab}	7.56^{b}	778^{ab}	727^{a}	26.4^{ab}
161	87.4^{a}	7.94^{a}	873^{a}	814^{a}	26.6^{a}
CV (%)	12.13	6.07	18.89	20.60	6.36
LSD (0.05)	7.5	0.34	102.3	104.2	1.3

Grain yield increased significantly with increased N rate (0 to 161 Kgha^{-1}). Therefore, the highest grain yield (5430.8 Kgha^{-1}) was obtained from the highest N rate (Table 3). Similarly, the straw yield increased with increasing N levels (Table 3). Several studies reported positive, linear and quadratic responses of grain yield to incremental rates of N (Gauer *et al*., 1992; and Ali, 2010). Birhan (2017), also reported at South Gonder, Farta district of Amhara region grain and total above ground biomass yield and quality of malting barley were significantly improved when using 150 Kgha^{-1} N.

Harvest index is the proportion of economical yield to biological yield (Ortiz-Monasterio *et al.*, 1997). The harvest index to N rate was also significant (Table 3). The plots which received 92 Kg N ha^{-1} had the highestharvest index. This could be explained by increased aboveground biomass yield as a result of incremental N fertilizer rates, as compared to grain yield. In Ethiopia, however, a mean HI of about 50% with a positive trend due to increasing N rate had previously been reported (Taye *et al*., 2002). This finding is also in accordance with the study reported by Munir (2002) and Biruk *et al.,* (2016) which indicated thatharvest index decreased with increased N rate.

Table 3. Mean response of malt barley grain & straw yield for different rates of N fertilizer under balanced fertilization over all sites at Basona Warana District, 2017/18 & 2018/19

N	Grain Yield Kgha^{-1}			Straw Yield Kgha^{-1}			HI
(Kgha^{-1})	2017/18	2018/19	Mean	2017/18	2018/19	Mean	(%)
0	2148.3^{e}	3450.7^{d}	2799.5^{d}	2584.6^{e}	3854.4^{d}	3219.5^{c}	45.6^{a}
23	2569.9^{e}	3769.2^{d}	3169.5^{cd}	3159.3^{e}	4203.9^{d}	3681.6^{c}	45.7^{a}
46	3627.5^{d}	4383.9^{c}	4005.7^{bc}	4579.7^{d}	6000.5^{cd}	5290.1^{b}	43.3^{c}
69	4072.3^{cd}	4468.6^{bc}	4270.5^{abc}	5138.5^{cd}	5498.3^{cd}	5318.4^{b}	44.3^{ac}
92	4508.6^{c}	4607.7^{abc}	4558.2^{ab}	5690.0^{c}	4891.9^{bcd}	5290.9^{b}	47.0^{a}
115	5208.3^{b}	4770.4^{abc}	4989.4^{ab}	6809.3^{b}	5159.7^{abc}	5984.5^{b}	44.9^{ac}
138	5770.8^{ab}	5081.6^{a}	5426.2^{a}	8058.8^{a}	7015.6^{abc}	7537.2^{a}	41.7^{cd}
161	5873.8^{a}	4987.8^{ab}	5430.8^{a}	8737.3^{a}	7657.2^{ab}	8197.3^{a}	39.5^{d}
CV (%)	12.64	11.08	11.90	10.79	25.65	34.20	9.69
LSD (0.05)	624.3	576.3	385.5	706.2	1686.0	1203.8	3.47

As shown in Figure 2, year 2 predicts the lowest yield response to N as compared to year 1 in slope and predicted malt barley yield. However, optimal malt yield occurs about the same N level, 138 Kgha^{-1}for both years.

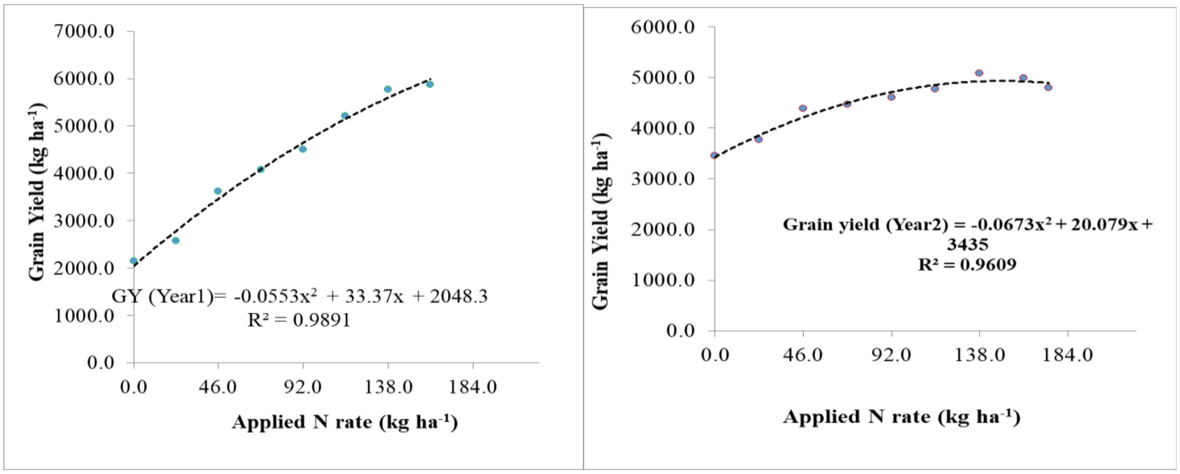

Figure 2. Regression curve for applied Nitrogen (2017 left side and 2018 right side)

The analysis of variance revealed that grain protein content was significantly influenced by Nitrogen rates (Fig. 3). The highest protein content in grain was obtained from the highest Nitrogen rate (161 N Kgha^{-1}). Generally, mean protein content significantly increased N rate. Application of the higher Nitrogen rate resulted in 11.2% (Table 3). Even though grain protein content is within Ethiopian malt barley standard of quality requirement; the mean effect of all N rates on protein content was significant. Protein content increased in proportion to the N rates up to the highest rate of 161 Kgha^{-1} N. According to Biruk *et al*., (2016), application of 98.5 Kgha^{-1} N resulted in grain protein content within the acceptable range on Sabine variety.

Malt extract yield determines the amount of beer produced after malting. The highest value for the trait was obtained from the application of Nitrogen at the rate of 46 Kgha^{-1} and the lowest from 161 Kgha^{-1} N (Table 3). Eagles *et al*., (1995) reported that malt extract would decrease with increased N application rate due to more increase of grain protein concentration. It is implied that higher N level in soil and plants leads to more protein synthesis and accumulation in barley grains, as a result causing a reduced ability of grain components to be decomposed during malting and mashing process (Wang *et al*., 2003).

Table 4. Combined effect over years of different rates of N fertilizer under balanced fertilization on quality parameters of malt barley at Basona Warana District

N (Kgha^{-1})	TSW* (g)	Extract content [% dm]	Friability [%]	Protein content [% dm]	ß-Glucan content [mg/L]
0	45.7	81.4^{a}	64.4^{ab}	8.5^{ef}	271.9^{b}
23	44.9	81.0^{a}	70.5^{a}	8.1^{f}	282.0^{b}
46	47.2	81.2^{a}	63.3^{ab}	8.6^{edf}	259.0^{b}
69	47.4	81.0^{ab}	62.1^{ab}	9.3^{cde}	216.6^{b}
92	46.9	80.4^{abc}	63.1^{ab}	9.4^{cd}	377.1^{ab}
115	46.7	79.9^{bcd}	60.1^{bc}	9.9^{bc}	318.4^{b}
138	48.1	79.4^{cd}	52.2^{c}	10.6^{ab}	529.9^{a}
161	46.6	78.9^{d}	54.9^{bc}	11.2^{a}	378.1^{ab}
CV (%)	12.85	1.98	19.24	11.49	46.16
LSD (0.05)	ns	1.29	9.57	0.88	146.5
EQSA, 2006	35-46	73.8-80.9	>60%	9-12	

**TSW=thousnds kenel weight, MEC=Malt Extract content, Fria= Friability, PC=Protein content and ß-G=ß-Glucan content*

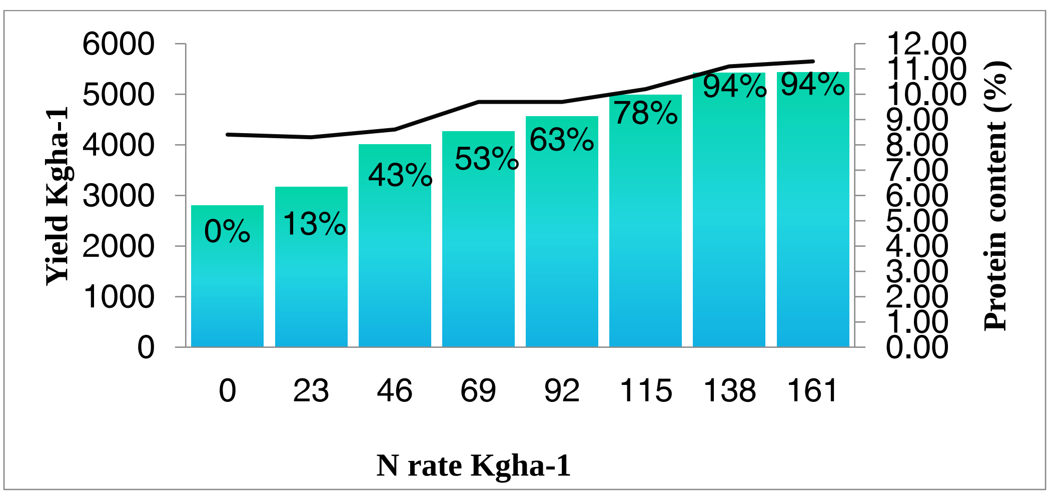

Figure 3 Relationship of Maltbarley yield and grain protein contente as influeced by Nitrogen fertilizer rate, 2017/18

Correlation among Quality Parameters of Malt Barley: Correlation analysis among quality parameters of malt barley revealed highly significant positive and negative associations among the quality parameters studied (Table 4). Accordingly, malt extract was significantly and positively correlated (r = 0.82) with friability. This means when malt friability increased, malt extractable was increasing, on the contrary malt extractable also negatively affected by increasing protein content (-0.95) and its b-glucan content (-0.76) was also increased. In similar manner, the level of Nitrogen was highly significantly and negatively correlated (r = -0.96) with friability and this indicated that when friability of malt is decreasing, its malt extract content was also decreasing.

Table 5. Correlations among Nitrogen level, grain protein concentration, β-glucan, and friability malt properties

	Nitrogen	Malt Extract	Friability	Protein content
Malt Extract	-0.96^{**}			
Friability	-0.85^{*}	0.82^{*}		
Protein content	0.96^{**}	-0.95^{*}	-0.92^{**}	
ß-glucan	0.69^{ns}	-0.76^{*}	-0.73^{*}	0.68^{ns}

Partial Budget Analysis: The highest net benefit was obtained from the application of 138 Kgha^{-1} N (Table 6). The maximum net benefit of 64173.5 ETB ha^{-1} with the optimum marginal rate of return (1258.5%) was recorded from 138 Kgha^{-1} N, followed by Nitrogen 115 Kgha^{-1} N (Table 6). However from quality perspective, application of 138 Kgha^{-1} N and beyond resulted in lower friablility percentage of malt barley which had negative impact on total malt extract content that in turn negatively affected total beer production. Thus, application of 115 Kg N ha^{-1} is more preferable with minimum acceptable quality parameters for beneficiaries

Table 6. Partial budget analysis of Nitrogen rates on malt barley at Basona Warana District

N ($Kgha^{-1}$)	TVC ($ETBha^{-1}$)	GY ($Kgha^{-1}$)	Ad.GY ($Kgha^{-1}$)	StY ($Kgha^{-1}$)	GB ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR %
0	1425	2799.5	2519.5	3219.5	33888.1	32463.1	
23	2023	3169.5	2852.6	3681.6	38465.8	36442.8	665.5
46	2621	4005.7	3605.1	5290.1	50334.4	47713.4	1884.7
69	3219	4270.5	3843.4	5318.4	52793.8	49574.8	311.3
92	3817	4558.2	4102.3	5290.9	55308.9	51491.9	320.6
115	4415	4989.4	4490.4	5984.5	61062.6	56647.6	862.2
138	5013	5426.2	4883.6	7537.2	69186.5	64173.5	1258.5
161	5611	5430.8	4887.7	7797.3	69929.5	64075.5	-16.4

Conclusion and Recommendation

According to the current study result, Nitrogen rates had significant effect on growth, yield and quality component of malt barley as compared to the control treatment with balanced fertilization techniques. The effect of N rate was consistently and positively increasing growth parameters. Application of Nitrogen at a rate of 161 $Kgha^{-1}$ also produced significantly higher grain and straw yield than all rates. Even though the economic analysis result revealed that the highest net return of 64,173.5 $ETBha^{-1}$ and the marginal rate of return 1258.5% was obtained in the treatment that received 138 $Kgha^{-1}$, friability percentage values were found below the Ethiopian malt barley quality standard (>60%). But, application of 115 $Kgha^{-1}$ N under balanced fertilization is recommended for the production of malt barley in the study area with minimum acceptable malt quality parameter especially acceptable friablity percentage.

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6. Verification of Phosphorus for Sorghum (*Sorghum bicolor*) and Tef (*Eragrostis tef*) in the Low Land Areas of North Shewa Zone, Ethiopia

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Abstract

On farm trials on verification of Phosphorus containing fertilizers for major cereals crops was conducted at Kewet, Efratana gedem, Antsokiya gemza and Ensarona wayu districts in 2018/19 main cropping season to verify the need of Phosphorus containing fertilizers for the major cereals crops in the lowland areas of North Shewa. *The experiment consisted of five treatments including:* T_1 *(0* P_2O_5 *Kgha*$^{-1}$*),* T_2 *(46* P_2O_5 *Kgha*$^{-1}$*TSP), T3 (19* P_2O_5 *Kgha*$^{-1}$*NPSB),* T_4 *(38* P_2O_5 *Kgha*$^{-1}$*NPSB) and* T_5 *(57* P_2O_5 *Kgha*$^{-1}$*NPSB) with recommended rate of Nitrogen (100 Kgha*$^{-1}$ *urea) NPS and TSP were applied as a straight fertilizer at planting. These treatments were distributed in randomized complete block design with three replications. Analysis over location showed that grain yield was not significantly (P<0.05) affected by the application of P fertilizer except on plant height for both sorghum and tef. However, relatively high sorghum grain yield (4837.9 Kg) and tef yield (1415.7 Kg) were, obtained from the application of 57 Kgha*$^{-1}$ P_2O_5*. Even though the soil analysis result of available Phosphorus was within the low range for the testing sites, application of P fertilizer sources did not significantly affected sorghum and tef grain yield and yield components. The organic carbon and available Phosphorus content of the testing sites was very low so that management of soil organic matter and application of adequate amount of Nitrogen containing external fertilizer sources as well as application of maintenance Phosphorus are indispensable. This result showed that further investment of Phosphorus fertilizer had not more agronomical advantageous. It is better to use at least 19 Kgha*$^{-1}$ P_2O_5 *for the maintenance of soil P depleted through crop up take, residue removal, animal grazing and other purposes. Special attention needs further considerations of crop type in external sources of P containing fertilizer sources. Otherwise, it is not economical to use P source fertilizer around the study areas.*

Keywords*: Grain yield, Phosphorus, sorghum, tef*

Introduction

Chemical fertilizers are believed to be the key components of nutrient sources of major production of agricultural crops. In Ethiopia, increasing crop production and productivity strategy is given a top priority implementation of high input and improved technology utilization (Araya & Sung-Kyu, 2019). Increasing crop yields and closing the yield gap can be accomplished by implementing and advancing a variety of practices and technologies, such as adequate fertilizer use and efficient nutrient management, which can play critical roles in global food security (Stewart, and Roberts, 2012 and, Van der Velde M *et al*., 2014). The production capacity of soil is determined by its chemical and physical properties which help in the full utilization of the essential elements in the soil by plant roots (Ibeawuchi *et al.,* 2007). Hailu, (2014) reported that most Ethiopian soils are deficient in macro and micronutrients.

The government of Ethiopia did several efforts to popularize the implementation of soil test based fertilizer application system through the use of soil fertility information with newly introduced fertilizer formulas such as NPS, NPSB, NPSBZn and NPSCu which contains N, P, S Bo, Zn, and Cu (MOANR, 2016). In addition, to address the newly developed fertilizer utilization information, several stakeholders promoted farmers by importing and distributing chemical fertilizers through cooperatives to improve crop productivity better than the previously blanket recommendation system. However, the survey reports in the low land areas of North Shewa zone indicated that farmers were complaining about the application of Phosphorus containing fertilizer sources for they didn't get yield advantage due to its application (Abiro *et al*., 2016). On the contrary, the Soil Fertility Status and Fertilizer Recommendation Atlas of the Amhara National Regional State indicated that most of the soil nutrients are in the low to very low range (ATA, 2016). Therefore, this study was executed to verify the need of Phosphorus containing fertilizers for the major cereals crops in the lowland areas of North Shewa.

Materials and Methods

Description of Study Area: The field experiment was carried out with 19 sites (9 for sorghum and 10 for tef) in Kewet, Efratana gedem, Antsokiya gemza and Ensarona wayu districts in the

Lowland areas of North Shewa during the main cropping season of 2018/19 to verify the need of Phosphorus containing fertilizers for sorghum (*Sorghum bicolor* L.) Moench]) and tef and validate the newly released soil fertility status and fertilizer recommendation map of Amhara Region respectively. Geographically, the experimental sites were located at 09° 54' 45" to 10°00'44" N and 39°33'34" to 40° 02'26" E in Kewet; 10°17'20" to 10° 24'22" N and 39°54'26" to 39° 55'23" in Efrata gedem; 10°39'59" to 10° 43'16" N and 39°41' 34" to 39° 47'43" E in Antsokiya, and 09^0 91' to 09^0 94'N and 36^0 61' to 39^0 67'E in Ensarona wayu districts with the altitude range of 1287-1323, 1488-1586, and 1443-1454 m.a.s.l. The study areas are characterized by a unimodal rainfall pattern and receive an average annual rainfall of 760.2 mm in Kewet, 762.5 mm in Efrata gedem, 1005.2 mm in Antsokiya gemza and 926.8 mm in Ensarona wayu districts. The long term annual mean minimum and maximum air temperatures were 14.53 and 29.72 in Kewet, 14.61 and 30.01 in Efratana gedem, 13.85 and 25.07 in Antsokiya gemza and 12.66 and 25.42 in Ensarona wayu. Generally, Vertisols are the dominant soil type across the study areas.

Before starting the experiment, initial composite and after harvesting from each experimental treatment soil samples were collected (to determine soil pH, Av.P, OC, TN, Av.K and soil texture). Soil pH was measured in H_2O (pH-H_2O) using 1:2.5 soil to solution ratio by pH meter as outlined by Van Reeuwijk (1992). Soil organic content which was analyzed as described by Walkley and Black (1934). The modified Kjeldahl procedure was followed for the deter- mination of TN of soils as described by Jackson (1958). Available Phosphorus in soil samples was extracted by Olsen extraction method (Olsen *et al*., 1954). The content of P in the extract was determined using spectrophotometer following the procedure described by Murphy (1968). They were five treatments including: T_1 (0 $Kgha^{-1}$ P_2O_5), T_2 (46 $Kgha^{-1}$ P_2O_5 from TSP**)**, T3 (19 $Kgha^{-1}$ P_2O_5 from NPSB), T_4 (38 $Kgha^{-1}$ P_2O_5 from NPSB) and T_5 (57 $Kgha^{-1}$ P_2O_5 from NPSB) with recommended rate of Nitrogen (46 $Kgha^{-1}$ from urea) NPSB and TSP were applied as a straight fertilizer at planting. These treatments were distributed in randomized complete block design with three replications.

The gross plot size for sorghum was 26.25m^2 and for tef was 25 m^2. The blocks were separated by 1m wide-open spaces; whereas the plots within a block were 0.5 m apart from each other. The seeds of sorghum were sown at the rate of 10 $Kgha^{-1}$ in rows of 75 cm at the spacing of 20 cm between seeds for sorghum after thinning, and for tef seeds were sown with the rate of 30 $Kgha^{-1}$

in broadcast. Among the total number of seven rows of sorghum the middle three rows and 2m by 2m ($4m^2$) for tef were used to evaluate the study variables. Girana-1 sorghum variety Kuncho tef varieties were used as a test were used as test crops. Sorghum seeds were treated with Apron star to protect head smut. Disease and pest controlled was according to the recommended methods.

Data Analysis: The agronomic and yield data were analyzed using the general linear model (GLM) procedures of the SAS statistical software (2002) to evaluate the effect of different sources of P fertilizer. Least Significant Difference (LSD) test at P≤0.05 was used to separate means whenever there were significant differences among different treatments.

Results and Discussion

Selected Soil Chemical Properties of the Experimental Sites: The selected soil chemical and physical properties of the composite samples of the experimental sites indicated in Table 1 and 2. The results revealed that the soil reaction was from neutral to slightly alkaline (Tekalegn, 1991). According to the criteria set by Landon (1991), the organic carbon content of soils ranged from 0.38 to 1.79% which is rated as very low (>85% of testing sites) and the total Nitrogen content was also ranged 0.03 to 0.22% as low (90% of testing sites) to medium. The Olsen extractable available Phosphorus was very variable which was ranged from very low (38%), low (44%) and medium (18%) from the total testing sites (Tekalign, 1991).

Table1. Selected physical and chemical properties of the experimental soil sorghum at Kewet, Efratagedem, Antsokiya and Ensaro Districts, 2018/19

Districts	Sites	pH (1:2.5)	OC (%)	TN (%)	Av.P (ppm)	Cl	Si	S	Textural Class
Kewet	Charie	7.28	1.04	0.09	2.44	52	36	12	Clay
	Medina	7.57	1.04	0.10	1.82	70	16	14	Clay
	Sefeberet	7.66	1.79	0.14	2.22	71	16	13	Clay
Efrata gedem	Yimlo	6.67	0.82	0.03	10.86	36	20	44	Clay loam
	Feredeweha	6.93	0.83	0.09	4.44	48	42	10	clay
Antsokiya gemza	Mekedesa	6.69	1.08	0.22	13.62	37	37	27	Clay
	Atiko	6.69	1.17	0.11	24.00	22	40	38	Loam
	Afso	6.68	1.26	0.10	10.62	34	37	29	Clay loam
Ensarona wayu	Jamma1	6.66	-	0.024	19.02	40	34	26	Clay

Table2. Selected physical and chemical properties of the experimental soil tef at Kewet, Efratagedem, Antsokiya and Ensaro Districts, 2018/19

District	Sites	pH (1:2.5)	OC (%)	TN (%)	Av.P (ppm)	Cl	Si	S	Textural Class
Kewet	Charie	6.79	0.38	0.02	5.34	64	26	10	Clay
	Medina	7.57	0.82	0.08	1.86	70	16	14	Clay
Efrata gedem	Yimlo	6.67	0.82	0.06	9.66	36	20	44	Clay loam
	Feredeweha	7.24	0.97	0.11	3.72	48	42	10	Clay
Antsokia gemza	Mekedesa	6.71	1.15	0.07	13.62	46	42	12	Clay
	Atiko	6.52	1.27	0.10	28.32	42	28	30	Clay
	Afso	6.40	1.26	0.10	10.62	22	40	38	Loam

Application of P fertilizer (Table 3) affected the mean sorghum plant height significantly. Averaged across all study districts, P fertilization increased the mean plant height from 195.9 cm recorded from the plot without P fertilizers to 204.0 cm with the application of 57 $Kgha^{-1}$ P_2O_5. In general, plant height increased almost consistently with increasing the rates of P fertilizers but there is no significant effect among 19, 46 and 57 $Kgha^{-1}$ P_2O_5. This result is in line with the report of Wakene *et al.*, (2014) who stated that plant height of barely increased with increasing rates of P_2O_5 from 0 to 69 $Kgha^{-1}$.

Table 3. Mean response of Sorghum plant height for application of Phosphorus fertilizer over all Districts, 2018/19

Treatment	Plant height (cm)				Mean
	Kewet	Efrata gedem	Antsokiya gemza	Ensarona wayu	
1. 0 P_2O_5 $Kgha^{-1}$	202.2^{c}	175.0^{bc}	204.1	202.1^{b}	195.9^{cd}
2. 46 P_2O_5 $Kgha^{-1}$ TSP	196.0^{bc}	167.9^{c}	203.1	197.0^{b}	191.3^{d}
3. 19 P_2O_5 $Kgha^{-1}$ NPSB	204.7^{ab}	178.6^{abc}	202.3	204.5^{ab}	197.3^{bc}
4. 38 P_2O_5 $Kgha^{-1}$ NPSB	210.5^{a}	183.7^{ab}	208.5	204.1^{ab}	201.9^{ab}
5. 57 P_2O_5 $Kgha^{-1}$ NPSB	206.5^{ab}	186.9^{a}	212.6	211.3^{a}	204.0^{a}
CV (%)	4.21	5.48	4.22	3.37	5.71
LSD (0.05)	8.29	11.86	ns	8.33	5.77

Application of P had an impact on the height of tef plants, with the exception of Antsokiya gemza and Ensarona wayu districts. P fertilizer did not all have the same effect on plant height other districts (Table 4). The longest mean plant height (126.6 cm) was recorded from 19 $Kgha^{-1}$ P_2O_5 at Ensarona wayu district whereas the shortest mean plant height (109.5) was recorded from 57 $Kgha^{-1}$ P_2O_5 at Antsokiya gemza district. Moreover, Table 4 shows that the application of P fertilizer did not affect plant height in the other districts.

Table 4. Mean response of tef plant height for application of P fertilizer over all sites of study Districts, 2018/19

Treatment	Plant height (cm)				Mean
	Kewet	Efrata gedem	Antsokiya gemza	Ensarona wayu	
1. 0 P_2O_5 $Kgha^{-1}$	128.7	122.7	121.7^{a}	121.4^{ab}	122.2
2. 46 P_2O_5 $Kgha^{-1}$ TSP	132.1	122.9	119.0^{a}	116.6^{c}	120.7
3. 19 P_2O_5 $Kgha^{-1}$ NPSB	131.2	126.4	119.0^{a}	126.4^{a}	123.3
4. 38 P_2O_5 $Kgha^{-1}$ NPSB	134.9	124.6	111.4^{b}	119.5^{bc}	119.7
5. 57 P_2O_5 $Kgha^{-1}$ NPSB	131.9	125.7	109.5^{b}	123.9^{ab}	120.4
CV (%)	3.88	4.36	5.20	4.58	9.65
LSD (0.05)	ns	ns	4.89	6.75	ns

Similarly, tef panicle length was highly significantly affected by the application of Phosphorus at Antsokiya gemza and Ensarona wayu districts only. The effect of Phosphorus on panicle length was not consistent (Table 4). The longest mean panicle length (48.5 cm) was recorded from 19 $Kgha^{-1}$ P_2O_5 at Ensarona wayu district whereas the shortest mean panicle length (40.0 cm) was recorded from 38 $Kgha^{-1}$ P_2O_5. But there was no significant variation in panicle length in the other districts due to the application of Phosphorus (Table 5).

Table 5. Mean response of tef Panicle length for application of P fertilizer over all of study Districts, 2018/19 sites

Treatment	Panicle length (cm)				
	Kewet	Efrata gedem	Antsokiya gemza	Ensarona wayu	Mean
1. 0 P_2O_5 $Kgha^{-1}$	50.3	43.9	44.9[a]	46.2[ab]	46.1
2. 46 P_2O_5 $Kgha^{-1}$ TSP	49.9	44.9	44.4[a]	43.4[c]	45.3
3. 19 P_2O_5 $Kgha^{-1}$ NPSB	49.8	46.3	42.7[ab]	48.5[a]	46.3
4. 38 P_2O_5 $Kgha^{-1}$ NPSB	50.7	45.0	40.0[c]	45.9[bc]	44.8
5. 57 P_2O_5 $Kgha^{-1}$ NPSB	49.2	44.9	40.8[bc]	47.6[ab]	45.1
CV (%)	4.69	5.98	5.44	4.52	9.54
LSD (0.05)	ns	ns	2.24	2.54	ns

Data shown on Table 6 the application of P fertilizer revealed that no significant difference was observed among treatments for yield parameters of Sorghum at all districts except application Phosphorus fertilizer had a positive effect on plant height of sorghum (Table 4). Generally, applications of P fertilizer from different sources did not significantly impact the yield of sorghum.

Table 6. Mean response of Sorghum grain yield for application of Phosphorus over all sites at Kewet, Efratagedem, Antsokiya, and Ensaro Districts, 2018/19

Treatment	Grain yield of sorghum ($Kgha^{-1}$)				
	Kewet	Efrata gedem	Antsokiya gemza	Ensarona wayu	Mean
1. 0 P_2O_5 $Kgha^{-1}$	3848.5	3775.3	4843.9	5832.5	4813.5
2. 46 P_2O_5 $Kgha^{-1}$ TSP	4007.1	3434.4	4779.6	6241.4	4759.8
3. 19 P_2O_5 $Kgha^{-1}$ NPSB	4183.5	3554.2	4856.1	5942.4	4861.1
4. 38 P_2O_5 $Kgha^{-1}$ NPSB	4160.9	3758.4	4786.2	6017.9	4804.7
5. 57 P_2O_5 $Kgha^{-1}$ NPSB	3812.1	3666.0	4788.0	6515.9	4837.9
CV (%)	11.95	14.02	12.12	12.55	12.37
LSD (0.05)	ns	ns	ns	ns	ns

The analysis of variance revealed that application of Phosphorus had no significant effect on sorghum grain yield at all districts (Table 7). Average grain yield responses of tef for each treatment of all trial sites (kebeles) of each district were not significantly affected for application P fertilizer Sources.

Table 7. Mean response of tef grain yield for application of P fertilzer over all sites of Districts, 2018/19

Treatment	Grain yield of tef ($Kgha^{-1}$)				Mean
	Kewet	Efratana gedem	Antsokiya gemza	Ensaro wayu	
1. 0 P_2O_5 $Kgha^{-1}$	1215.8	1629.2	900.28	1829.9	1314.1
2. 100 $Kgha^{-1}$ TSP	1322.9	1640.3	884.72	2028.3	1369.2
3. 50 $Kgha^{-1}$ NPS	1322.9	1583.3	879.17	2104.2	1342.6
4. 100 $Kgha^{-1}$ NPS	1285.4	1609.7	920.83	1988.2	1342.6
5. 150 $Kgha^{-1}$ NPS	1493.8	1655.6	951.39	1988.2	1415.7
CV (%)	16.23	10.29	13.17	17.95	18.94
LSD (0.05)	ns	ns	ns	ns	ns

Conclusion and Recommendation

Generally, applications of Phosphorus did not significantly impact the grain yields of sorghum and tef. Even though, soil analysis result of available Phosphorus were within the range of low for some testing sites, application of Phosphorus did not affect the yield components of both crops. However, the organic carbon, TN and available Phosphorus contents of most testing sites were in the low to very low ranges and need management of soil organic matter and application of adequate amount of Nitrogen containing external fertilizer sources. In addition, though Phosphorus didn't significantly affect yield and yield parameters of both crops, application of the smallest rate (19 $Kgha^{-1}$ P_2O_5) for maintenance purpose is indispensable for the replacement of the removed Phosphorus with the harvested parts of the crops.

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7. Maize Yield-Limiting Nutrients under Variable Locations in Major Maize Growing Areas of North West Ethiopia

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Abstract

Globally, crop production is affected by soil nutrient deficiency. The application of nutrients is desirable to a given crop, soil type, and agroecology under changing climates. Thus, this experiment was initiated to investigate the yield-limiting nutrients through a nutrient omission trial on maize in the 2020/2021 cropping season in North West Ethiopia. It was arranged in a randomized complete block design with three replications. The treatments were compriosed of N, P, K, S, B, and Zn omitted treatments. Besides, NPKSZnB (All), recommended NP, no fertilizer, and RNP+S_1 treatments were added. The application of different nutrient types significantly ($p \leq 0.001$) affected grain yield. The highest grain yield (9.2tha^{-1}) was achieved by applying NPKSZnB nutrients, while the omission of K, S, Zn and B nutrients had no discernible effect. The lowest grain yield of 1.3tha^{-1} was recorded from treatment with no fertilizer followed by N omitted treatment (1.4tha^{-1}). The omission of N and P nutrients provided significantly lower grain yield as compared to the treatments receiving all the nutrients. Without N treatment decreased, grain yield by 55%, followed by the absence of P, which decreased grain yield by 25%, while the absence of K,S,Zn,B had no statistically significant impact on grain yield as compared to NP nutrients alone. Therefore, N and P nutrients are the most yield-limiting nutrients in Ethiopian soils. Overall, this finding showed that Nitrogen and Phosphorus were the most important nutrients to boost the yield of maize. So, optimizing the rate of yield-limiting nutrients are required for judicious use of fertilizers in the study areas and similar agroecological zones of Ethiopia. It is suggested to conduct timely assessment of indigenous soil supplying capacity of KS and micronutrients in agricultural soils.

Keywords: *Omission, Nitrogen, Nutrients, Phosphorus, Productivity, Yield.*

Introduction

Agriculture contributes about 50 % to the annual gross domestic product in Ethiopia (Tamene *et al*., 2017). The cereal crops production is covered large proportion in areas and production which is about 81%, and 88%, respectively (CSA, 2021). The share of imported fertilizer inputs used by major cereal crops mainly tef, maize, and wheat is 60% (Mesfin, 2009). The agriculture development led industrialization economic policy brought about dramatic progress in agriculture with an annual growth rate of over 8% (ADLI, 2001). The main goal of this strategy is to increase the use of agricultural inputs including improved seeds, fertilizers, and pesticides. Thus, fertilizer use has shown a linear increase from below 37 metric metric tons in 1985 jumped to over 134 metric metric tons at the end of 1994.

Currently, the country imports about 1.4 million metric metric tons of multi-nutrient fertilizers and is projected to use over 2 million metric metric tons at the end of 2025. However, a steady increase in yields in crop yield has been shown with the application of an imported high dose of fertilizers. The declining returns of fertilizers in Ethiopia could be the use of a low proportion of the most limiting nutrients such as Nitrogen and Phosphorus. For over 35 years, the proportion of imported Nitrogen in the fertilizer system of the country is 15 %, whereas between 2000 and 2015 it increased to 35 % (IFDC, 2012). However, contrary to the experience of Ethiopia, reports from other countries show that Nitrogen is the leading nutrient in global agriculture followed by Phosphorus and Potassium (Heffer *et al*., 2017; Yara, 2018; Sinha and Tandon, 2020).

Research reports on responses of N and P fertilizers by major crops (tef, maize, and wheat,) in Ethiopia accounted for over 75 % of the crop production and fertilizer consumption (Rashid *et al*., 2014). However, it lacks right ratio between the fertilizer imported and used concerning the demand for NP nutrients in the crop production system of the country. There are also different factors affecting the response of crops to fertilizers; these may include poor targeting of the right fertilizers in the right places (Tamene *et al*., 2017). In Ethiopia, fertilize is not applied by considering site and crop type in previous decades. Thus, the 4Rs principles (right fertilizers, right methods, right time, and right rate) in the use of multi-nutrient fertilizers are important guidlines to exploit the potential of fertilizers (Johnsmetric metric ton and Bruulsema, 2014; Bruulsema *et al*., 2019; IFA, 2020). Cognizant of this fact, the EthioSIS projecthas mapped the soil nutrient status of agricultural lands in the country (EthioSIS, 2016). EthioSIS project identified many essential nutrients that are deficient and critically required by the agricultural soils of the country. The deficient nutrients include N, P, K, S, B, Zn, Fe, and Cu. However, the Map developed by EthioSIS was not validated under field conditions. Yield response is used to assess the capacity of the soil to supply nutrients (Xu *et al*., 2014). The application of proper nutrients in specific soils could reduce the risks and uncertainties associated with agricultural crop productivity (Tijjani *et al*., 2022) and increase the potential to achieve the attainable yield. The objective of this experiment was to investigate the most maize yield limiting nutrients in Nitisols of North West Amhara, Ethiopia.

Materials and Methods

Study Site Characteristics: The omission trials to identify yield-limiting nutrients were implemented in Jabitahnan, Burie, Womberma, Ayehu Guagusa, south Achefer, and Mecha in the Amhara region, Ethiopia. Jabitahnan, Burie, Womberma, South Achefer, and Mecha, districts are parts of the West Gojjam administration zone of the Amhara National Regional State whereas Ayehu Guagusa district is found in the Awi administration zone. These districts are the predominantly maize-growing belts of Amhara region, north western part of Ethiopia. About 23 on farm experimental sites where each district received 2 to 5 sites were chosen.

Experimental fields were selected considering the dominant soil types, different cropping systems, and farm management practices with a range of socioeconomic settings. Nitisols are the dominant soil type in study areas. Cereal-based cropping system is the dominant type of cropping system in the study areas. Maize, Tef, wheat, and finger millet are the major cereal crops grown in the study areas. Noug (*Guizotia abyssinica Cas*s) crop also produced as oil sources for farmers.

Descriptions of Experimental Sites Selected Soil Chemical Properties: The state of soil chemical properties before planting varied between sites (Table 2). The selected soil properties of multi-location experimental sites varied due to the intrinsic nature of soils and management. Soil pH (H_2O exhibited wide variability with mean value ranging from 5.1 to 5.6. The maximum and minimum pH value recorded in the study areas are 4.7 and 6.0, respectively. The lower pH (H_2O) values were observed in Womberma, Jabitehnan, Mecha, and South Achefer districts.The highest Phosphorus value (19 $mgKg^{-1}$) is observed in one of the sites found in the Koga irrigation command area at Mecha District. The available Phosphorus is found between 2.9 to 19.0 $mgKg^{-1}$. All experimental sites, except the Engutie trial site in the Mecha district, had a mean available

Phosphorus far below the critical value. The higher soil Phosphorus in the soil might be associated with the frequent application of phosphate fertilizers in the double cropping seasons at Koga irrigation site in Mecha district. The cation exchange capacity ranged from 26.6 to 33.9 Meq/100g soil. Total Nitrogen content ranged from 0.10-0.22 % in soils of the study area. The total Nitrogen content varied from site-to-site experimental locations. The total Nitrogen of study soils ranged from medium to high based on Tekalign *et al*., (1991) ratings. This is associated with the mining of native soil nutrients in the farming system as a result of the complete removal of crop residue and livestock feed. The organic carbon content of the soil was found between 1.8 and 3.2 % with a range of low to medium organic carbon for Ethiopian soils as per criteria developed by (Tekalign *et al*., 1991).

Table1. Selected soil physic-chemical properties during planting across study sites

Soil parameters	Statistics	Locations						Critical value	Rating	Reference
		Ayehu Guagusa [4]	Bure [2]*	Jabitehnan [4]	Mecha [4]	S. Achefer [5]	Womberma [5]			
pH (H_2O)	Mean	5.4	5.2	5.2	5.1	5.4	5.6	5.5	Strong to moderately acidic	(Tekalign *et al*., 1991)
	Min	5.1	5.2	4.8	4.9	4.9	4.7			
	Max	5.8	5.3	5.8	5.3	6.0	5.6			
	Mean	8.0	6.6	7.9	7.8	4.7	7.8	10.0	Low to high	(Tekalign *et al*., 1991)
	Min	7.1	6.0	5.1	2.9	3.9	3.8			
	Max	9.7	7.1	14.0	19.0	5.7	11.0			
	Mean	34.7	29.4	28.1	28.2	30.3	30.2	-	Medium to very high	FAO (2006)
	Min	28.2	27.5	20.7	25.0	23.2	26.6			
	Max	42.8	31.9	38.6	31.6	36.9	34.1			
OC (%)	Mean	2.6	2.6	2.0	1.8	2.3	2.6	2.0	Low to medium	(Tekalign *et al*., 1991)
	Min	2.2	2.2	1.9	1.8	1.8	2.1			
	Max	3.2	2.8	2.2	1.9	2.6	3.1			
TN (%)	Mean	0.16	0.13	0.13	0.14	0.15	0.18	0.2	Medium to high	(Tekalign *et al*., 1991)
	Min	0.10	0.10	0.10	0.10	0.10	0.20			
	Max	0.20	0.22	0.20	0.18	0.16	0.22			

** Numbers in the parenthesis are No. of sites, CEC: cation exchange capacity, Min; minimum, Max: maximum, OC: organic carbon, P: available Phosphorus, TN: total Nitrogen*

Research Design: This experiment was conducted on a total of 23 sites across six districts. The experiment was arranged in a randomized complete block design and replicated three times at each farmer field. The nutrient omission experiment consisted of ten treatments including a no fertilizer (All omitted), All (NPKSZnB), All-S (S omitted), All-K (K omitted), All-Zn (Zn omitted), All-B (B omitted), All-P (P omitted), All-N (N omitted) and recommended NP (KSZnB omitted). Another NP treatment (NPS_1) with the additional of Sulphur nutrients with a 30 $Kgha^{-1}$ was used to further evaluate Sulphur fertilizer with a higher amount.

The rate for Nitrogen, Phosphorus, Potassium, Zinc, and Boron were 138, 92, 60, 5, and 1 $Kgha^{-1}$, respectively at all experimental sites. The rate of Sulphur was 10.5 and 30 $Kgha^{-1}$ for S and $S_{1,}$ respectively. The second rate of S, 30 $Kgha^{-1}$ was used to exhaustively see the effects of S on maize yield in the farming system.

Sources of Nitrogen, Phosphorus, Potassium, Sulphur, Zinc, and Boron were urea (46-0-0), triple super phosphate (0-46-0), Potassium chloride (0-0-60), magnesium sulfate (28% SO_3^-), EDTA Zinc (12 % Zn), and borax (11 % B), respectively. Recently released early maturing maize variety BH-546 was used in the Mecha district whereas late-maturing maize variety BH 660 was used for the other all districts.

Trial Management: Soil and crop management practices were done following research recommendations. After preparing the fields, all the sites were planted from 5 June to 30 June 2021. An average maize plant stands of 44444 per hectare was reached by sowing two seeds in each hole at intervals of 0.3 m in 0.75 row spacing, which were then thinned to one plant per hill. All fertilizers were applied by band application at planting except Nitrogen. Three equal split applications of Nitrogen were done: at planting, 35 days following emergence, and 65 days after emergence. Weed management was started after 2 weeks after planting. Each site has been weeded three times.

Data Collections: One composite soil sample of 0-20 cm was collected from each trial site to determine the status of soil fertility before planting. Major soil properties such as soil pH-H_2O, organic carbon (OC), available Phosphorus (AP), exchangeable acidity, and total Nitrogen (TN) analysis were conducted in Adet Agricultural Research Center's soil laboratory.

Maize was harvested from a net plot of 9 m^2 (36 plants), that is, constituting the 4 middle rows in each plot, leaving 0.75 m as border on each side of the row.

Above Ground Biomass: all plants in the net plots were harvested and the total fresh weights of cobs and stover were measured at the field using digital balance and then converted into $Kgha^{-1}$.

Grain Yield: all cobs were taken for drying. It was dried by air to constant weight and converted to $Kgha^{-1}$. The grain yield was expressed on dry weight by adjusting 12.5% moisture content. Moreover, measurements such as plant height, ear length, ear width, number of cobs per plant and 1000 seeds weight were also done from net plot. Thousand seed weight was measured by counting 1000 seeds of maize from grain yield and then measuring its weight by sensitive balance.

Data Analysis: Analysis of variance for the response of treatments was done at the site level and then combined at the district level using R software (version 4.5.1, Foundation for statistical computing, 2011). Thus, about 810 experimental datasets were collected and analysed. Mean separation for the treatments was made for significant results as outlined by Cochran and Cox (1957) for situations with heterogeneous variance among treatments. Contrast analysis was done to compare positive control and other treatments. Graphs are generated using R software.

Results

Response of Maize Yield to Nutrient Types at Variable Sites: Tables 2 and 3 displayed that grain yield varied highly significantly ($p \leq 0.001$) from 79 % of trial sites, significantly ($p \leq 0.01$) from 17 % of trial sites, and non-significantly ($p > 0.05$) from 4% of trial sites. From 50 % of sites, lower yield ranging from 0.9 to 6.5 metric metric tons ha^{-1} yields were recorded without fertilizer application (negative control) whereas yield between 1.1 and 7.6 tha^{-1} was obtained from Nitrogen omitted treatment in the remaining experimental sites. The maximum grain yield (10.7 tha^{-1}) was recorded from All (NPKSZnB) applied treatments at trial site 9 in the study area. The higher grain yields (4.5-7.7 tha^{-1}) were attained from recommended NP treatment in 38 % of trial sites. From 5.1 to 8.8 tha^{-1} and 5.0 to 7.1 tha^{-1} of higher yields were recorded from the omission of Boron (All-B) and Zinc (All-Zn) treatments at four trial sites, respectively. About 43 percent of sites exhibited higher grain yields ranging from 3.5 to 10.1 tha^{-1} from the application of Sulphur with recommended Nitrogen and Phosphorus but not significantly differed from NP nutrients applied treatment. The remaining sites were shown higher yields (3.2-8.9 tha^{-1}) from the addition of recommended Nitrogen and Phosphorus fertilizers across all experimental sites.

Table2. Maize grain yield (tha^{-1}) response to nutrient types in Mecha [4], Ayehu Guagusa [4], and South Achefre [5] districts (2021/22)

Treatment	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13
All	8.9	5.8	6.7	6.8	6.2	4.4	4.3	7.7	10.7	5.9	7.8	6.3	6.2
All-B	8.8	6.7	6.8	7.1	6.8	3.5	3.1	7.1	9.2	6.0	7.0	6.9	7.6
All-Zn	8.1	5.5	6.9	6.9	5.5	3.8	4.2	7.9	8.9	5.4	7.0	6.1	7.1
All-S	8.5	6.5	6.9	6.7	6.4	4.0	4.7	5.0	9.7	6.2	7.8	6.1	7.6
All-K	8.1	6.6	6.8	6.8	6.0	4.9	4.1	5.6	8.0	7.2	7.2	5.2	6.6
All-P	5.2	4.2	4.5	3.0	5.6	4.4	3.8	7.1	9.6	3.2	6.1	3.0	3.9
RNP	8.3	6.9	6.9	6.4	5.8	4.0	4.3	6.4	8.9	7.3	7.0	6.2	7.7
NF	3.0	0.9	3.4	1.8	1.3	0.5	2.1	3.6	6.2	2.2	2.5	2.4	2.3
$NP+S_1$	8.6	5.8	6.8	7.4	5.1	3.4	4.6	7.9	10.1	6.9	7.0	6.7	5.9
All-N	3.4	1.1	2.7	1.6	1.3	0.8	2.0	5.1	7.6	2.1	2.7	1.9	1.7
LSD (0.05)	1.2	2.0	1.3	1.4	1.9	1.4	1.5	2.8	2.2	2.2	1.3	1.4	2.1
CV	9.8	23.6	13.1	15.0	22.3	24.1	23.5	25.6	14.7	24.7	12.4	16.1	19.4
SEM	0.42	0.43	0.30	0.42	0.41	0.39	0.28	0.22	0.30	0.41	0.36	0.36	0.43
p	***	***	***	***	***	***	**	*	*	***	***	***	***

Table3. Maize grain yield (tha^{-1}) response to nutrient types in Jabitehnan [3], Burie [2], and Womberma [5] districts (2021/22)

Treatment	Site 14	Site 15	Site 16	Site 17	Site 18	Site 19	Site 20	Site 21	Site 22	Site 23
All	6.7	3.8	4.6	4.3	4.4	3.8	5.7	6.7	4.8	2.3
All-B	7.2	2.9	4.4	4.6	4.7	4.0	4.4	6.3	5.1	3.6
All-Zn	6.7	3.2	4.4	5.0	5.2	4.3	3.6	6.3	4.2	2.9
All-S	7.4	3.2	4.7	4.6	4.8	4.3	5.1	6.8	4.9	2.6
All-K	7.1	3.2	4.8	4.6	4.7	5.0	5.8	6.1	4.7	3.5
All-P	6.9	2.9	3.5	3.1	3.1	4.3	3.8	5.5	4.3	2.9
RNP	7.5	3.2	4.0	4.7	4.9	5.6	4.4	6.0	4.8	4.5
NF	4.4	1.1	1.5	2.3	2.4	1.4	3.3	2.9	2.2	1.8
$NP+S_1$	7.3	3.5	4.4	4.0	4.1	3.6	5.1	6.1	5.0	3.8
All-N	3.6	1.9	1.1	2.7	2.8	2.4	4.0	3.7	1.7	1.7
LSD (0.05)	1.7	1.2	1.6	1.3	1.3	2.1	2.0	1.4	1.0	2.1
CV*	15.1	23.3	26.5	18.9	18.7	31.8	26.4	14.6	14.0	38.2
SEM	0.28	0.19	0.21	0.20	0.21	0.25	0.25	0.19	0.22	0.18
p	***	**	***	**	**	*	ns	***	***	ns

*CV: coefficient of variation, LSD: least significant difference, SEM: standard errors of the mean, ***: significant at 0.1 %. **: significant at 10 %., *: significant at 5 %, and ns: non-significance at 5 %.

Table 4 displays the combined results of nutrient effects on maize grain yield across sites. The combined analysis result in each district revealed that grain yield was highly significant ($p \leq 0.001$) in response to the application of nutrient types in all studied districts. The lowest grain yield from no fertilizer treatment (1.3 - 3.1tha^{-1}) was obtained from the Ayehu Guagusa midland, Mecha, Womberma, and Burie districts. Next to no fertilizer, All-N treatment also gained lower yields ranging from 1.8 to 5.2tha^{-1} in Jabitehnan and Ayehu Guagusa lowland districts. The highest (9 tha^{-1}) mean grain yield was recorded from the addition of NPKSZnB nutrients in the Ayehu Guagusa lowlands district compared to other studied districts. Fertilizer application of all nutrients provided 40-70% yield increment compared to no fertilizer application in the study districts.

Table4. The combined maize yield (tha^{-1}) response to nutrient types in the studied districts of North West Amhara (2021/22)

Treatment	Mecha	South Achefer	Ayehu Guagusa lowlands	Ayehu Guagusa midlands	Womberma	Burie	Jabitehnan
All	6.9 ± 0.38	6.6 ± 0.34	9.2 ± 0.70	4.3 ± 0.22	4.6 ± 0.49	4.4 ± 0.15	4.5 ± 0.50
All-B	7.0 ± 0.34	6.9 ± 0.36	8.2 ± 0.51	3.3 ± 0.36	4.7 ± 0.35	4.7 ± 0.14	4.3 ± 0.56
All-Zn	6.6 ± 0.31	6.4 ± 0.30	8.4 ± 0.26	4.0 ± 0.52	4.3 ± 0.38	5.1 ± 0.54	4.3 ± 0.54
All-S	7.0 ± 0.27	6.9 ± 0.40	7.4 ± 1.41	4.3 ± 0.39	4.7 ± 0.46	4.7 ± 0.20	4.4 ± 0.65
All-K	6.9 ± 0.23	6.6 ± 0.30	8.3 ± 0.30	4.5 ± 0.45	5.0 ± 0.34	4.6 ± 0.22	4.6 ± 0.54
All-P	4.5 ± 0.33	4.1 ± 0.41	8.3 ± 0.73	4.1 ± 0.18	4.2 ± 0.25	3.1 ± 0.31	3.9 ± 0.58
RNP	6.8 ± 0.33	7.1 ± 0.31	7.7 ± 0.70	4.2 ± 0.15	5.1 ± 0.32	4.8 ± 0.29	4.5 ± 0.58
NF	2.0 ± 0.29	2.4 ± 0.25	6.5 ± 1.34	1.3 ± 0.39	2.3 ± 0.22	2.4 ± 0.20	1.9 ± 0.48
RNP+S_1	6.7 ± 0.42	6.6 ± 0.27	9.0 ± 0.63	4.0 ± 0.44	4.7 ± 0.36	4.1 ± 0.34	4.5 ± 0.63
All-N	2.3 ± 0.46	2.1 ± 0.28	5.2 ± 1.16	1.4 ± 0.34	2.7 ± 0.29	2.8 ± 0.17	1.8 ± 0.38
CV*	18.2	18.1	15.7	24.0	24.2	17.0	25.2
p	***	***	***	***	***	***	***

**CV: Coefficient variation, Figures followed by ± sign are standard errors of the mean for each treatment, NF: no fertilizer. LSD: least significant difference.*

Role of Nutrients to Biological Grain Yield and Association with Yield Component Parameters: Figure 1 displays the mean percentage of deficient nutrients in the study area. About 55.3% of maize grain yield declined was recorded due to the absence of Nitrogen fertilizer application in the maize growing belts of the study area. Similarly, the omission of Phosphorus fertilizer reduced maize grain yield with a range of 24.5% over the study areas of north western Amhara of Ethiopia. With out fertilizer application 57.2% yield drop was observed.

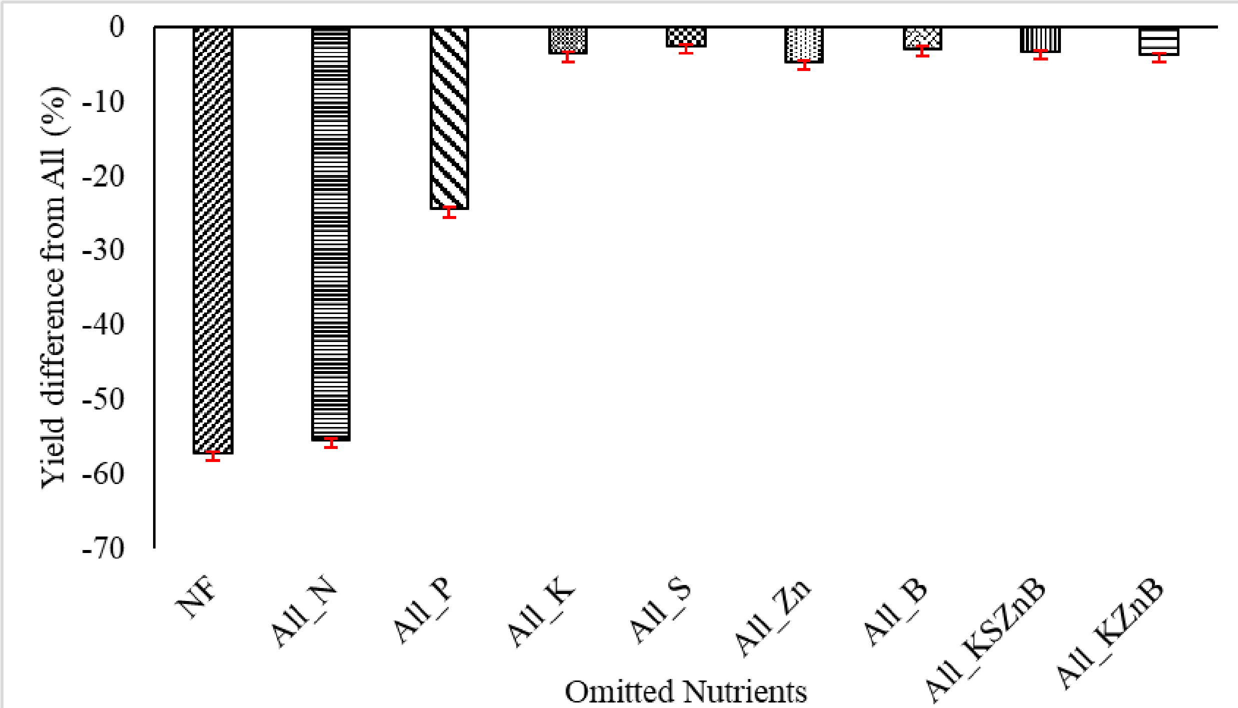

Figure 1. The contribution of each omitted nutrient in the study area

Correlation analysis showed 36 significant associations between all traits measured under the nutrient omission study (Table 5). Grain yield with crop parameters such as ear length (r =0.61***), ear diameter (r =0.61***), plant height (r = 0.46***), and thousand seed weight (r= 0.43***). All correlation analysis results showed highly significant ($p \leq 0.001$) positive associations between yield and yield component parameters. Highly significant ($p \leq 0.001$), but weak positive correlation (r=0.12) was also reordered between plant height and ear diameter whereas a strong positive correlation was recorded between grain yield and cob weight per plant (r = 0.89***). Figure 2 presents the application of all nutrients (NPKSZnB) and NP had a highly significant strong correlation (r = 0.7***) to maize yield.

Table5. Correlation matrix of yield and yield components of maize due to applications of different nutrient types across sites in North West Amhara (2021/22)

Parameters	Ph*	EL	ED	TSW	CwP	Gy	By	Sample size
Ph		***	**	***	***	***	***	810
EL	0.58		***	***	***	***	***	810
ED	0.12	0.53		***	***	***	***	750
TSW	0.43	0.31	0.29		***	***	***	238
CwP	0.43	0.59	0.62	0.48		***	***	779
Gy	0.46	0.61	0.61	0.43	0.89		***	810
By	0.68	0.62	0.36	0.52	0.64	0.63		810

**Ph: plant height, CwP: cob weight per plant, EL: ear length, ED: ear diameter, TSW: thousand seed weight, Gy: grain yield, and By: biomass yield*

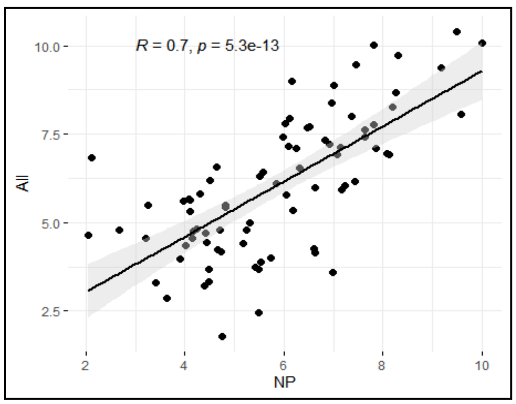

Figure 2. Maize grain yield (metric metric ton ha^{-1}) under All (NPKSZnB) and recommended NP nutrients across trial sites of study area (2021/22).

Discussion

Response of Grain Yield to Nutrients: The overall response of NPKSZnB application on maize yields varied across sites. The variation of nutrient responses from site to site indicates the need for site-specific nutrient management for crops. The variability in crop responses to nutrients supplied is a reflection of the intrinsic heterogeneity of soils among farmer fields, which is mostly brought on by soil management in the maize belt region of Ethiopia's Amhara Region (Balemi *et al*., 2019). Similar results were reported by Aliyu *et al*., (2021) maize yield is varied due to native soil variability in Nigeria, and sub-Saharan Africa (Kihara *et al*., 2016). The yield variability is happened due to spatial variability in the soil's nutrients supply capacity throughout the farmer's field. So, it is vital to assess of soil and environment for effective nutrient use to boost maize productivity.

The application of Nitrogen and Phosphorus was brought 100 yield increments compared to control treatment in Burie, Jabitehnan, South Achefer, Ayehu Guagusa midlands, and Mecha districts, whereas an increase of over 15 % was obtained in Ayehu Guagusa lowlands. This result shows that the addition of limiting nutrients as fertilizer is mandatory to improve crop production (van Beek *et al*., 2016; Mueller *et al*., 2012; Pradhan *et al*., 2015; Balemi, *et al*., 2019; Leitner *et al*., 2020; Yokamo *et al*., 2022). Nitrogen omission substantially reduced grain yield across all the studied districts owing to low Nitrogen soil content. There is severe Nitrogen nutrient depletion in Ethiopian highland soils (Haileslassie *et al*., 2005; van Beek *et al*., 2016; Mesfin *et al*., 2021). Our finding shows that Nitrogen is the most limiting nutrient to maize yield in the study areas. This tells the larger requirement of soils of the study area is Nitrogen fertilizer which signals high Nitrogen deficiency (Balemi *et al*., 2019; Amare *et al*., 2022; Hayashi, 2022).

The response to Phosphorus varied across sites with higher response observed from Mecha, South Achefer, and Burie districts due to a wide range of soil Phosphorus deficiency. Previous findings also indicated that the response of crop yield to N and P varied from site to site (Balemi, *et al*., 2019). Next to Nitrogen, the absence of Phosphorus is also limiting the maize yield in soils of maize growing belts (Girma, 2016; Pokharel *et al*., 2016). Preceding studies also indicate that Nitrogen and Phosphorus are widely deficient nutrient types in Ethiopian soils (EthioSIS, 2016). The present result agreed with many research findings that showed a reduced yield of maize in without Nitrogen and Phosphorus plots gave as compared to other plots in the study area as well as many parts of the country (Balemi *et al*., 2019; Amare *et al*., 2018; 2022). Thus, Nitrogen and Phosphorus are key nutrient types to boost crop productivity. However, grain yield was not declined due to Phosphorus omission in Ayehu Guagusa, and Womberma, districts which was in conformity with the finding of G. Selassie, (2016) who reported low P response in some soils of the Amhara region.

The analysis of variance shows non-significant grain yield differences among Potassium, Sulphur, Zinc, and Boron omitted treatments across all trial sites. The lack of response to Potassium and Sulphur nutrients suggests that KS nutrients are not a significant limiting nutrient in most of the soils in the study areas. This tells that the inherent Potassium and Sulphur-supplying capacity of the soils are relatively high in the Northwest Amhara region (G. Selassie *et al*., 2020; Amare *et al*., 2022). Yet, the need of supplying these nutrients is suggested by other findings in Ethiopia (Habtegebrial, and Singh, 2009; Bekele *et al*., 2022), and other countries (Rawal *et al*., 2018; Aliyu *et al*., 2021).

The omission of born and Zinc nutrients was shown inconsistently non-significant yield response in all studied districts. Either addition or omission of these nutrients leads increase grain yield of maize in some trial sites. This mighthave associated with soil variability across trial sites. Our finding indicates that the use of the micronutrients has not brought a substantial yield increase (Balemi *et al*., 2019; Amare *et al*., 2022). In contradiction with our result Alemu *et al*., (2016), Girma (2016) and EthioSIS (2016) reported that Zn and B nutrients are deficient in Ethiopian soils which must be added as mineral fertilizer.

The addition of Sulphur with recommended Nitrogen and Phosphorus gave almost equal non-significant grain yield compared with recommended Nitrogen and Phosphorus nutrients in all districts of Northwest Amhara, Ethiopia. Generally, recommended NP and NP plus Sulphur treatments show almost equal grain yield of maize in all study areas. So, the application of Sulphur might not be profitable in the farming system. Our result is contracted with the findings of EthioSIS, (2016) and Girma (2016) who reported that Sulphur is deficient in the soils of Ethiopia. The addition of all nutrients (NPKSZnB) and NP had similar trends across all trial sites. Both treatments have responded almost equally to maize yield. This tells us that only Nitrogen and Phosphorus have responsible to yield. Other added nutrients are not limiting due to their adequate delivery by the soils. Contrary to our findings Hailu *et al*., (2015) suggested application of NPKSZnB fertilizers in vertisols of central highlands of Ethiopia. Moreover, the addition of Sulphur and micronutrient fertilizers is suggested to enhance production in sub-Saharan Africa (Kihara *et al*., 2017).

Conclusions and Recommendations

The results of the soil analysis revealed that the soil of the study sites was deficient in Nitrogen and Phosphorus. The response of fertilizers to yield was significantly varied among soils from various sites. Nitrogen followed by Phosphorus nutrient omission declined maize yield in the study soils. Hence, Nitrogen and Phosphorus are the most yield-limiting nutrients in all trial sites. To reduce the production gap of maize in the farming system, these nutrients must be applied. The addition of Potassium, Sulphur, Zinc, and Boron nutrients did not significantly increase yield constantly compared to Nitrogen and Phosphorus nutrients in all experimental sites, and therefore, they are not yield limiting nutrients to improving yield targets. In conclusion, Nitrogen and Phosphorus nutrients are key fertilizer inputs to boost the yield of maize in Ethiopian highlands. This implies that the yield gap of maize should be minimized by addressing the demand for Nitrogen and Phosphorus fertilizers. Future assessment of Potassium, Sulphur, and micronutrients, which are not limiting for maize yield in this study, is recommended to decide their requirement in the farming system.

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8. Response of Tef (*Eragrostis Tef (Zucc.) Trotter)*) to Nutrient Types under Rainy and Irrigation Production Systems in Highlands of Ethiopia

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Abstract

Crops respond differently to nutrient types as a result of variations in the environment, soil, and management. The main problem with Ethiopian agricultural crop production is the poor selection of the necessary fertilizers for usage as an input. The objective of this study was to determine the most important nutrients to tef productivity on Vertisols and Nitisols. The experiments were conducted in three districts for the rainfed season, and one district irrigation season in the Amhara region, Ethiopia. Quncho and Gibie tef varieties were used as test crops for rainfed and irrigation seasons, respectively. Ten treatments composed of no fertilizer, All (NPKSZnB), All-B, All-Zn, All-S, All-K, All-P, All-N, RNP, and RNPS as well as RNP+S1 which have 30 Kgha^{-1} S were applied. Three replications with a completely randomized block design were used to set up the experiment. Biological data were collected from a net plot area and analyzed using R version 4.1.1. When significant treatment means were found, mean separation using the least significant difference ($p \leq 0.05$) was performed for treatment comparisons. Before planting, soil results revealed that the mean available P contents in vertisols and nitisols were 5.1 and 8.9 mgKg^{-1}, respectively, which is a low range. Whereas under the irrigation system, nitisols were found with 21.4 mgKg^{-1} of soil P. The soil Nitrogen contents were found about 0.12% for nitisols and 0.15% for vertisols under rain fed season as well as 0.14% for nitisols under irrigation which was medium. Grain yield significantly ($p \leq 0.01$) varied to omitted nutrient types compared to the negative control (without fertilizer application) and All-N treatments during the rainy and irrigation season. During the rainfed and irrigation seasons, grain yield significantly ($p \leq 0.01$) varied to omitted nutrient types compared to l without fertilizer application and All-N treatments. However, there was no significant ($p < 0.05$) decline in yield due to the omission of Potassium, Sulphur, Zinc, or Boron. The lowest grain yields, 342 Kgha^{-1} for vertisols and 491 Kgha^{-1} for nitisols, were obtained when no fertilizer treatment was used. Application of K, S, Zn, and B did nothave any effect on tef yield compared to the applied NP nutrients. For vertisols and nitisols, N omission resulted in a 65 and 49% decrease in grain production. During the irrigation season, a yield decline of about 19% was also observed when N was omitted. As conclusion, P is only a limiting nutrient during the rain-fed season, but N is the nutrient that limits the yield of tef in both production seasons. To boost tef productivity, Ethiopian agriculture has to import the proper quantity of NP fertilizers with site-specific recommendations. It is suggested that the KSZnB nutrients in the farming system be periodically monitored.

Keywords*:* Fertilizer, Limiting, Nutrient, Omission, Soil, Tef, Yield.

Introduction

Maintaining soil resources while meeting the food demand of a high population is an unsolved problem (FAO, 2017). Chemical fertilizer played a major role in global food production over the past 60 years to feed the ever-increasing population. The current challenge for the Ethiopian agriculture sector is low productivity due to a high level of nutrient mining, low use of external inputs, traditional farm management practices, and limited capacity to respond to environmental shocks (Menna *et al.*, 2015; Desalegn *et al*., 2017; Agegnehu *et al*., 2015). The cropping area is subject to severe losses of nutrients due to soil erosion and the removal of dung and crop residue for fuel (Hurni, 1993). Nutrient balance studies by Stoorvogel and Smaling (1990) show that Ethiopia is among the countries with the highest rates of net nutrient losses. The annual nutrient deficit is estimated at -41 Kg N, -6 Kg P, and -26 $Kgha^{-1}$ K (Van Beek *et al*., 2016; Haileslassie *et al.,* 2005). Moreover, the nutrient balances in tef cropping systems are negative (–28 $Kgha^{-1}$ N) (Haileslassie *et al.,* 2006).
The maintenance of soil health depends on balanced fertilization, which includes the application of all the required plant nutrients in proper amount and form (Rakshit *et al*., 2017). Therefore, site-specific nutrient management involving along with spatial and temporal soil variability, crop requirements of nutrients, and cropping systems as well as without deteriorating soil and environmental quality is the most ideal system that needs to be practiced to achieve the targeted goals (Tiwari, 2007; Meena *et al.,* 2015; Sarkar *et al.,* 2017; Verma *et al.,* 2015). This situation leads to the use of correct fertilization which helps to boost the resilience of crops and therefore plays an important role in climate change adaptation. Though higher output and productivity are achieved by the application of more and different chemical fertilizers into the farmland (Rakshit *et al*., 2017) the application of selected nutrient types to the crop is vital. Because, crop plants are only able to convert about 33 % of the applied Nitrogen fertilizer (Ram and Johnson, 1999) and 10 – 15% of P (Roberts, and Johnston, 2015) to useful food products (grain).

Tef is a tropical grain that originated in Ethiopia and has a large diversity. It is thought to have been domesticated there and is recognized as a resilient crop (Ketema, 1997; Assefa *et al*., 2011). Because ithas grown under different environmental stresses in many parts of Ethiopia. Tef is also a C_4 annual small grain crop native to Ethiopia (Halpern *et al.*, 2021). It is also a gluten and gluten-like protein-free stable food crop (Spaenij-Dekking *et al.,* 2005; Baye, 2014). Tef grains are used as a daily protein source by two-thirds of the population in Ethiopia (Ereful *et al.,* 2022). It is cultivated on about two million hectares of land covering about 30% of the area under cereals.

Many efforts have been delivered to improve the productivity of tef in the rainy season although it still needs continuous work. Accordingly, many improved varieties and management options are included in tef production package. Nevertheless, less emphasis has been given to its production under irrigation and hence there is a technology package for tef under irrigation. The Amhara region is well known for its richness of water resources for irrigation. There is a successful start of tef production by irrigation in the Fogera and Mecha districts and the surrounding areas. Preliminary observations show that tef needs fewer amounts of water and labor compared to other horticultural crops. Therefore, this research proposal is designed to generate roles of different nutrient types under irrigation water management to enhance the productivity of tef and effectively use the existing water and market potential.

Fertilizer application has significantly increased the yields of crops (Belachew *et al.*, 2022). About 70 to 80 % of the inorganic fertilizer purchased by the smallholders is known to be applied to tef (Yirga and Hassan, 2013). Though fertilizer use in Ethiopia has increased notably since 1990, there is no concomitant yield increase (Zelleke *et al.,* 2010), especially in tef. Tef yield has been limited by low soil fertility and soil acidity (Agegnehu *et al.,* 2019), inappropriate use of fertilizer, low fertilizer use efficiency (Tarekegne and Tanner, 2001; Yirga *et al.,* 2002), inappropriate tillage, and climate variability (Habtegebrial *et al.,* 2007). Tef production is labor-intensive with low productivity (an average of 1.5 tha^{-1} nationally) (Fissehaye *et al.,* 2009). Despite the potential for increasing yields of tef and farm income by the use of fertilizer, many small-scale and poor farmers do nothave the resources to make use of fertilizer for various reasons.

Commonly, Nitrogen and Phosphorus fertilizers have been applied in tef production for many years (Bekele, 2017). Previous blanket fertilizer recommendations are commonly used across different environmental conditions. These have not considered agro-ecological differences and soil variability (Shewangizaw *et al.*, 2021; Sileshi *et al.*, 2022; Dargie *et al*., 2022). Despite substantial increases in fertilizer use in the country (Zelleke *et al.,* 2010), deficiencies of N and P, K S, B, and Zn are reported in most of the Ethiopian soils (Beyene, 1983; Hailu *et al.*, 2015; EthioSIS, 2016) as well as Cu, Mn, and Fe are also deficient in some soils of sub-Saharan Africa (Kihara *et al.*, 2020). The higher use of mineral fertilizers is considered to be an essential option to close yield gaps (IFDC, 2015; Pradhan *et al.*, 2015; Chamberlin *et al.*, 2021), but profits cannot be maximized and sustained by applying unbalanced fertilizer applications over many years. Several fertilizer experiments on different crop types have been conducted over the last five decades and thus the empirical evidence confirmed that NP are deficient nutrients that must be supplied to crops in Ethiopia (Tanner and Hulluka, 1991; IFPRI, 2010; Amare *et al.*, 2018;2019; Bekele *et al.,* 2022). However, some researchers recently argued that KSZnB nutrients are also deficient and thus other nutrients are deficient with concrete evidence.

Currently, N, P, S, Zn, and B-containing fertilizers are imported and distributed in Ethiopia by the ministry of agriculture. To shift national fertilizer, and import policy, identifying and confirming the right fertilizer sources is mandatory in the farming system. Nowadays, developing a site and crop-specific nutrient recommendation for different agroecology and soil types as well as socioeconomic variabilities of farmers is a prerequisite agenda for sustainable crop production and profit in Ethiopian agriculture (Dargie *et al.*, 2022; Sileshi *et al.*, 2022). Selecting the right fertilizer types and balanced application of nutrients at appropriate rates to the local climate and every soil type is important to maximize tef yield (Johnston and Bruulsema, 2014). Though tef yield response to different soil nutrient types has been studied in some parts of Ethiopia, it is not well addressed in different soil types and locations in Northwestern Ethiopia. Despite, the recent expansion of tef with an irrigation system in the Amhara region, there are no research recommendations on nutrient management to enhance the productivity and profitability of tef production with irrigation systems. The purpose of this study is to elucidate the response of tef to different applied soil nutrients in nitisols and vertisols under rainy and irrigation production seasons in North West Ethiopia.

Materials and Methods

Study Site: Nutrient omission experiments were conducted on multi- locations across farmers' fields on vertisols and nitisols in North Western Ethiopia. This experiment was conducted at 12 sites across three districts. The study was conducted across sites in farmlands of smallholder farmers in the Amhara region, Ethiopia (Figure 1). A similar nutrient omission trial was implemented during the irrigation production systems at two farmers' fields in the Mecha district which have the Koga irrigation scheme. The locations include; Yilmana Densa, Gonji Kollela, and Hulet Ejunebse districts. Yilmana Densa, Gonji Kollela, and Hulet Ejunebse are found about 42, 74.5, and 119 km from Bahir Dar on the way to Addis Ababa through Bichena, respectively. Mecha district is located *30 km south of Bahir Dar* on the way to Addis Ababa through Fnote Selam town. Three locations represent the major tef growing areas of west and east Gojjam Ethiopian highlands. Both vertisols and nitisols are the major soil types in the study sites. The experiment was conducted on nitisols in all districts whereas it was conducted on vertisols in both Yilmana Densa and Gonji Kolela districts during the rainy production season. Cereal-based cropping system is the dominant type of farming system in the study areas. The experimental sites received a uni-modal type of rainfall which extending from June to Augst in higher amounts. Maize, Tef, and Finger millet are the dominant cereal crops grown in the study areas. Bread wheat is also a dominant crop grown in Hulet Ejunebse district.

Fertilizer Sources and Test Crop: Fertilizers including urea (46-0-0), triple super phosphate (0-46-0), Potassium chloride (0-0-60), magnesium sulfate (28 % SO_3^-), EDTA Zinc (12 % Zn), and borax (11% B) were used as the source of nutrients for Nitrogen, Phosphorus, Potassium, Sulphur, Zinc, and Boron, respectively. Kuncho and Gibe varieties of tef were used as a test crop for experiments in rainy and irrigation seasons.

Experimental Design: This study was conducted on farmlands across different locations. The trial was arranged in a completely randomized design with three replications at each study site. The nutrient omission was used as a design of this experiment. During the rainy production season, the recommended Nitrogen and Phosphorus rates were used for nitisols and vertisols in the districts (Table 2). The treatments were composed of: one treatment which has six nutrients (N, P, K, S, Zn, and B). and the omitted of N, P, K, S, Zn, and B are composed of the remaining treatments in this trial. In addition, positive control (recommended NP), negative control (without fertilizer application), and NPS_2 (30 $Kgha^{-1}$) were used. NPS_2 treatment was used to support further evaluation of Sulphur fertilizer rate compared with NP fertilizers.

Fertilizer Rates

Table 1. Rates of applied nutrients in vertisols and nitisols under the rainy season

No.	Treatment	Nutrient rates* ($Kgha^{-1}$) used in the treatment application							
		N		P_2O_5		K_2O	S	Zn	B
		Vertisols	Nitisols	Vertisols	Nitisols				
1	All (NPKSZnB)	80	46	46	69	60	10.5	5	1
2	All – B	80	46	46	69	60	10.5	5	0
3	All – Zn	80	46	46	69	60	10.5	0	1
4	All – S	80	46	46	69	60	0	5	1
5	All – K	80	46	46	69	0	10.5	5	1
6	All - P	80	46	0	0	60	10.5	5	1
7	RNP	80	46	46	69	0	0	0	0
8	No fertilizer	0	0	0	0	0	0	0	0
9	RNP + S_2	80	46	46	69	0	30	0	0
10	All – N	0	0	46	69	60	10.5	5	1

**Note: the rate of NP is based on previous recommendations for each location.*

A total of nine treatments were used for irrigation production season which includes one All treatment with six nutrients (N, P, K, S, Zn, and B), and the other six treatments were composed by omitting N, P, K, S, Zn, and B. Moreover, positive control (recommended NP) and negative control (without fertilizer application) treatments were also comprised. The Nitrogen, and Phosphorus rates of 92, and 69 $Kgha^{-1}$ were used, respectively. The rate of Potassium, Sulphur, Zinc, and Boron nutrient rates was used as similar to the rainy season shown in Table 1.

Experimental Management: The agronomic practices were conducted based on recommendations. After preparing the fields, all the sites were planted with broadcasted and row for rainy and irrigation seasons, respectively. The fertilizer and seed rate had been calculated without considering furrow spaces for trials under irrigation. The irrigation water had been applied in furrows with 40 cm furrow width at 7-14 days irrigation intervals. All fertilizers were applied by band application at planting except three split urea for top dressing. The first split of Nitrogen was applied one month after emergence. Weed management was started just after 2 weeks after the emergence of the trials.

Each site has been weeded three times. All experimental sites of the rainy season were harvested from 15 November 2021 to 15 December 2021 whereas the experiment under irrigation was harvested in May 2021.

Data Collection: Composite soil samples from 0-20 cm soil depth were collected from each experimental field. Major soil parameters such as soil pH-H_2O, organic carbon (OC), available Phosphorus (AP), exchangeable acidity, and total Nitrogen (TN) analysis were conducted in Adet Agricultural Research Center's soil laboratory.

Measurements of plant height, panicle length, aboveground biomass, and grain yield were collected for this trial. The measurement of plant height was recorded from the soil surface to the tip of a spike from 10 randomly selected plants from the net plot area at physiological maturity. Panicle length was measured from 10 randomly selected plants. Harvesting was done from the middle 16 rows of 3 m by 3.2 m (9.6 m^2) net plot area, leaving the border rows as a barrier. Then, biomass was measured from harvested plants in the net plot area at the field using digital balance and then converted into Kg per hectare. Grain yield was also measured after threshing of collected biomass from the net plot area and then measured its weight by sensitive balance then converted into $Kgha^{-1}$. Finally, grain yield was adjusted by 12.5% moisture content.

Data Analysis: All collected samples were air-dried and crushed to pass a 2-mm sieve. Analyses were performed on surface samples including pH, organic C, total Nitrogen (N), available Phosphorus (P), and cation exchange capacity following standard soil laboratory procedures. Soil pH-H2O was determined in soil-water suspensions of 1:2.5 ratios (Lean, 1982). Available Phosphorus was also done following the Olsen method (Olsen, and Sommers, 1982) while total Nitrogen was done using the Kjeldahl method (Bremner, and Mulvaney, 1982). The wet oxidation method was used to determine soil organic carbon (Walkley, and Black, 1934). Cation exchange capacity was also determined by the ammonium acetate extraction procedures (Houba et al., 1986).

Analyses of variance were executed for grain yield and yield-related test crop data from each site and all sites combined in the district. A test of significance for the treatment was made for significant results as outlined by Cochran and Cox (1992) for situations with heterogeneous variance among treatments. Mean comparisons were done to compare positive control and other treatments. Graphs were generated using R software.

Results and Discussion

Soil Chemical Properties of the Experimental Area: The results of the nutrient analysis of soils are displayed in Table 2. The experimental sites of vertisols were observed with a pH range of 6.0-6.9, which is slightly acidic (Tekalign *et al*., 1991). The pH of nitisols was also found between 5.1 to 5.9 which is moderately acidic. In the study area, the highest and lowest mean soil pH values of 6.49 and 5.13 in the top 20 cm soil depth were found under vertisols and nitisols, respectively (Table 2). The result confirms that nitisols were more acidic than vertisols. The total Nitrogen content of the soil of experimental sites varied from 0.06-0.14% and from 0.08-0.18 % in nitisols and vertisols, respectively. The soil has low to medium N contents according to the rating by Tekalign (1991). Relatively vertisols have lower Nitrogen content which is associated the higher Nitrogen loss in soil nature. The organic carbon content of the soil was between 0.7-1.3 and 1.0-2.2 % for vertisols and nitisols, respectively. The soil organic carbon is ranged between low to medium study soils as per criteria developed by Tekalign *et al*., (1991).

Table 2. Soil parameters descriptive statistics at planting time across sites of study districts under rainy and irrigation production seasons (2021/22)

Variation	pH	OC* (%)	P ($mgKg^{-1}$)	CEC (cmol/Kg)	TN (%)
			Vertisols [Rainy season]		
Minimum	6.02	0.70	4.31	41.56	0.06
Maximum	6.86	1.28	5.69	59.20	0.14
Mean	6.49	1.00	5.11	49.16	0.12
Rating	Slightly acid	Low-medium	Very low-low	High-very high	Medium-high
			Nitisols [Rainy season]		
Minimum	5.13	0.95	5.25	24.62	0.08
Maximum	5.88	2.20	14.80	39.52	0.18
Mean	5.39	1.89	8.87	29.80	0.15
Rating	Moderately acid	Low_ medium	Low-high	High-very high	Medium-high
			Nitisols [Irrigation season]		
Site 1	5.01	1.76	7.15	-	0.13
Site 2	5.42	1.76	35.74	-	0.14
Mean	5.22	1.76	21.44	-	0.14
Rating	Strongly acid	Medium	Medium-high	-	Medium
Critical	5.50	2.00	10.00	-	0.20
Reference	(Tekalign *et al.*, 1991)	(Tekalign *et al.*, 1991)	(Olsen *et al.*, 1954)	FAO (2006)	(Tekalign *et al.*, 1991)

** CEC: cation exchange capacity, P: available Phosphorus, OC: organic carbon, TN: total Nitrogen content.*

The available Phosphorus content of the soil of the experimental site was 4.3-5.7 and 5.3-14.8 $mgKg^{-1}$, respectively which lies in a range of deficiency for vertisols (Olsen *et al.*, 1954). It ranged from medium-high for nitisols in the study area. However, the available p content in the soil at trial sites in the irrigation command area is higher, ranging from 7.2 to 35.4 $mgKg^{-1}$. This may be related to P fertilizer addition build-up during both production seasons. The cation exchange capacity value of both soils is high to very range according to the rating by Hazelton and Murphy (2019). This tells that the addition of chemical fertilizer is needed for improving tef yield in study sites.

Response of Tef Yield to Applied Nutrients: Grain yield significantly ($p \leq 0.01$) varied to omitted nutrient types compared to the negative control and All-N treatments during the rainy season. Grain yield was also significantly ($p \leq 0.01$) affected by recommended Nitrogen and Phosphorus compared to no fertilizer treatment. Compared to treatments that got all types of nutrients (NPSBZnK), certain sites had highly significant ($p \leq 0.01$) higher yields (Table 4). However, the grain yield of tef was not significantly ($p > 0.05$) increased with the application of KSZnB with NP compared to NP alone. Our finding was in disagreement with Gebrehawariyat *et al.,* (2018) who suggested that applying K fertilizer increases tef production.

A higher tef yield was recorded from All-B (1695 Kgha^{-1}) in nitisols at site 7 and All-Zn (1712 Kgha^{-1}) in vertisols at site 4 (Table 3). However, the lower yield obtained from no fertilizer treatment ranged from 209 to 432 Kgha^{-1} across the studied sites. As we can see from our study, the majority of plant nutrients (KSZnB) come from the soil, but the soil did not provide an adequate amount of all the nutrients, particularly the Nitrogen and Phosphorus that plants need in the proper amounts. Nitrogen is the most yield-limiting nutrient in most soils, agroecology, and regions (Amare *et al.*, 2022; Alemayehu *et al.*, 2022). It is also a universal yield-limiting nutrient (Yara, 2018). So, synthetic Nitrogen fertilizers accounted for the food increase in the world. Different studies indicate that crops grieve a severe N deficit and reduced yields as a result of inadequate amounts of Nitrogen and other nutrients (Cassman and Dobermann, 2022). This might be associated with applied NP fertilizer and native soil nutrients being severely eroded in agricultural fields *(Haileslassie et al.,* 2005). Our research contradicts assertion of Habte and Boke (2017) that NPS had increased tef yield. Furthermore, our findings conflict with those of Kihara *et al,* (2020), who claimed that African soils are deficient in micronutrients. Biological yield results had a direct correlation with the locations where our soil analysis revealed low Nitrogen and Phosphorus concentrations in trial sites. Thus, fertilization is mandatory to address deficiencies.

Table 3. Tef grain yield (Kgha^{-1}) response to nutrient types at different sites in GonjiKolela, Yilmana Densa, and Hulet Ejuenbesie districts (2021/22)

Treatments	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
All*	1440	1629	1264	1508	973	933	1141	1039	1323	1443
All-B	1438	1695	905	1547	1023	1078	1209	1088	1179	1652
All-Zn	1346	1569	1470	1712	938	1065	1138	957	1258	1328
All-S	1349	1446	1120	1618	1127	1104	1110	1011	1138	1415
All-K	1215	1675	1190	1473	1147	1076	1231	887	1198	1393
All-P	1330	1372	1356	1660	369	829	1030	1013	1162	1139
RNP	1044	1552	1260	1613	1154	1118	1202	974	1218	1144
NF	432	418	209	398	253	571	469	526	440	448
RNP+S_1	1292	1568	1182	1506	986	967	1135	1032	1131	1305
All-N	547	490	232	804	312	728	663	485	543	557
LSD (5%)	287	354	277	337	156	242	305	221	242	258
CV	14.6	15.4	15.9	14.2	11.0	15.0	17.4	14.4	13.4	13.0
SEM	±71.4	±91.5	±83.1	±81.2	±66.8	±38.9	±52.7	±42.8	±58.0	±72.4
p	***	***	***	***	***	**	***	***	***	***

All= NPKSZnB, CV = coefficient of variance, LSD= least significant difference, NF= no fertilizer, RNP= recommended N and P, RNP+S_1= recommended N and P with the addition of 30 Kgha^{-1} S, SEM= standard error of the mean, *: significant at 0.1%.*

Overall grain yield of tef had significantly ($p \leq 0.01$) varied with the application of different plant nutrients across districts. Response to omitted plant nutrients significantly varied with the interaction effect of nutrient types across sites (Table 3). It shows the presence of variability across sites. The mean grain yield highly significantly ($p \leq 0.001$) increased in response to plant nutrient application compared with All-N and control across all trial sites vertisols of study districts (Figure 1). Figure 1 also displays that the grain yield was also significantly ($p \leq 0.001$) different in the omission of nutrient types. Generally, the higher yield was witnessed from All-Zn and All in vertisols. A non-significant ($p > 0.05$) grain yield increments were observed from Potassium, Sulphur, Zinc, and Boron omitted fertilizers in vertisols and nitisols (Figure 1).

The highest (1241 Kgha^{-1}) and the lowest (491 Kgha^{-1}) grain yields were recorded from All-Zn and no fertilizer treatments in nitisols, whereas the maximum (1407 Kgha^{-1}) and the minimum (342 Kgha^{-1}) grain yields were obtained from All-Zn and no fertilizer treatments in vertisols. The All-N treatment gave a lower yield following negative control for both soil types. The production of tef is not limited by the absence of P nutrient application in vertisols. This result contradicts those of Alemayehu *et al.*, (2022) who found that P limits the amount of tef productivity in vertisols.

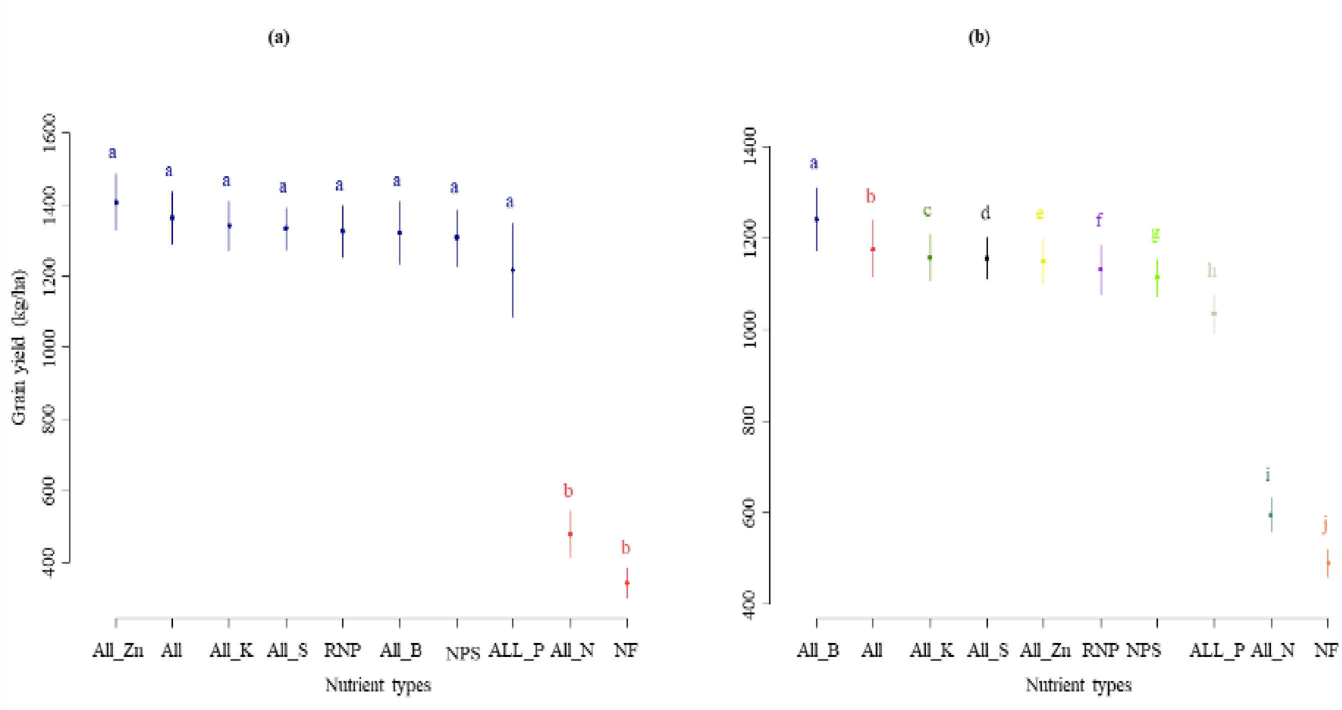

Figure 6. The combined analysis of tef yield response to nutrients in a) vertisols and b) nitisols of Yilmana Densa, Gonji Kolela, and Hulet Ejuenebsie districts under rainfed production system. Short lines at the top of each bar represent the standard error of lime amendment, lowercase letters indicate significant differences ($p<0.05$) among treatments.

The absence of KSZnB nutrients resulted in nearly comparable grain yields with the only application of recommended NP and All fertilizers in both soil types under rainfed production season. This shows that currently, the soil can supply those nutrients without limiting them (Amare *et al.*, 2018; and 2019; Alemayehu *et al.*, 2022; Chala *et al.*, 2022). G. Selassie *et al.*, (2020) also demonstrated that K fertilizer cannot increase agricultural crop productivity in North West Ethiopia, which supports our findings. However, the result differed from the previous findings which show Ethiopian soils are deficient in macronutrients (KS) and some micronutrients (Abera and Kebede, 2013; Hailu *et al.*, 2015; EthioSIS, 2016). Tesfaye *et al.*, (2021), who reported that the application of blended NPS and K fertilizer increases crop productivity in Southern Ethiopia, did not support our findings. The result reached by Brhane *et al.*, (2017) that the application of K fertilizer boosts the yield of cereal crops in vertisols in the northern part of Ethiopia is also in disagreement with our findings.

Response of Tef to Nutrient Types under Irrigation Production System: Both grain and biomass yields showed highly significant ($p \leq 0.01$) differences among treatments at all experimental sites under the irrigation production system. Table 4 indicates that the application of Nitrogen and Phosphorus nutrients at both sites resulted in greater grain yields of 1693 and 1835 Kgha^{-1}. The minimum grain yield (1053 and 1151 Kgha^{-1}) was observed from no fertilizer treatment. From sites 1 and 2, the N omitted treatment also contributed grain yields of 1501 and 1184 Kgha^{-1}, respectively. The observed significant difference among treatment means for grain and biomass yields was caused by the omission of N and P as well as control treatments (no fertilizer) when comparing them with other remaining omitted nutrient treatments. Different soil characteristics at the trial sites showed up in variable responses to grain and biomass yield. This showed that NP nutrients have the main role in tef biological yield determination under irrigation systems which is a similar result to main season tef production (Acharya *et al.*, 2020; Alemayehu *et al.*, 2022; Chala *et al.*, 2022) stated N is limiting nutrient for crop productivity.

Table 4. The combined analysis of grain and biomass yield (Kgha^{-1}) response to applied nutrients under irrigation in Mecha district

Treatments	Grain yield		Biomass yield	
	Site 1	Site 2	Site 1	Site 2
All*	1584.8	1741	5111.1	5486.1
All-B	1659.7	1972.2	5930.6	5486.1
All-Zn	1605.8	1656.9	5601.9	5277.8
All-S	1397.6	1926	5138.9	5486.1
All-K	1512.7	1600.3	4949.1	4791.7
All-P	1079.6	1971.9	4122.2	5694.4
RNP	1693.2	1835.1	6034.7	5555.6
NF	1052.5	1150.7	3402.8	2986.1
All-N	1501.4	1184	5083.3	3263.9
p	**	**	**	**
LSD	308.8	347.6	1248.6	896.7
CV	12.4	12.1	14.4	10.7

**All= NPKSZnB, CV = coefficient of variance, LSD= least significant difference, NF= no fertilizer, RNP= recommended N and P, **: significant at 1%.*

Similar to the individual experimental sites from the combined statistical analysis result showed that both grain and biomass yields of tef showed highly significant differences among treatment means. Automatic response on both grain and biomass yields of tef was observed when either of the two or both major nutrients (NP) are omitted. The two nutrients majorly affect tef productivity and showed their clear potential influence on limiting tef biological yields under irrigation systems which is in line with the findings of Amare *et al.*, (2018) who reported NP nutrients are important nutrients compared to other plant nutrients in Northwest Ethiopia areas.

Table 5. Combined analysis of yield (Kgha^{-1}) response to applied nutrients types in the study district under irrigation.

Treatments	Grain yield	Biomass yield
All*	1662.9	5298.6
All-B	1816.0	5708.3
All-Zn	1631.4	5439.8
All-S	1661.8	5312.5
All-K	1556.5	4870.4
All-P	1525.7	4908.3
RNP	1764.1	5795.1
NF	1101.6	3194.4
All-N	1342.7	4173.6
Mean	1562.5	4966.8
p	**	**
LSD	316.3	860.1
CV	17.4	14.9

**All= NPKSZnB, CV = coefficient of variance, LSD= least significant difference, NF= no fertilizer, RNP= recommended N and P, **: significant at 1 %,*

Either adding or omitting K, S, Zn, and B nutrients had no visible contribution or no significant ($p > 0.05$) difference on both grain and biomass yields of tef. In the combined analysis, except for the control and N omitted treatments other treatments did not show any significant ($p > 0.05$) difference with each other omitted nutrients on grain and biomass yields. Especially, the yield without Nitrogen was nearly equal to the yield attended on the control treatment even if all other nutrients were applied at optimal levels. Thus, Nitrogen is the governing production input in Ethiopian soils. In a combined analysis result, N was also still the leading tef yield-limiting nutrient in the study district followed by P which is in line with the research results reported by Amare *et al.*, (2022) who found that low N and P availability of soils to cereal production in Mecha district where Koga irrigation scheme is found.

Contribution of Nutrients to Tef Grain Yield: Figure 4 displays that without Nitrogen fertilizer about 49 and 65 % of yield decrement was recorded in nitisols and vertosols, respectively.

Similarly, the omission of Phosphorus fertilizer also reduced a grain yield of tef by 12 and 10% in nitisols and vertisols, respectively. It might be related to the native soil stock's limited availability of plant nutrients, specifically its low Nitrogen and Phosphorus concentration, as seen in Figure 2. This finding agreed with many research reports which revealed that Nitrogen is the first and most limiting nutrient for tef production followed by Phosphorus in vertisols of Ethiopia (Girma *et al.*, 2012; Amare *et al.,* 2018; 2019; Alemayehu *et al.,* 2022). Thus, N deficiency can be corrected by Nitrogen fertilization and soil management (Atkinson *et al.,* 2005; Guignard *et al.,* 2017). Nevertheless, from the applied Nitrogen between 30 and 50% is taken up by cereal crops *(Omara et al.,* 2019). Future research is required to improve Nitrogen fertilization efficiency via different technologies. From global fertilizer total consumption, 57% of Nitrogen is demanded followed by Phosphorus (24%) to increase grain yield (Heffer *et al.,* 2017; Yara, 2018). This indicates that Nitrogen is also the most significant key nutrient in the world. However, our finding disagreed with Yara (2018) and Heffer *et al.,* (2017) who reported that Potassium (19%) fertilizers are looked-for and applied to improve crop quality. Therefore, every year application of Nitrogen is mandatory to sustain yield and biomass production.

Nutrient deficiency is a serious threat to Ethiopian soils, particularly Nitrogen and Phosphorus (Hailu *et al.,* 2015). It is also an eminent critical yield-limiting nutrient to agricultural crop production in the world particularly in the tropics due to the fluctuation of temperature and precipitation (Zhaohui *et al.*, 2012; Guignard *et al.*, 2017). According to Singh (2008), widespread multi-nutrient deficiencies and deteriorating soil health are the cause of low nutrient use efficiency, productivity, and profitability. So, the right use of yield-limiting nutrients in crop production is crucial for increasing crop yield and quality, environmental safety, and economic considerations (Rütting *et al.,* 2018).

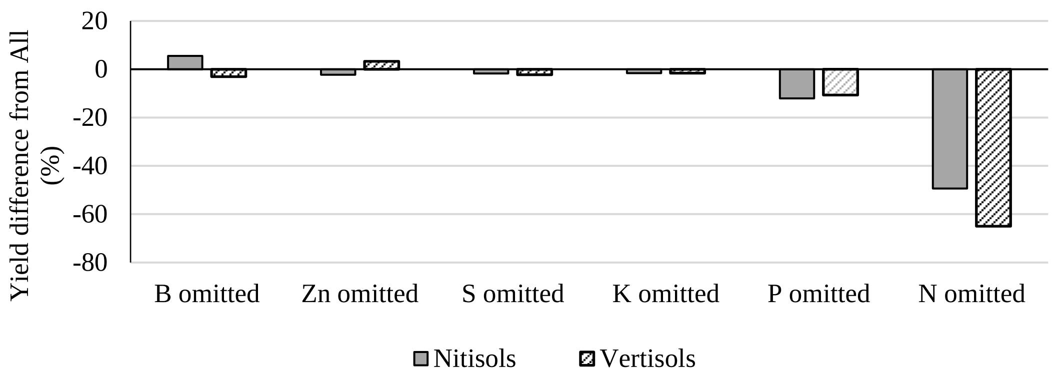

Figure 7. The difference Tef yield-limiting nutrients in percentage to the response of each nutrient to all applied nutrient types in study soils under rainfed production system.

Phosphorus is the second essential plant nutrient for global food production (Roberts and Johnston, 2015). Only 10 to 15% of applied P fertilizer is taken by crops this tells that it must be applied to feed the ever-increasing population. The residual P fertilizer is not recovered by the crop due to its change into the unavailable form). To meet the goal of the productivity and profitability of food crop production, 4R nutrient stewardship strategies are critically important (Bruulsema *et al.*, 2019). Thus, optimizing nutrient management practices and technologies is required in our agricultural crop production systems under rainfed and irrigation seasons.

The omission of Boron improved tef yield by 5.5% in nitisols whereas Zn omission increased tef grain yield by 3.2% in vertisols (Figure 4). This indicates that Zn in vertisols and B in nitisols are adequately available in soil nutrient stock. Below 2% non-significant yield decrements were observed when Potassium and Sulphur fertilizers are omitted which shows that they are supplied by the indigenous soil.

The omission of Nitrogen diminishes grain and biomass yields by 19 and 21% under irrigation, respectively. Without fertilizer (control) grain and biomass yield declined by 34 and 40%, respectively. A non-significant less than 10% yield reduction was observed when P, K, S, and Zn fertilizers were omitted under the irrigation production system. However, the omission of B increases the tef yield by 9 % in nitisols under irrigation season. The result is supported by the result of our finding in nitisols under the rainy season production system. This shows that Nitrogen is also the major required nutrient type for tef under irrigation. Our finding is in line with the results found under the main season crop production system in the region.

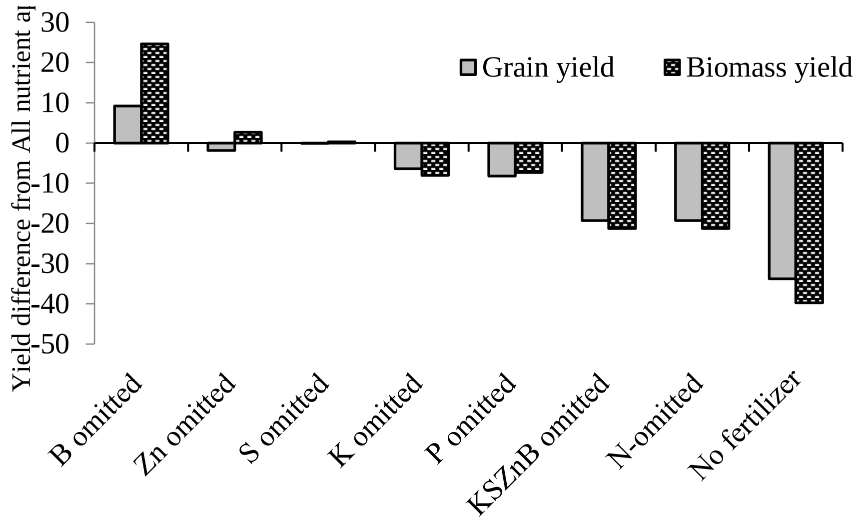

Figure 8. The difference Tef yield-limiting nutrients in percentage to the response of each nutrient to all applied nutrient types in study soils under irrigation production system.

Phosphorus was not limiting nutrient of tef productivity under Koga irrigation scheme, Mecha district. The grain yield result is directly expressed the before planting soil result where available Phosphorus content of the soil was ranged high. This might be associated with the accumulation of residual Phosphorus due to higher application of P fertilizer under two production seasons (rainfed and irrigation).

*Relationship between Applied Nutrients and Tef Biological Parameters:*In different applied fertilizers, the grain yield was significantly and positively correlated with biomass (r=0.94***), plant height (r=0.80***), and panicle length (r=0.63***) whereas it was inversely and significantly correlated with harvest index with a correlation coefficient of 0.46***, and 1000-seed weight with r = -0.45 at $p < 0.001$ (Figure 4). Generally, fertilizer application and crop yields often have a very positive relationship. Aboveground biomass, plant height, and panicle length are the most crucial yield attribute parameters in the tef fertilizer study which contributes to grain. Alemayehu *et al.*, (2022), following our findings, that tef yield, and applied nutrients had a significant influence on the yield component parameters.

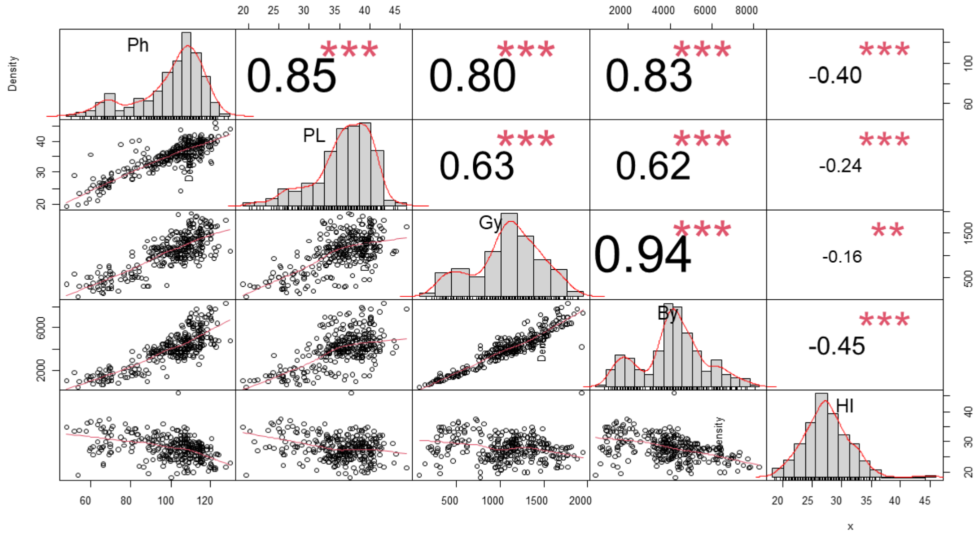

Figure 9. Correlation of yield and yield components of tef under applied nutrient types across sites in North West Amhara (2021/22). Ph: plant height, PL: panicle length, Gy: grain yield, By: biomass yield; HI: Harvest index, **: significant at 5% and *** significant at 1%. The numbers in the figure indicate the correlation coefficient values.

Conclusions and Recommendations

In this study, a significant biological yield advantage was recorded from the recommended Nitrogen and Phosphorus but, the yield was not improved due to the application of K, S**,** Zn, and B nutrients. Tef yield obtained from Nitrogen omitted treatment was equivalent to the yield attended from no fertilizer added treatment although all other nutrients were applied in optimal levels at N omitted treatment. Nitrogen is the first and major limiting nutrient for tef production in all the district soil types under rainfed and irrigation production systems. Next to N, Phosphorus is also a critical nutrient to produce tef grain yield in nitisols under rainfed production. The role of Potassium, Sulphur, Zinc, and Boron nutrients are not mandatory compared to Nitrogen and Phosphorus for tef production. The investigation of Nitrogen and Phosphorus fertilizer rate is required to know the optimum production curve.

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9. Response of Tef [*Eragrostis tef (Zucc.) Trotter*] to N and P Application Rates in the Highland Vertisols of North Shewa

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Abstract

Blanket application of Nitrogen and Phosphorus could increase crop yield relatively compared to the plots which didn't apply with these nutrients. However, this blanket recommendation couldn't increase crops yield to their potential due to soil fertility depletion from time to time. Therefore, impacts of Nitrogen and Phosphorus rates on tef yield and yield componenthave been tested in Moretinajiru, Ensaro and Merhabete districts of North Shewa, Ethiopia in 2019 and 2020. The experiment was comprised of four levels of P (0, 30, 60 and 90 Kgha^{-1} P) and five levels of N (0, 60, 120, 180 and 240 Kgha^{-1} N). The factorial combinations of the factors were laid out in RCBD with three replications. All these treatment combinations were assigned in two soil types (light and heavy Vertisols) and two precursor crops (pulse and cereal). Lentil and wheat at Moretinajiru, chickpea/grasspea, tef and wheat at Ensaro, and tef and chickpea at Merhabete are the most important precursor crops for tef. For this study, plant height, panicle length, total tillers, fertile/productive tillers, biomass yield, grain yield, straw yield, and harvest index were collected for this study. The collected data were subjected to analyses of variance (ANOVA) using R statistical software and linear mixed modeling used for the analysis. The analysis of variance showed that N rate, Precursor crops and soil types significantly influenced most of the measured parameters. Nevertheless, application of different rate of P significantly influenced biomass and grain yield in Ensaro and Merhabete districts. Tef grain yield progressively increased with increasing N rates from zero to 240 Kgha^{-1} N in both locations. In Moretinajiru district, the grain yield increment ranged from 130-229%. Similalry, in Ensaro and Merhabete, grain yield increment ranged from 107-219% and from 122-331%, respectively. Application of P fertilizer increased tef grain yield only in Ensaro and Merhabete districts. Generally, the grain yield obtained from heavy Vertisols and pulse precursor crops was found superior over that obtained from the light Vertisols and cereal precursor. The combined application of N/P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 N/P resulted in the highest net benefit in the respective areas. The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit of 105664 ETB, 72697 ETB, and 70419 ETB in Moretina

Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 resulted in the highest net benefit of 113429 ETB, and 57863 ETB in Moretina Jiru, and Ensaro areas, respectively. Therefore, applications of those treatment combinations were recommended for the district, soil type and precursor crops.

Keyword: *Tef, heavy Vertisols, light Vertisols, Precursor crops*

Introduction

Vertisols, a black cracking clay soil are an important resource in the tropics and subtropics (Syers *et al.,* 2001). Vertisols are montmorillonite-rich clay soils with characteristic shrinking and swelling properties. They have high clay content and when dry they show cracks of at least 1 cm wide and 50 cm deep ((FAO), 2000). They have high calcium and magnesium contents. Considering its high clay content, Vertisols are generally high moisture retention capacity. The pH of Vertisols on Ethiopian highlands varies from slightly acidic to strongly alkaline and depends on different factors (Zewdie, 2001).Therefore, it is an important agricultural soil in Ethiopia covering about 12.7 million ha for production of mainly wheat, tef and chickpea (Mesfin, 1998). Vertisols of the Ethiopian highlands were reported as low in total Nitrogen (TN), available P and organic matter content (OM) (DUDAL, 1963; Hubble, 1984; Mamo and Haque, 1991; Kiflu and Beyene, 2013; Giday *et al.*, 2014; Hailu *et al.*, 2015). Its severe water logging problems limit their productivity. Studies show that N fertilizer application enhanced the productivity of Vertisols with the 55 $Kgha^{-1}$ N for tef (Mamo *et al.*, 1996) and 64 $Kgha^{-1}$ N for durum wheat were determined to be the economic optimal rates (Workneh and Mwangi, 1992).

Tef (*Eragrostis tef* (Zucc.) Trotter) is one of the major cereals grown for thousands of years (D'Andrea, 2008). Tef is adapted to diverse agro-ecological regions of Ethiopia and grows well under stress environments better than wheat, barley and other cereals (Leta, 2012). The crop plays a vital role in the country's overall food security and it is the staple food for most Ethiopian people (Kassaye *et al.*, 2021). Since recently, tef received global attention as a health food because of its gluten-free nature that renders it suitable for people suffering from gluten allergy known as celiac disease (Spaenij-Dekking *et al.*, 2005). Tef plays an important role in supplying the population of the country with protein, carbohydrates and minerals. Moreover, the straw is an important cattle feed source. The national average mean tef grain yield was 1465 $Kgha^{-1}$ for Ethiopia, 1495 for Amhara Region and 1513 $Kgha^{-1}$ for North Shewa (CSA, 2018/19).

Most of the Ethiopian soils contain low nutrients due to erosion and absence of nutrient recycling. Most of the areas used for production of grains especially tef, wheat and barley fall under the low fertility soils (Tefera *et al.*, 2000). Low availability of Nitrogen and Phosphorus were major constraint to cereal production. Fertilizer usage plays a major role in the universal need to increase food production to meet the demands of the growing world population (Melaku, 2008).

Berhe and Zena (2008), recommended 60 Kg N and 26 P_2O_5 $Kgha^{-1}$ for tef production on heavy clay soils (Vertisols) while Ketema (1997) and Achakzai and Taran (2011) recommended 40 Kg N and 26 P ha^{-1} for tef production on sandy clay loam soils (*Andosols*). Recently, Tesfahun (2018) recommend 120 Kg NPS fertilizer (20 $Kgha^{-1}$ P, 22.8 $Kgha^{-1}$ N, 8.4 $Kgha^{-1}$ S) with transplanting method as one effective ways to maximize tef grain yield around Debre Zeit. Nevertheless, in some areas like Moretinajiru, Merhabete and Ensaro farmers use fertilizer beyond the recommended fertilizer rates. In Moretinajiru district, farmers apply 186.5 $Kgha^{-1}$ N and 57.1 $Kgha^{-1}$ P for tef production on Vertisols. Likewise, in Ensaro district farmers also apply 131.8 $Kgha^{-1}$ N and 50 $Kgha^{-1}$ P, which are far above the national recommendation of the crop in Vertisols (preliminary assessment). Farmers in the study areas classify Vertisols as heavy Vertisols called "Mererie" and light Vertisols as "kelal Mererie or bushel). Therefore, the objective of this study was to evaluate the effect of combined application N and P nutrients on yield and yield component of Tef on different soils (having different vertic properties) and precursors.

Materials and Methods

Description of the Study Sites

Merhabete: Merhabete district is situated in Northern Shoa zone of Amhara Regional State. Its altitude ranges from 1050-2650 m.a.s.l. The total area of the district is estimated to be about 121,000 ha. From this area, 27% was covered by cultivated land, (53%) by grassland and fallow, (10%) was covered by bushes and shrubs and (10%) was degraded land. The major proportion of the area lies in Weyna Dega (73%) followed by Kolla (20%), and Dega (6%). The dominant soil type is Vertisols on the plateau of the district. The average annual rainfall is estimated to be 1017.8 mm with unimodal pattern. The mean min and mean max temperature of the district was estimated to be 13.1 and 25.3^0C, respectively Rain fed mixed farming is a predominant occupation in the district with average land holdings of less than 2 ha. The major crops grown in the district are sorghum (*Sorghum bicolor* L), tef ([*Eragrostis tef (Zucc.) Trotter*] (30%), barley (*Hordeum vulgare)*, wheat (*Triticum aestivum*), pulse, and horticultural crops (3%).

Moretina Jiru: Moretina jiru district is situated in Northern Shoa Zone of Amhara Regional State. Its altitude ranges from 1500-2694 m.a.s.l. The total area of the district is estimated to be 66,116 ha of which 87% of the area is cultivated. Vertisols is a dominant soil type especially in the highland plateau of the district. The average annual rainfall is estimated to be 981.8 mm with unimodal pattern. The mean min and mean max temperature of the district was estimated to be 9.4 and 22.1^{0}C, respectively (Table 1). The farming system is characterized by mixed crop-livestock farm. The crops widely grown in the study area include wheat (*Triticum aestivum*), Tef ([*Eragrostis tef (Zucc.) Trotter*], faba bean (*Vicia faba)* and lentil (*Lens culinaris)*, whereas chickpea (*Cicer arietinum)*, grass pea **(***Lathyrus sativus)* and others have low area coverage and mostly grow on residual soil moisture at the end of the rainy season (Chanyalew *et al.*, 2018).

Ensaro District: Ensaro district is situated in Northern Shoa Zone of Amhara Regional State. Geographically, the district is located between 9^{0}35'-9^{0}55'N and 38^{0}50'-39^{0}5'E. Its altitude ranges from 1200 to 2700 m.a.s.l with an average elevation of 2435 m.a.s.l. The total area of the district is estimated to be 44,217.6 ha. Vertisols is a dominant soil type in the districts. The average annual rain fall is estimated to be 1276.4 mm with a unimodal pattern. The average mean min and max temperature of the district was estimated to be 6.9 and 22.2^{0}C, respectively. The farming system is characterized by mixed crop-livestock farm. The crops widely grown in the study area include wheat (*Triticum aestivum*), Tef ([*Eragrostis tef (Zucc.) Trotter*], sorghum (*Sorghum bicolor* L), chickpea (*Cicer arietinum)*, grass pea **(***Lathyrus sativus)*. The growth period average rain fall, maximum and minimum temperature of all districts were presented Figure

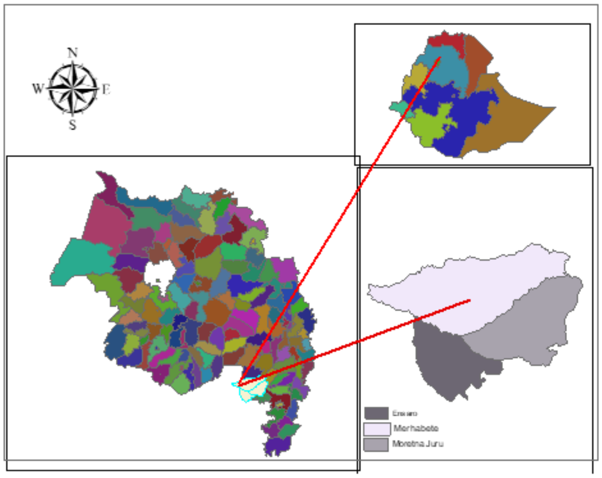

Figure 10. Location map of the study areas

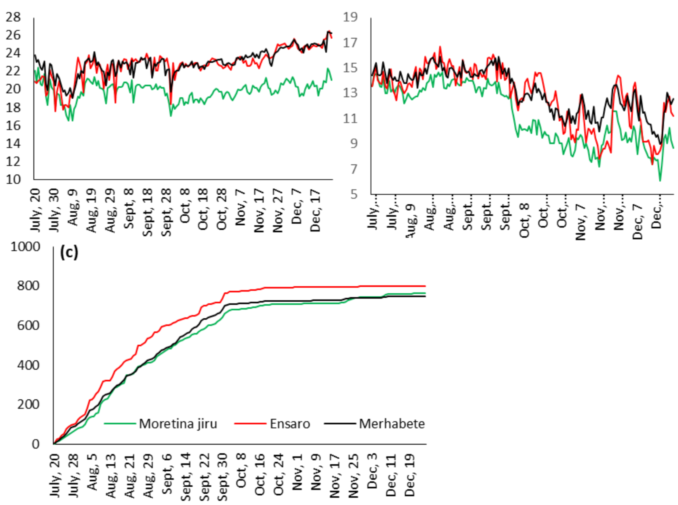

Figure 2. (a) Average daily minimum temperature, (b) daily average maximum temperature and (c) cumulative rainfall during the growth period.

Fertilizer Use Practice of Farmers: From the two districts, 46 farmers (21 in Moretinajiru and 25 in Ensaro) were interviewed for the amount of N and P they were applying to their farm. Hence, in Moretinajiru, of the interviewed farmers, 4.5%, applied 60-120 Kg N; 59%, applied 120-180 Kg N; 13.6% applied 180-240 Kg N; and 22.7% applied above 240 $Kgha^{-1}$ N. Likewise, 36.4% of the interviewed farmers applied 30-60 Kg P and 63.6% applied 60-90 $Kgha^{-1}$ P. In Ensaro district 54%, applied 60-120 Kg N; 33.3%, applied 120-180Kg N; 8.3% applied 180-240 Kg N and 4.2% applied 240 Kg and above N ha^{-1}. Similarly, 4.2% of the interviewed farmers applied 0-30 Kg P; 66.7% applied 30-60 Kg P; 2.5% applied 60-90 Kg P and 4.2% 90 Kg and above Pha^{-1}. Indicating that farmers are not applying recommended N and P fertilizer for the test crop on Vertisols (60 and 26 $Kgha^{-1}$ P) (Berhe and Zena, 2008). Farmers in the study area use higher fertilizer rate especially N for heavy Vertisols. The most important precursor crop for tef were lentil and wheat in Moretinajiru, chickpea/grass pea, tef and wheat in Ensaro and tef and chickpea in Merhabete

Treatments, Design and Experimental Procedure: The experiment comprised of four levels of P (0, 30, 60 and 90 $Kgha^{-1}$ P), and five levels of N (0, 60, 120, 180 and 240 $Kgha^{-1}$ N). The factorial combinations of the three factors (4x5=20) were laid out in RCBD with three replications. Considering the type of Vertisols and precursor crops, the total number of treatments were 80. All these treatment combinations were assigned in two soil types (light Vertisols and heavy Vertisols) and two precursor crops (pulse and cereal) in each district. Nevertheless, we haven't found light Vertisols with pulse precursor crops in Merhabete district. The test crop, tef variety, Dega (In Moretinajiru and Ensaro) and Kora in Merhabete were broadcasted in the rate of 25.0 $Kgha^{-1}$ in a unit plot size 6.25 m^2. The space between blocks and plots will be 1.5 and 1m respectively. Planting was in the mid of July and all plots were fertilized with equal amount of S, Zn and B with a rate of 10, 2 and 0.1 $Kgha^{-1}$ respectively. The entire Phosphorus, Sulphur, Zinc and Boron fertilizer as per the treatment were applied at planting as triple super phosphate, calcium sulfate, Zinc sulfate and borax. While the recommended N fertilizer as urea indicated in the treatment was applied two times half at planting and the other half at tillering stage of the crop on the presence of soil moisture

Soil Sampling and Analysis: Pre-planting composite surface soil samples (0-20 cm depth) were collected from each farm from 10 sampling spot of the entire experimental site for the determination of soil physico-chemical properties using auger in zigzag pattern. The soil sample were composited in to one for each farmer's field. The soil samples from each farmer's field were composited to one with sample weight of 1 Kg. The samples were then brought to Debre Birhan agricultural research Center soil laboratory where it was analyzed. The samples were air-dried ground and passed through a 2 mm sieve for most parameters except for OC and TN, which passed through 0.5 mm sieve. The processed samples were analyzed for texture following by Bouyoucous hydrometer method (Bouyoucos, 1951). The pH of the soil was measured using pH-water method by making soil to water suspension of 1:2.5 ratio and was measured using a pH meter (Chapman, 1965)). The soil OC (organic carbon) content was also determined by wet digestion method (Walkley, 1934). The total Nitrogen (TN) was determined by using the modified micro Kjeldhal method (Cottenie, 1980), while the available Phosphorus was determined by following Olsen's calorimetric method as described by Olsen (1954).

Crop Data Collection: The following data were collected for this study.

Plant Height (cm): ten randomly selected plants were measured from ground level to the tip of the main shoot panicle using steel tape at the maturity stage of the crop. The average was computed for statistical analysis.

Panicle Length (cm): ten randomly selected plants from each plot were measured from the node where the first panicle starts to the tip of the panicle using steel tape at the maturity stage of the crop. The average was used for statistical analysis.

Total Tillers (plant-1): The numbers of tillers (both effective and non-effective tillers) were determined by counting all the tillers of randomly selected ten plants from each plot at physiological maturity.

Number of fertile tillers plant^{-1}: The numbers of tillers bearing panicle were determined at maturity by counting the tillers from randomly selected ten plants from each plot.

Biomass Yield (Kgha^{-1}): Atharvest maturity, aboveground dry biomass was weighted after sun drying until constant weight obtained from the net plot area. It was expressed in Kgha^{-1}.

Grain Yield (Kgha^{-1}): was weighted after harvesting and threshing the crop from the net plot area and the yield was expressed in Kgha^{-1} then the weight was adjusted to 12.5% moisture content

Straw Yield (Kgha^{-1}): After threshing and measuring the grain yield, the straw yield was determined by subtracting the grain yield from the total aboveground biomass yield.

Harvest Index: Harvest index was calculated by dividing grain yield by the total aboveground dry biomass yield.

Data Analysis: The collected data were subjected to statistical analyses of variance (ANOVA) using R statistical software (Team, 2018). A generalized linear modeling framework was used to determine the variation in plant height, panicle length, total/ferile tiller, biomass yield, grain yield, and harvest index with the different levels of N and P, combining soil type for the first analysis and different levels of N and P combining precursor crops for the second analysis. The general linear model ((in PROC GLM of the SAS system) was selected for different level of analysis because it allows for comparing how several variables affect different continuous variables.

The initial model was of the following form:

$Y = \mu + Year + Block + Soil + N + P + Soil * N + Soil * P + N * P + Soil * N * P + \varepsilon$
(1),

where μ is the grand mean, soil is type of vertisols according to farmers classification, N is N rate, P is P and ε is the error term

$Y = \mu + Year + Block + Prec + N + P + Prec * N + Prec * P + N * P + Prec * N * P + \varepsilon$
(2), where μ is the grand mean, prec is the precursor crops for tef, N is N rate, P is P and ε is the error term. Wherever the treatment effect was significant, mean separation was made using Tukey's HSD. Means were considered to be significantly when $p \leq 0.05$.

Partial Budget Analysis: The partial budget analysis was done following the procedures described by (Program *et al.*, 1988). For partial budget analysis, the variable cost of fertilizer and labor were taken at the time of planting and during other operations. Field price of the grain and straw yield of tef was considered one month from the time of crop harvesting. The average yield was adjusted down ward by 10 % to reflect the farmer's field yield as described by (CIMMYT, 1988). The return was calculated as total gross return minus total variable cost. Field grain price (38 $ETBKg^{-1}$ grain in Moretina Jiru and Ensaro, and 37 $ETBKg^{-1}$ grain in Merhabete area) was considered by average of one month from the time of crop harvesting. Farm gate price of P (52.6 ETB Kg P), Farm gate price of N (32.9 ETBKg N) during planting in all locations was considered for partial budget analysis.

Results and Discussion

Soil Physico-Chemical Properties of the Experimental Site/S: The dominant soil texture of all experimental sites was clay (Table). The CEC of the soils in the experimental plots was high (Hazelton and Murphy, 2016). Similarly, others scholars also reported Vertisols are high CEC content. The results also indicated that soil pH of all the experimental sites was neutral which is ideal for the production of most field crops including tef (Tadesse *et al.,* 1991; Landon, 2014). According to (Mamo and Haque, 1991), the total Nitrogen content and soil organic matter content of the soil were rated as low. Others authors also reported that Vertisols of Ethiopia is deficient in total N (Finck and Venkateswarlu, 1982; Mengel and Kirkby, 1987; Mesfin, 1998; Hailu *et al.*, 2015). While the available P content was rated as medium (Olsen, 1954).

Table 1. Soil-physico-chemical properties of the experimental sites

Location	Soil physico-chemical properties	Values	Rating	Method
Moretina jiru	Textural Class		Clay	Hydrometer method
	Clay	76.34		
	Silt	14.21		
	Sand	9.45		
	pH	6.9	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	56	Very high	Ammonium acetate
	SOC (%)	0.87	Low	Walkley and Black
	TN (%)	0.08	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	14.3	Medium	Olsen
Ensaro	Textural Class		Clay	Hydrometer method
	Clay	68.12		
	Silt	23.4		
	Sand	8.48		
	pH	6.8	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	42	High	Ammonium acetate
	SOC (%)	0.99	Low	Walkley and Black
	TN (%)	0.094	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	6.9	Medium	Olsen
Merhabete	Textural Class		Clay	Hydrometer method
	Clay	63.9		
	Silt	22.2		
	Sand	13.9		
	pH	6.8	Neutral	1:2.5 water
	CEC ($CmolKg^{-1}$)	37	High	Ammonium acetate
	SOC (%)	1.041	Low	Walkley and Black
	TN (%)	0.088	Low	Kjeldahl method
	Av.P ($mgKg^{-1}$)	5.3	Medium	Olsen

The three-way interaction of precursor, N and P fertilizer rate were found significant only on harvest index in Moretinajiru district.

In Moretinajiru district, tef having pulse precursor crop was found superior over cereal precursor in all the measured parameters (Table 2). The highest biomass yield, grain yield, plant height, and panicle length, which were observed from pulse precursor crop. This factor increased the respective parameters by 6.6% (427.1 Kgha-1), 7.2% (122.8 Kgha-1), 3.5% (3.5 cm) and 6% (1.7 cm), respectively compared with the lowest value observed from cereal precursor. The present study established a higher response of yield to pulse precursor compared to cereal precursor crop. This was explained by the fact that pulse crop fixes atmospheric N and make portion of the fixed N for the subsequent crop (Ross et al., 2015; Lal, 2017; Liu et al., 2020). Soil fertility through reduction of soil erosion and hence soil depletion is improved by crop rotation that involves legume crops (Azene et al., 2005). Pulse crops also reduce disease, increase availability and uptake of P, K and S nutrient from the soil, improve the structure of soil, and release crop growth promoting substance (Stevenson and Kessel, 1996; Lupwayi and Kennedy, 2007; Arcand et al., 2014; Mazzilli et al., 2016). Similarly, different authors reported the impact of pulse precursor crop on subsequent crop (Anderson, 2008; Kirkegaard et al., 2008; Strydhorst et al., 2008; Bennett et al., 2012; Angus et al., 2015; Ross et al., 2015; Mazzilli et al., 2016; Adamu, 2018).

In Merhabete district, the highest grain yield, harvest index, plant height panicle length which were observed from tef plothaving pulse precursor crop increased the respective parameters by 13.5%% (173.5 Kgha^{-1}), 23.8% (0.05), 4% (4.8 cm) and 5.8% (2 cm), respectively. This was justified by the fact that pulse crop fix Nitrogen from the air and make a portion of the fixed N to the subsequent tef crop. Nevertheless, the highest (6191 Kgha^{-1}) and lowest (5739 Kgha^{-1}) biomass yield was observed from tef plothaving cereal precursor crop. In Ensaro district, the highest grain yield and harvest index were observed from tef plothaving cereal precursor (Table 3). In other hand, the highest biomass yield and plant height were observed from pulse precursor crop.

Table *2* The impact of precursor on tef growth, yield related and yield data

Parameters	Moretinajiru		Ensaro		Merhabete	
	Pulse	Cereal	Pulse	Cereal	Pulse	Cereal
Biomass yield	6906^{a*}	6478.9^{b}	4980.4^{a}	4561.4^{b}	5738.7^{b}	6191.1^{a}
Grain Yield	1817.3^{a}	1694.5^{b}	1263.4^{b}	1432.5^{a}	1463.3^{a}	1289.8^{b}
Harvest Index	0.28	0.27	0.27^{b}	0.33^{a}	0.26^{a}	0.21^{b}
Plant height	76.8^{a}	74.2^{b}	71.4^{a}	69.1^{b}	99.4^{a}	95.6^{b}
Panicle length	29.9^{a}	28.2^{b}	27.1	27.5^{b}	36.4^{a}	34.4^{b}
Number of tiller	4.5	4.6	4.4	4.7		

**Means followed by same letter at each location in a row are not significantly influenced at P>0.05 level of probability following DMRT*

The analysis of variance showed grain and biomass yields were increased with increased N rates in all locations (Figure 11). This is attributed the highest loss of applied N from the soil. The mode of application of fertilizer for tef cultivation is broadcasting the fertilizer on the surface of the soil without covering the fertilizer with soil by trampling and compacting the soil using a large number of cattle or donkeys. This will contribute to highest loss of N from the surface of Vertisols (Terman, 1980; Bock, 1984; Patra *et al.*, 1996; Sigunga *et al.*, 2002; Zhou *et al.*, 2003; Solomon *et* *al.*, 2007; Sigunga *et al.*, 2008; Owino and Sigunga, 2012; Somasundaram *et al.*, 2018; Nachimuthu *et al.*, 2019; Singh *et al.*, 2020). This loss includes surface washing of fertilizer with rainfall through erosion especially when highest rainfall comes immediately after fertilizer application. Trampling of the soil before broadcasting the seed and fertilizer also increase surface washing of fertilizer from the soil by decreasing infiltration and hence aggravating soil erosion (Pietola *et al.*, 2005; Lipiec *et al.*, 2006; Muche *et al.*, 2014).

However, the rate at which the yield increased will progressively decreased. From all location, the highest grain and yield of tef were recorded from Moretinajiru district (Figure 2). In Moretinajiru district, application of 60, 120, 180 and 240 Kgha^{-1} N increased tef yield by 130% (907 Kgha^{-1}), 182% (1274 Kgha^{-1}), 217% (1515 Kgha^{-1}) and 229% (1597 Kgha^{-1}) compared with the lowest tef yield observed from the N un-fertilized control plot, respectively. In Ensaro site, the increased in grain yield were found to be 107% (605 Kgha^{-1}), 160% (905 Kgha^{-1}), 198% (1121 Kgha^{-1}) and 219% (1237 Kgha^{-1}) respectively. Likewise, the increased in these parameters in Merhabete district with those rates were found to be 122% (525 Kgha^{-1}), 256% (1106 Kgha^{-1}), 314% (1358 Kgha^{-1}) and 331% (1431 Kgha^{-1}), respectively. Similar trends were also observed on biomass yield too (Figure 11).

The N rate at which highest grain yield recorded from with current finding were found higher from previously recommended N rate for the same soil type (Mamo *et al.*, 2000; Liben, 2004; Berhe and Zena, 2008; Tulema *et al.*, 2008; Assefa *et al.*, 2016; Asfaw *et al.*, 2020). The fertilization recommendation of the former research conducted in Vertisols of Ethiopia ranged from 41 to 80 Kgha^{-1}. This might be probably because of the depletion of this nutrient from the soil through time. For instance, Haileslassie *et al.*, (2005) reported that N nutrient depletion of -147 Kgha^{-1} was recorded from Amhara region. This rate is the highest compared with other regions of Ethiopia. The same authors also reported that, the main determinants of nutrient depletion are with nutrient removal through harvested product, residual removal, leaching, denitrification and erosion. Van Beek *et al*., (2016) also noted that diverse Ethiopian agro-ecologies experience accelerated soil nutrient depletion that is severe in N, with average annual depletions of 0.2% of the entire stock, or 4.2% of the accessible soil N pool. Others authors also reported nutrient depletion especially N in Ethiopia (Hurni, 1988; Beek *et al*., 2018; Haileslassie *et al*., 2005; Elka and Laekemariam, 2020; Adimassu *et al*., 2017).

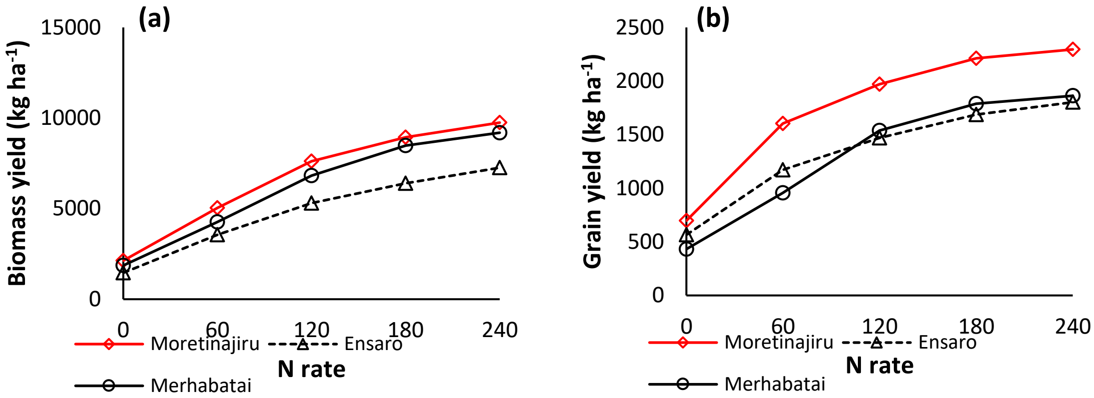

Figure 11. a= effect of N fertilizer rate in biomass yield; b = effect of N fertilizer in grain yield

Application of P fertilizer significantly increase yield of tef in Ensaro and Merhabete district. The yield increase ranged from 14% (164 Kgha^{-1}) to 24% (276 Kgha^{-1}) in Ensaro and from 33% (335 Kgha^{-1}) to 50% (499 Kgha^{-1}) in Merhabete district compared with the lowest grain yield observed from the P un-fertilized control plot (Table 3). This could be justified by the fact that those districts are low in their available P content and application of P containing fertilizer can have increased grain yield of tef. In Moretinajiru district, application of different rate of P fertilizer could not brought any significant yield change. This might be due to the continuous application of highest rate of P fertilizer could be gradually increased soil P level.

In Merhabete areas, combined application of N and P resulted in significant yield difference (Table 3 and 4). The lowest (1735 Kgha^{-1}) and highest (10385 Kgha^{-1}) biomass yield of tef was recorded from application of 0/0 and 240/90 Kgha^{-1} N/P, respectively. The respective increase in yield due to combined application of N/P ranged from 3% (49 Kgha^{-1}) to 499% (8650 Kgha^{-1}). In Ensaro and Merhabete area combined application of N and P significantly influenced biomass yield

Table 3. Effect of P rate on biomass and grain yield of tef

P rate	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})		
	Moretinajiru*	Ensaro	Merhabete	Moretinajiru	Ensaro	Merhabete
0	6528	3941.8^{c}	4833.9^{c}	1746.2	1168.6^{b}	999.6^{c}
30	6735.8	4767.1^{b}	6140^{b}	1783.9	1332.9^{ab}	1334.1^{b}
60	6805.2	5211.8^{ab}	6565^{ab}	1800.6	1445^{a}	1430.8^{ab}
90	6700.8	5256^{a}	6954.3^{a}	1692.8	1407.6^{a}	1498.8^{a}
LSD0.05	ns	469.5	445.7	ns	187.9	126.7

**Means followed by same letter at each location are not significantly influenced at P>0.05 level of probability following DMRT, LSD least significance difference*

Table 4. The two-way interaction of N and P on biomass and grain yield of tef

Location	N/P rate	Biomass yield (Kgha^{-1}) 0	30	60	90	Grain yield (Kgha^{-1}) 0	30	60	90
Moretinajiru*	0	2053.0	2128	2261	2074	7301	708	732	619
	60	4825.1	5293	5027	5018.5	1535	1655	1662	1564
	120	7546.4	7470	7590	7821	2043	1980	1923	1937
	180	8871.1	9029	9032	8825	2199	2310	2252	2090
	240	9344.3	9758	10117	9766	2224	2266	2434	2254
$LSD_{0.05}$		ns				ns			
Ensaro	0	1422^{k}	1461^{k}	1422^{k}	1514^{jk}	541	569	588	563
	60	2933^{ij}	3629^{hi}	3945^{fghi}	3759^{ghi}	974	1194	1326	1187
	120	4424^{efgh}	5248^{def}	5742^{cde}	5775^{cde}	1280	1445	1604	1547
	180	5180^{defg}	6239^{bcd}	7104^{abc}	7061^{abc}	1518	1646	1818	1761
	240	5749^{cde}	7259^{ab}	7846^{a}	8171^{a}	1531	1809	1889	1980
$LSD_{0.05}$		1451.4				ns			
Merhabete	0	1735^{i}	1940^{hi}	1784^{i}	1990^{hi}	360^{i}	453^{i}	424^{i}	491^{i}
	60	3253^{gh}	4152^{fg}	4505^{fg}	5165^{f}	692^{hi}	911.5^{gh}	1069^{fgh}	1156^{defg}
	120	5255^{ef}	6606de	7583^{cd}	7833^{cd}	1087^{efg}	1470^{cde}	1775^{abc}	1821^{abc}
	180	6639^{d}	8630^{bc}	9246^{ab}	9400^{ab}	1329^{def}	1862^{ab}	1966^{a}	2002^{a}
	240	7288^{cd}	9374^{ab}	9708^{ab}	10385^{a}	1530^{bcd}	1975^{a}	1921^{ab}	2025^{a}
$LSD_{0.05}$		1378.7				392			

**Means followed by same letter in each location are not significantly influenced at P>0.05 level of probability following DMRT; LSD least significance difference*

The interaction of soil type with N rate also *found* significantly influenced biomass yield in Ensaro and Merhabete, grain yield in Moretinajiru and Merhabete, harvest index in all districts, plant height in Moretinajiru and Merhabete and number of tillers in Moretinajiru district (Table 4 and 5).

In Ensaro district, the tef yields observed from heavy Vertisols were found superior over light Vertisols at every N level. This might be due to the highest N loss through leaching and denitrification on such kind of soil. Ammonia fixation also affects fertilizer efficiency in heavy Vertisols (Finck and Venkateswarlu, 1982). The increased in tef yield were found 170% (548 Kgha^{-1}), 45% (436 Kgha^{-1}), 37% (470 Kgha^{-1}), 39% (562 Kgha^{-1}) and 52.9% (772 Kgha^{-1}) at 0, 60, 120, 180 and 240 Kgha^{-1} N) respectively. In Moretinajiru district, the yield observed from heavy

Vertisols were found superior over the yield recorded from light Vertisols only in the first three rate of N. After forward, the yield observed from light Vertisols is higher than from heavy Vertisols. Nevertheless, in Merhabete district the yield recorded from light Vertisols from the first three N rate were higher on light Vertisols (Table 6).

Table 5. The impact of soil type on growth, yield related and yield of tef

Parameters	Moretinajiru		Ensaro		Merhabete	
	HVS	LVS	HVS	LVS	HVS	LVS
BY*	6746.2	6602.9	5678.3^{a}	4086.9^{b}	5979.3	6339.3
GY	1761.9	1745.8	1648.2^{a}	1090.8^{b}	1296.8	1344.4
HI	0.28^{a}	0.27^{b}	0.32^{a}	0.28^{b}	0.22	0.22
PH	73.3^{b}	79.3^{a}	74.4^{a}	67.1^{b}	92^{b}	102.4^{a}
PL	28.4^{b}	30^{a}	27.6^{a}	27^{b}	33.4^{b}	36.7^{a}
NT	5.1^{a}	4.2^{b}	4.0	4.1		

**BY= Biomass yield (Kgha^{-1}); GY = Grain yield (Kgha^{-1}); HI = Harvest index; PH = Plant height (cm); PL= Panicle length (cm); Nt = Number of tillers per plant; Means followed by same letter at each location in a row are not significantly influenced at P>0.05 level of probability following DMRT, HVS = heavy Vertisols, LVS = light Vertisols*

Table 6. Interaction of N rate with soil type on biomass and grain yield of tef

Location	N rate/Soil	Biomass yield (Kgha^{-1})		Grain yield (Kgha^{-1})	
		HVS	LVS	HVS	LVS
Moretinajiru*	0	2187	2032.6	791.4^{d}	540.5^{e}
	60	5052.4	5021.8	1627.2^{c}	1565.4^{c}
	120	7774.3	7327.4	1983.4^{b}	1949.7^{b}
	180	8986.2	8861.0	2187.2^{ab}	2255.2^{a}
	240	9731.1	9771.8	2220.5^{a}	2418.1^{a}
Ensaro	0	1938.1^{f}	1068.2^{g}	869.4	321.7
	60	4129.9^{d}	3116^{e}	1412.2	976.6
	120	6098^{c}	4657.1^{d}	1730.5	1260.8
	180	7517.7^{b}	5498.4^{c}	1997.7	1435.9
	240	8707.7^{a}	6095^{c}	2231.3	1458.9
Merhabete	0	1576^{e}	2290.6^{e}	354.7^{f}	547.8^{f}
	60	3905.5^{d}	4812.5^{c}	815.6^{e}	1168.6^{d}
	120	6705.6^{b}	6989.4^{b}	1498.5^{c}	1596.9^{bc}
	180	8532.8^{a}	8397.2^{a}	1837.4^{ab}	1718.4^{bc}
	240	9176.3^{a}	9206.9^{a}	1977.5^{a}	1690^{bc}

**Means followed by same letter at each location are not significantly influenced at P>0.05 level of probability following DMRT; HVS = heavy Vertisols; LVS = light Vertisols.*

Partial Budget Analysis: The combined application of N and P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit of 102480 ETB, 84619 ETB, and 94402 ETB in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 Kgha^{-1} N/P resulted in the highest net benefit of 103975 ETB, 94402 ETB, and 81448 ETB in the respective areas (Table 24). The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit of 105664 ETB, 72697 ETB, and 70419 ETB in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 Kgha^{-1} resulted in the highest net benefit of 113429 ETB, and 57863 ETB in Moretina Jiru, and Ensaro areas, respectively (Table 7).

Table 7. Net benefit as influenced by location, precursor crop, soil type, N and P rate

		N/P	Heavy Vertisols				Light Vertisols			
LOC	Pre	rate	0	30	60	90	0	30	60	90
Mo	Cereal	0	23163	24223	11017	12543	24126	29603	32073	20368
		60	58815	69232	60195	51753	56892	63418	75756	61240
		120	89268	83859	77005	73121	81072	76302	71600	82824
		180	102480	92735	95700	81319	94276	93195	89025	91031
		240	94339	94667	101146	94742	94163	104441	105664	88236
	Pulse	0	46637	36332	40269	33531	11354	12045	18052	10669
		60	68429	73568	65112	69599	77647	58912	58231	51662
		120	87909	90505	87915	81907	101036	81890	88029	87965
		180	90680	103975	93652	85602	100876	102079	107146	95227
		240	93350	94749	98412	89782	112610	96211	109423	113429
En	Cereal	0	26510	20621	22916	12967	14392	18578	18414	14142
		60	40542	40346	49589	41139	37000	45143	48349	33109
		120	57748	57446	60293	54000	54015	43094	60495	56500
		180	69546	64931	67857	70803	58855	60126	72697	64036
		240	73192	84619	82360	82407	59035	61541	71225	55115
	Pulse	0	41700	39283	34652	41922	7553	8213	6197	4150
		60	55681	65721	61707	52986	20574	29906	34295	36179
		120	64065	76908	71416	71553	26843	43103	47042	43572
		180	77752	72918	84123	86505	28841	49855	50213	41662
		240	77458	81348	86214	94402	25927	47511	46541	57863
Me	Cereal	0	11382	9947	7002	7781	18128	23052	18647	18640
		60	20329	27969	33347	32733	34173	40446	43809	51358
		120	35295	49950	61326	58535	48865	57738	61751	65699
		180	52339	687933	73322	72772	48705	66947	67251	70419
		240	53723	76189	74137	80685	53621	66223	64086	64650
	Pulse	0	18053	202340	21099	24471				
		60	25753	33708	35085	33379				
		120	39221	59806	81448	81355				
		180	45354	76161	81220	72855				
		240	65212	76189	70666	69778				

**LOC = location; Me = Merhabete district; En = Ensaro district; Mo = Moretinajiru district.*

Conclusion and Recommendation

Most of the Ethiopian soils contain low nutrient content due to erosion and absence of nutrient recycling. Low availability of Nitrogen and Phosphorus has been demonstrated to be major constraint to cereal production in Ethiopia. The analysis of variance showed that N rate, Precursor crops and soil types significantly influenced most of the measured parameters. Nevertheless, application of different rate of P significantly influenced biomass and grain yield in Ensaro and Merhabete district. Increasing N rate from zero to 240 Kgha^{-1} N, grain yield also progressively increased in both locations. However, the rate in which the yield increased will progressively decreased. In Ensaro site, the increased in grain yield were found to be 107% (605 Kgha^{-1}), 160% (905 Kgha^{-1}), 198% (1121 Kgha^{-1}) and 219% (1237 Kgha^{-1}) respectively. Likewise, the increased in this parameter in Merhabete district with those rates were found to be 122% (525 Kgha^{-1}), 256% (1106 Kgha^{-1}), 314% (1358 Kgha^{-1}) and 331% (1431 Kgha^{-1}), respectively. Application of P fertilizer in the rate of 60 and 90 Kgha^{-1} P increased grain yield of tef by 24% (276) and 50% (499 Kgha^{-1}) compared with the lowest grain yield observed from the P un-fertilized control plot, respectively. The yield obtained from heavy Vertisols were found superior over from light Vertisols. The yield increments were found ~1% (16 Kgha^{-1}) in Moretinajiru, 51% (557 Kgha^{-1}) in Ensaro and ~4% (48 Kgha^{-1}) in Merhabete. Likewise, tef yield recorded from pulse precursor increased tef yield by 7.2% (122.8 Kgha^{-1}) in Moretinajiru and 13.5% (173.6 Kgha^{-1}) in Merhabete district. In Moretinajiru district, application of 240/60 Kg N/P could be recommended for heavy and light Vertisols having cereal precursor crop. For pulse precursor, application of 240/90 and 180/30 Kg N/P resulted in higher tef yield on light and heavy Vertisols, respectively. Application of 240/90 N/P resulted in higher tef yield on both soil types having pulse precursor crop. Likewise, application of 240/30 and 180/30 NP resulted in higher tef yield on heavy and light Vertisols having cereal precursor, respectively. In Merhabete district, application of 120/90 N/P resulted in higher tef yield on heavy Vertisols having pulse precursor. Application of 90 Kg P with 240 and 180 Kgha^{-1} N resulted in higher tef yield on cereal precursor having heavy and light Vertisols, respectively.

The combined application of N and P at the rate of 180/0, 240/30, and 240/90 on heavy Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 180/30, 240/90, and 120/60 Kgha^{-1} N/P resulted in the highest net benefit in the respective areas. The combined application of N and P at the rate of 240/60, 180/60, and 180/90 on light Vertisols with cereal precursor crops resulted in the highest net benefit in Moretina Jiru, Ensaro, and Merhabete areas respectively. For the same type of Vertisols with pulse precursor crops, application of 240/90, and 240/90 $Kgha^{-1}$ resulted in the highest net benefit in Moretina Jiru, and Ensaro areas, respectively (Table 24). Therefore, these treatment combinations were recommended for the district, soil type and precursor crops.

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Appendix Table 1. Mean square value of biomass, grain yield and harvest index as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis								
	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})			Harvest Index		
	Mo	En	Me	Mo	En	Me	Mo	En	Me
Year (1)	36511875***	1232230^{ns}	69832^{ns}	5963987***	25099926***	3653761***	0.1972***	0.8255***	0.03344***
Block (3)	5995867**	59208750***	16081338**	863173*	327324^{ns}	35233^{ns}	0.04374**	0.3014***	0.00021^{ns}
Rep (2)	2492886^{ns}	65889^{ns}	3998771^{ns}	59623^{ns}	176934^{ns}	58331^{ns}	0.00213^{ns}	0.025^{ns}	0.01334*
Prec(1)	17962980***	7415683^{ns}	8362538*	1362968**	3130^{ns}	345717^{ns}	0.0004^{ns}	0.0761*	0.07473***
N (4)	930301711***	581534972***	740552984***	40530372***	26437356***	29658522***	0.13426***	0.2308***	0.00905**
P (3)	1668704^{ns}	50175202***	84952526***	274411^{ns}	2025693***	4901715***	0.00692^{ns}	0.0051^{ns}	0.00358^{ns}
Prec:N (4)	889153^{ns}	1481558^{ns}	2816193^{ns}	289443^{ns}	757857^{ns}	216986^{ns}	0.00393^{ns}	0.0028^{ns}	0.00089^{ns}
Prec:P (3)	51723^{ns}	4945692^{ns}	415382^{ns}	35311^{ns}	700057^{ns}	65303^{ns}	0.00777^{ns}	0.0276^{ns}	0.00054^{ns}
N:P (12)	661569^{ns}	4745003*	5833586***	96451^{ns}	148863^{ns}	314622**	0.00189^{ns}	0.0076^{ns}	0.00236^{ns}
Prec:N:P (12)	840522^{ns}	749780^{ns}	564532^{ns}	173374^{ns}	132500^{ns}	104744^{ns}	0.00899*	0.0059^{ns}	0.00087^{ns}
Residuals(*,**,***)	872066	2239752	1490623	131746	358796	120507	0.00467	0.0131	0.00266

*Degree of freedom for biomass (*Moretinajiru (Mo)=437; ** Ensaro (En) =497; *** Merhabatai (Me)=357) grain yield (* Moretinajiru = 437; ** Ensaro= 497 ***; Merhabatai = 357), Harvest Index (* Moretinajiru=436; ** Ensaro= 497; *** Merhabatai= 357)*

Appendix Table 2. Mean square value of Plant height, panicle length and number of tillers as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis							
	Plant height (cm)			Panicle length (cm)			Number of tiller	
	Mo	En	Me	Mo	En	Me	Mo	En
Year (1)	1933^{***}	3425^{***}	30792^{***}	1251.7^{***}	1839.9^{***}	4043^{***}	838.8^{***}	52.79^{***}
Block (3)	72^{ns}	2474^{***}	3252^{***}	74.3^{*}	237.4^{***}	232^{***}	19.5^{**}	5.86^{ns}
Rep (2)	21^{ns}	164^{ns}	401^{*}	13.8^{ns}	0.2^{ns}	101^{**}	$34*^{**}$	0.53^{ns}
Prec(1)	1137^{***}	1501^{***}	1171^{***}	494.7^{***}	53^{**}	74^{**}	2.6^{ns}	0.01^{ns}
N (4)	27031^{***}	28084^{***}	10880^{***}	2011.4^{***}	2553^{***}	657^{***}	29.1^{***}	43.41^{***}
P (3)	37^{ns}	1458^{***}	615^{***}	10.3^{ns}	140.2^{***}	28^{ns}	4.1^{ns}	8.07^{ns}
Prec:N (4)	245^{**}	207^{ns}	127^{ns}	42^{ns}	9.3^{ns}	13^{ns}	2.5^{ns}	1.13^{ns}
Prec:P (3)	13^{ns}	219^{ns}	9^{ns}	17.8^{ns}	28.3^{*}	6^{ns}	0.5^{ns}	4.97^{ns}
N:P (12)	59^{ns}	125^{ns}	57^{ns}	32^{ns}	10.9^{ns}	11^{ns}	0.9^{ns}	2.44^{ns}
Prec:N:P (12)	53^{ns}	55^{ns}	22^{ns}	13.4^{ns}	3.8^{ns}	7^{ns}	0.3^{ns}	2.36^{ns}
Residuals(*,**,***)	53	123	68	18.9	7.6	11	1.8	2.43

Degree of freedom for Plant height (Moretinajiru (mo)=425; ** Ensaro (En)= 492; ***Merhabatai (Me)=357) panicle length (* Moretinajiru=425; ** Ensaro= 492 ***; Merhabatai=357); number of tiller (* Moretinajiru=425; ** Ensaro= ***=492; Merhabatai= 357)*

Appendix Table 3. Mean square value of biomass, grain yield and harvest index as influenced by N and P rate, Soil type

Source of variation	Mean squares values with respective degrees of freedom in parenthesis								
	Biomass yield (Kgha^{-1})			Grain yield (Kgha^{-1})			Harvest Index		
	Mo	En	Me	Mo	En	Me	Mo	En	Me
Year (2)	36511875***	1232230^{ns}	69832^{ns}	5963987***	25099926***	3653761***	0.19775***	0.8255***	0.03344***
Block (3)	5995867*	59208750***	16081338**	863173*	327324^{ns}	35233^{ns}	0.04375**	0.3014***	0.00021^{ns}
Rep (2)	2492886^{ns}	65889^{ns}	3998771^{ns}	59623^{ns}	176934^{ns}	58331^{ns}	0.00211^{ns}	0.025^{ns}	0.01334*
Soil (1)	113652^{ns}	336944918***	17014^{ns}	524581*	48614713***	17149^{ns}	0.05234***	0.2831***	0.0003^{ns}
N (4)	930301711***	581534972***	740552984***	40530372***	26437356***	29658522***	0.13373***	0.2308***	0.00905*
P (3)	1668704^{ns}	50175202***	84952526***	274411^{ns}	2025693***	4901715***	0.00695^{ns}	0.0051^{ns}	0.00358^{ns}
Soil:N (4)	782716^{ns}	14019349***	3767293*	620060***	458772^{ns}	1234227***	0.04258***	0.0594***	0.01487***
Soil:P (3)	2008382^{ns}	1760569^{ns}	700247^{ns}	119995^{ns}	373172^{ns}	112223^{ns}	0.00099^{ns}	0.0233^{ns}	0.00116^{ns}
N:P (12)	661569^{ns}	4745003***	5833586***	96451^{ns}	148863^{ns}	314622***	0.00186^{ns}	0.0076^{ns}	0.00236^{ns}
Soil:N:P (12)	673502^{ns}	560544^{ns}	546552^{ns}	130147^{ns}	84470^{ns}	6644^{6ns}	0.00599^{ns}	0.0059^{ns}	0.00097^{ns}
Residuals (*,**,***)	905039	1499602	1501554	131244	266525	110923	0.00432	0.0122	0.0027

Degree of freedom for biomass (Moretinajiru (Mo)=437; ** Ensaro (En)=497; *** Merhabatai (Me)= 357) grain yield (* Moretinajiru=437; ** Ensaro= 497; *** Merhabatai = 357), Harvest Index (* Moretinajiru=436; ** Ensaro= 497; *** Merhabatai= 357)*

Appendix Table 4. Mean square value of Plant height, panicle length and number of tillers as influenced by N and P rate, Precursor crop

Source of variation	Mean squares values with respective degrees of freedom in parenthesis							
	Plant height (cm)			Panicle length (cm)			Number of tillers	
	Mo	En	Me	Mo	En	Me	Mo	En
Year (2)	1933***	3425***	30792***	1251.7***	1839.9***	4043***	838.8***	1839.9***
Block (3)	72ns	2474***	3252***	74.3ns	237.4***	232***	19.5***	237.4***
Rep (2)	21ns	164ns	401**	13.8ns	0.2ns	101**	34***	0.2ns
Soil (1)	2729***	8027***	4167***	60.8ns	114.5***	504***	10.8*	114.5***
N (4)	26929***	28057***	10880***	2062.6***	2552***	657***	27.8***	2552***
P (3)	37ns	1523***	615***	10.3ns	143.2***	28*	4.1ns	143.2***
Soil:N (4)	156*	187ns	205**	5.1ns	13.4ns	18ns	8.2***	13.4ns
Soil:P (3)	38ns	384*	12ns	27.4ns	22.9*	1ns	0.6ns	22.9*
N:P (12)	58ns	129ns	57ns	32.1ns	10.9ns	11ns	0.9ns	10.9ns
Soil:N:P (12)	52ns	84ns	52ns	15.7ns	3ns	11ns	1.1ns	3ns
Residuals (*,**,***)	51	108	58	19.6	7.5	9	1.7	7.5

Degree of freedom for Plant height (Moretinajiru (Mo)=425, ** Ensaro (En)= 492 ***Merhabatai (Me)=357) panicle length (* Moretinajiru=425, ** Ensaro= 492 ***Merhabatai=357), number of tiller (* Moretinajiru=425, ** Ensaro= ***Merhabatai= 357)*

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10. Verification of Split Application of Lime on Acid Soils for Food Barley Production at North Shewa Zone highlands

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Abstract

The present study was conducted to investigate the response of food barley to row application of micro-dosing, which involves application of small, affordable quantities of lime during planting. A field experiment was carried out at Tarma ber and Basona warana districts of North Shewa Zone of Amhara Regional state, Ethiopia. A randomized complete block design with three replications was used. The treatments comprised of control (without fertilizer and lime), recommended fertilizer, 12.5, 25, 50, and 75% of the full dose of lime calculated based on exchangeable acidity method. The rate of recommended Nitrogen and Phosphorus fertilizer were 64 N and 46 P_2O_5 $Kgha^{-1}$. Phosphorus fertilizer was applied as a straight fertilizer at planting in the form of NPSB. Half of N was applied at planting and the remaining N was at tiller stage in the form of split application. Lime and fertilizer were applied to the soil by hand after planting using the band application method. The highest grain yield of barely (2.70 tha^{-1}) was recorded under the treatment of 75% lime with recommended fertilizer and followed by 50% lime with recommended fertilizer, while lower grain yield (1.24 tha^{-1}) was recorded under the treatment of control without lime and recommended fertilizer. Generally, application of lime in the form of micro-dosing and in row improved soil pH and significantly reduced exchangeable acidity of the soil after harvesting. As a result, grain yield of barley was improved. Even though, micro-dose application of lime didn't give significantly s grain yield of barley among treatment, which was significantly different from control the yield advantage as compared to with other treatments the lime application of 12.5 is economical.[1]. Therefore, 12.5% of the required lime applied in row could give better economic advantages for resource poor farmers who cannot afford to invest the total amount of required lime to be applied once at a time.

Keywords: food barley, lime, micro-dose application

Introduction

A major challenge to barley production in the highlands of Ethiopia is low soil pH and low fertilizer application which resulted low soil fertility status. Low soil pH reduces availability of several plant nutrients, increases levels of some elements to phytotoxic concentrations (i.e., Al^{3+} toxicity), and influences microbial activity or other soil properties (Brady, 1990; Merino *et al.*, 2010). These poor growth conditions can lead to reductions in root development which consequently causes slow vegetative growth and low total biomass per unit area. Application of lime is no doubt the best alternative to alleviate topsoil acidic problem and provide suitable conditions for adequate crop development. In Kenyan highlands application of 25-50% from actual lime requirement (3.09 tha^{-1}) application increased grain by 14-31% (Dillion and Hardkar, 1993) and 5-17% maize yield (Kisinyo and Palapala, 2015). Even though application of 46-69 $Kgha^{-1}$ P_2O_5 and 1-2 tha^{-1} of lime for barley at highland of North Shewa of Tarma ber district gave maximum yield increment (120-128%) as compared to plots without lime and phosphors fertilizer (Agumas *et al.*, 2016) to recommended and promote the above amount is challenged due to its bulkiness and unaffordable by small holder farmers.

A lot of efforts were done to improve the productivity of acid soils of Ethiopian highlands. Among those developed technologies, 25% of the actual lime amount determined using exchangeable acidity method (EAx1.5) applied in row during planting was economical and applicable to farmers (Agumas *et al*., 2021. Evaluation and verification of this technology has paramount importance. As a result, this research was done with the objective of evaluating and verifying the comparative advantage of micro-dose lime application compared to full dose synthetic fertilizer without lime and its effect on food yield barley.

Materials and Methods

Description of the Study Areas: The experiment was carried out at high land areas of north Shewa of Tamara Ber and Basona Warana districts for two consecutive seasons (2017/18-2018/19). Geographically, the experimental sites were located at a range of 09^0 9' to 10^0 03'N and 40^0 02' to 380 9'E in Tarma Ber and 09^0 36' to 09^0 48'N and 39^0 39' to 39^0 50'E in Basona Warana with a mean altitude of 2678-2935m and 2650-2868m m.a.s.l respectively. The long term climate data of the study areas characterized the area as a unimodal rainfall pattern and receive an average annual rainfall of 984 and 928 mm at Tarma Ber and Basona Warana districts respectively with a dominant soil type of Cambisols.

The experimental design was randomized with 3 replications and within each season three sites. The land was divided in to three blocks. Each block also was divided in to six plots with a size of 3.6 x 3.2m. Recommended rate of 64 N and P_2O_5 Kgha^{-1} fertilizers for barley was applied using urea and NPS sources respectively**.** Half of N was applied at planting and the remaining N was at tillering stage in the form of split application. Full dose of P_2O_5 was applied at planting only. The control group comprises those who did not apply lime or the recommended fertilizer. At planting, each treatment received the entire recommended amount of fertilizer to the specific site. When planting, the band application method was used to apply lime and fertilizer, which were then manually mixed into the soil. HB1307 variety of food barley with a seed rate of 137.5 Kgha^{-1} was used as the test crop. The seed was drilled in rows and the space between rows was 20cm apart. From total rows 10 middle rows was harvested for yield measurement during harvesting.

In each seasons three farmers were selected based on their willingness and acid soil properties and exchangeable acidity which were determined at Debre Birhan Agricultural Center Soil laboratory (Table 2). Based on the result of exchangeable acidity, the actual requirement of lime was calculated using equation 1for each site. Different rates of lime were calculated based 12.5, 25, 50, and 75% from each site actual requirement of lime (Equation 2).

$$\mathrm{LR}\ (\mathrm{kg\ ha}-1) = \left[\frac{\mathrm{EA \times SD X 10^4}\, m^2 \times \mathrm{BD\, x1000}}{2000}\right] \times 1.5 \ldots \text{ Equation (1)}$$

$$\text{Lime application in rows (kg/ha)} = \left[\frac{\text{Equation 1}}{100}\right] \text{x Y\%} \ldots \ldots \text{Equation (2)}$$

Where, **LR**=lime requirement in Kgha^{-1}

EA= Exchangeable Acidity **SD**=Soil Depth in cm

BD=Bulk density in Kg m^{-3} **Y%**=rate of Lime (0 12.5, 50 and 75%)

Soil Sampling and Analysis: Prior to planting and following harvesting, a diagonal pattern of composite soil samples were taken from the experimental plots at a depth of 0–20 cm. The sub-samples were combined into a composite soil sample after uniform slices and soil volumes were obtained in each sub-sample through the vertical insertion of an auger. Following air drying and grinding with a pestle and mortar, soil samples were then allowed to pass through a 2 mm sieve. Standard laboratory techniques were then used to analyze the soil samples for the chosen chemical properties, primarily soil pH, exchangeable acidity, and available Phosphorus. Potentiometric measurement of the pH of the soil was done in a 1:2.5 (w/v) soil to water supernatant suspension using a pH meter equipped with a combined glass electrode (Van Reeuwijk, 1992). In order to ascertain exchangeable acidity, the base titration method—described by (Rowell, 1994) which entails saturating the soil sample with a 1 M KCl solution and titrating with sodium hydroxide was used. Utilizing the Bray II method (Bray and Kurtz, 1945), the amount of available soil Phosphorus was extracted and measured colorimetric ally using a spectrophotometer set to 882 nm.

Statistical Analysis: All agronomic and soil data were analyzed using SAS software version 9.3 (SAS, 2002). Treatment means were separated using the least significant difference (LSD) at a statistical significance level of $P \leq 0.05$. Partial budget analysis was carried out using the CIMMYT (1988) technique based on local market prices.

Results and Discussion

The total lime requirements of the sampled sites were ranged from 0.46 to 2.71 tha^{-1}. These values were calculated from the analyzed value of exchangeable acidity (0.43-2.01 $CmolKg^{-1}$). According to Tekalign (1991) the pH of soils was ranged from strongly (5.01) to moderately (5.4) acidic value (Table 1). Soil sample analysis prior to planting revealed that soil exchangeable acidity and available Phosphorus levels ranged from 0.43 to 2.01 $CmolKg^{-1}$ and 5.54 to 7.11 ppm, respectively (Tekalign, 1991).

Table 1. Laboratory analysis result of selected soil chemical properties and calculated amount of lime for each site during 2017/18 and 2018/19 at Basona warana and Tarma Ber districts

Year	Districts	Site	pH (1:2.5)	Av.P (ppm)	Exch. Acidity ($CmolKg^{-1}$)	calculated lime (tha^{-1})
2017	Basona	Faji	5.30	6.86	0.53	0.72
		Angolela	5.01	5.58	2.01	2.71
	Tarma ber	Wiyenber	5.40	5.54	0.43	0.46
2018	Basona	Angolela	5.30	7.11	1.14	1.54
	Tarma ber	Wiyenber1	5.25	7.06	1.97	2.66
		wiyenber2	5.30	6.89	0.75	1.01

Soil sample analysis after barley harvest showed that soil pH value was significantly increased due to lime application as compared to control regardless of the lime amount. The higher soil pH was obtained when soil is limed while the lowest soil pH was observed at control (Table 2). These changes of soil pH might be attributed to the neutralizing effect of lime in acid soil due to application of lime at increasing rates (Tisdale *et al.,* 1997). Caires *et al.,* (2005) and Nekesa (2007) also reported that the application of lime decreased exchangeable acidity and increased the available P of acidic soils. In contrary, the highest exchangeable acidity was observed from control and recommended NP treatments (Table 2). The increase in pH and reduction of exchangeable acidity is related with the existence of basic cations such as Ca^{2+} and Mg^{2+})) and anions CO_3^{-2} in liming material which can able to exchange H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH (Fageria *et al*., 2007).

Table 2. Soil chemical properties as influenced by lime application

Treatments	2017/18			2018/19		
	pH (1:2.5)	Av.P (ppm)	Exch. Acidity ($CmolKg^{-1}$)	pH (1:2.5)	Av.P (ppm)	Exch. Acidity ($CmolKg^{-1}$)
Control (0)	5.48^{c}	7.02^{b}	0.72^{ab}	5.37^{b}	6.41^{b}	0.92^{a}
64/46 N/P_2O_5 (RF)	5.47^{c}	6.30^{b}	0.84^{a}	5.40^{b}	6.91^{ab}	0.69^{a}
12.5% Lime + RF	5.55^{bc}	7.39^{b}	0.75^{ab}	5.57^{a}	7.24^{ab}	0.43^{b}
25.0% Lime + RF	5.58^{ab}	7.80^{ab}	0.71^{ab}	5.64^{a}	7.63^{ab}	0.42^{b}
50.0% Lime + RF	5.55^{bc}	7.79^{ab}	0.60^{bc}	5.73^{a}	7.80^{a}	0.41^{b}
75.0% Lime + RF	5.66^{a}	9.39^{a}	0.41^{c}	5.58^{a}	7.78^{a}	0.36^{b}
CV (%)	2.43	22.51	32.80	2.98	19.06	46.23
LSD (0.05)	0.09	1.63	0.21	0.08	1.32	0.25

The application of lime in micro-doses has been found to have a positive effect on improving the grain yield of food barley. Research has shown that the yield of food barley can be significantly improved by row applications of lime. The advantage in yield of barley by using 12.5% to 75% of the full dose of lime ranged from 10.2% to 25.0% on acidic soils. Even though, it was observed that the grain yield was consistently increased above the 50% lime application rate (see Fig 1). In the Kenyan highlands, it was found that applying 25% to 50% of the actual lime requirement (3.09 tons per hectare) increased grain yield by 14% to 31% for barley and by 5% to 17% for maize (Dillion and Hardkar, 1993; Kisinyo *et al*., 2015). Furthermore, in the acid soils of Ethiopia's central highlands, Dereje *et al*., (2022) demonstrated the efficiency of applying lime in small doses at a rate of 25% of the recommended rate based on exchangeable acidity at planting time to improve soil pH and Phosphorus availability and enhance fababean yield.

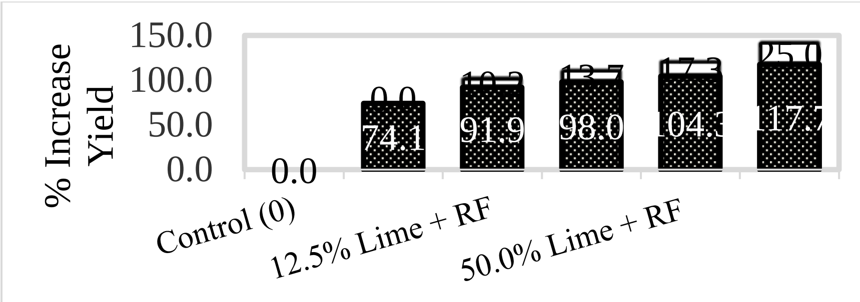

Figure 1. Grain yield increased with split application of lime on acidic soils (value in white shaded bar indicates the contribution of lime only and value in black shaded indicated that contribution of both inorganic fertilizer and lime application)

The application of lime in the form of micro-dosing has been shown to have a significant impact on grain yield as compared to control and recommended fertilizer treatments only (Table 3). The highest mean grain yield of 2.70 tha^{-1} was achieved with treatment combinations of 75% lime with recommended fertilizer, followed by 50% of the full dose lime, which was not significantly different each other. Moreover, the findings reveal that the grain yield from the 75% dose of lime was statistically comparable to treatments involving 12.5% and 25% doses of lime applied (Table 3). This implies that even low levels of lime application can lead to significant increases in grain yield. The effect of micro-dose application of lime on straw yield followed a similar trend as that of grain yield, indicating its potential benefits for overall crop productivity.

In general, Calcium-containing lime materials can improve nutrient availability, particularly Phosphorus, by lowering Phosphorus fixation (Mesfin, 1998; Rahman *et al*., 2002). Lime treatment increased soil nutrient availability, resulting in better crop yields and yield components. The study discovered that increasing the lime application rate had a clear association with grain yield in barley production, which increased correspondingly.

Table 3. Effect of row application of lime on food barley grain and straw yield of barley at Basona warana and Tarma ber districts 2017/18-2018/19.

Treatment	Grain yield(tha^{-1})						Grain yield (tha^{-1})	Straw yield (tha^{-1})
	2017/18			2018/19				
	Sit1	Site2	Site3	Sit1	Site2	Site3		
Lime (tha^{-1})	0.72	2.71	0.46	1.54	1.01	2.66		
Control (0)	1.72^{d}	0.08^{e}	2.17^{d}	0.86^{b}	2.14^{b}	0.46^{d}	1.24^{c}	2.28^{c}
64/46 N/P_2O_5 (RF)	2.70^{c}	0.42^{d}	3.20^{c}	2.36^{a}	2.86^{a}	1.40^{c}	2.16^{b}	3.33^{b}
12.5% Lime + RF	2.91^{bc}	0.80^{bc}	3.82^{ab}	2.33^{a}	3.11^{a}	1.76^{bc}	2.38^{ab}	3.61^{ab}
25.0% Lime + RF	3.42^{a}	0.58^{cd}	3.86^{ab}	2.39^{a}	2.57^{a}	1.88^{ab}	2.45^{ab}	3.51^{ab}
50.0% Lime + RF	3.30^{ab}	0.94^{ab}	4.18^{a}	2.00^{ab}	2.81^{a}	1.95^{ab}	2.53^{a}	3.63^{ab}
75.0% Lime + RF	2.93^{abc}	1.05^{a}	3.68^{b}	3.24^{a}	3.03^{a}	2.23^{a}	2.70^{a}	3.99^{a}
CV (%)	9.55	17.62	16.66	12.79	11.48	14.11	23.24	22.78
LSD (0.05)	0.51	0.25	0.43	0.39	0.55	0.43	0.35	0.51

Mean values within column followed by the same letter are not significantly different P>0.05)

Economic Analysis: As shown in table 4, total variable costs, which are responsible for yield increase in each treatment, were listed. The economic analysis revealed that application of 12. 25% of recommended lime gave marginal rate return values above 100% which is acceptable. The treatments were dominated by application of 12.5 of micro-dose lime application and full application of recommended lime. The net benefit and the MRR were 18152.8 ETBha^{-1} and 407.99%, from the application of 12.25% of recommended lime application per hectare. The control plot showed the lowest net benefit of 11143.6 ETB ha^{-1} (Table 4). As a result, among all treatments, micro dose application is the most cost-effective. The results are consistent with other studies (Twomlow *et al*., 2010; Afework and Yenesew, 2018), who indicated that micro dosing is one technology that can be affordable to farmers and assures that poor farmers get the best returns from this strategy since they cannot spend the largest dose of lime to reclaim the almost all of soil (Akibode S, Maredia M, 2011). Most treatments' returns improved as crop yield increased due to a minimal rise in production costs when compared to the achieved net returns with an acceptable

MRR. An increase in output will always improve profit as long as the marginal rate of return is more than the 100% (CIMMYT, 1988).

Table 4. Dominance and marginal analysis of barley grain yield.

Tr	GY* ($Kgha^{-1}$)	ADGY ($Kgha^{-1}$)	GB ($ETBha^{-1}$)	TVC ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR%
control	1238.2	1114	11143.6	0.0	11143.6	_
RF	2155.8	1940	19402.4	2843.3	16559.1	190.46
12.5%+RF	2376.3	2139	21386.7	3233.9	18152.8	407.99
25%+RF	2451.1	2206	22059.7	3793.3	18266.4	20.31
50%+RF	2529.2	2276	22762.9	4743.3	18019.6	-25.98
75%+RF	2695.2	2426	24256.6	5693.3	18563.3	57.23

**GY=Grain yield, ADGY=Adjustable yield@10%, GB=Gross Benefit, TVC=- Total Variable Cost, NB=Net Benefit, MRR=Marginal Rate of Return (1 Kg of lime with transport costs=2.5 ETB and 1 Kg of Barley costs=10 ETB)*

Conclusion and Recommendation

The economic analysis of lime application in agriculture indicated that applying 12.25% of the recommended lime per hectare produced a marginal rate of return (MRR) greater than 100%, which is regarded acceptable. This suggests that investing in lime at this rate resulted in a strong return on investment. The net benefit of this application was estimated to be 18152.8 $ETBha^{-1}$, with a MRR of 407.99%. In comparison, the control plot resulted in the lowest net benefit of 11143.6 $ETBha^{-1}$. The study also discovered that of all treatments, micro-dose lime application was the most cost-effective. The total variable costs associated with a yield increase in each treatment were demonstrated, and it was revealed that most treatments' returns improved as crop output grew, minor increase in production costs. This resulted in an increase in net returns at an acceptable MRR. Finally, the economic analysis of lime application in agriculture revealed that applying 12.25% of the recommended lime per hectare yielded a significant net benefit and a positive marginal rate of return. Furthermore, of all the treatments studied, micro-dose lime application was shown to be the most cost-effective.

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11. Identifying Major Yield-Limiting Nutrients for Bread Wheat (*Triticum Aestivum* L.) in Major Wheat Growing Areas of North Western Amhara, Ethiopia

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Abstract

Application of soil nutrients in the form of synthetic fertilizers is the primary option to enhance crop productivity and feeding over increased population size in Ethiopian context. On-farm research was conducted in Amhara Region with the objective of identifying major yield-limiting nutrients on bread wheat (Triticum aestivum L.) productivity. The experiment was conducted in 2021 under rain-feed cropping season on eighteen farms fields which are located at three major wheat growing domains (Womberema-Burie, Yilmana Densa-Gonje and Deber Eliyas). Ithad a total of ten treatments [NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, NP, NPS2 and control (no input)]. Randomized complete block design (RCBD) with three replications was used. Improved bread wheat variety TAY with 150 Kgha^{-1} seed rate was also used. Urea, TSP (triple super phosphate), KCl (muriate of potash), $MgSO_4$ (magnesium sulphate), EDTA and Borax was used for the sources of N, P, K, S, Zn and B nutrients, respectively. Except urea, all fertilizer types were applied at planting using basal application. Urea fertilizer was applied in three equal splits (planting, tilering and butting) stage of the crop. Before planting, one composite soil sample from each experimental site was taken at 0-20 cm depth and analysed for selected soil parameters. Both biological yields (grain + biomass) showed highly significant differences among treatment means at each individual experimental site as well as from combined analysis in the district. The main driving force for the occurrence of significant difference among treatment means in the ANOVA was due to omission of Nitrogen and Phosphorus nutrients. In the ANOVA result, both grain and biomass yields showed quick and automatic responses for Nitrogen followed by Phosphorus nutrient. Especially yield without Nitrogen in all study districts is equivalent with yield attained on the control treatment even if all other nutrients existed at optimal levels. However, both grain and biomass yields didn't show any significant differences either due to adding or omitting of sulphur (S), Zinc (Zn), Boron (B) and Potassium (K) nutrients. This showed that, Nitrogen (N) and Phosphorus (P) nutrients are still the major bread wheat yield-limiting nutrients in North West Amhara.

Keywords: Bread wheat, nutrient, omission, yield

Introduction

Agriculture plays an important role in the Ethiopian economy. It contributes over 35% to the annual GDP, about 80% to the export earnings and it employs over 75% of the population (CSA, 2018). Of the agricultural GDP, the contribution from crop production takes the lion's share which is about 70% or more. Within the crop production system, the share of cereals in area coverage and production potential is about 80% and 85%, respectively (CSA, 2017). The most important three crops (wheat, maize and tef) have a share of 60% of the fertilizer inputs, 55% of the production area coverage and 60% of the annual production potential (CSA, 2017).

Wheat is the most widely cultivated cereal crop in the world, and provides 20% of the protein and calories consumed by the world population (FAOStat, 2013). It is currently the staple food for more than 35% of the global human population (FAOSTAT, 2013). Continues nutrient depletion, newly emerging diseases and pests and unstable weather conditions deriving from climate change are the major threats for declining wheat productivity globally (CIMMYT, 2016). Ethiopia is the second-largest wheat producer in Sub-Saharan Africa, following South Africa (White *et al.*, 2001). The crop covers 1.7 million ha area and 4.6 million tons production (CSA, 2018). From the country, Amhara Region accounts 32.7% of area coverage and 30.3% of production volume (CSA, 2018). However, average wheat productivity in the Amhara region is about 2.53 tha^{-1} which is below the national average 2.74 tha^{-1}.

Due to increased use of agricultural inputs (improved seeds, fertilizers and pesticides), agriculture showed a dramatic progress with the annual growth rate of over 8%. Particularly, fertilizer consumption has shown a linear increment from below 37 tons in 1985 jumped to over 134 tons at the end of 1994. Following Plan for Accelerated and Sustained Development to End Poverty (PASDEP) consecutive five-year plans from 1995 through 2009, fertilizer consumption was increased by 10 tons every year for 16 years. During the subsequent growth and transformation plan of the country (GTP I, 2010 to 2015), the import and consumption rate of fertilizers had grown several folds which is 78,000 $tyear^{-1}$. After the introduction of soil fertility map by the Ethiopian Soil Information System (EthioSIS, 2015) and the second growth and transformation plan (GTP II, 2016-2020), the country has increased the fertilizer types used from two to over five. For this reason, the annual import and consumption raised to over 100,000 $tyear^{-1}$. Currently, the country imports about 1.4 million tonns of multi nutrient fertilizers and projected to use over 2 million tons at the end of 2025 (in GTP III). In targeting the right fertilizers to the right places, the

EthioSIS project team has mapped the soil nutrient status of agricultural lands in Ethiopia and identified that a number of essential nutrients are deficient and critically required for enhancing crop productivity in the country. Based on the developed map by the project, N, P, K, S, B, Zn, Fe and Cu are the deficient nutrients identified and recommended for enhancing crop productivity in most of Ethiopian soils. Even though the newly formulated fertilizer types needed a validation work, Agricultural Transformation Agency (ATA) and Ministry of agriculture (MoA) in collaboration conducted direct demonstration trials over at 60,000 trial sites within the regions and they confirmed what the EthioSIS soil map saying. However, this work had a major limitation from different aspects. Now, the problem is that the country has already customized the use of above-mentioned soil nutrients and made available in fertilizer form and appeared on the fertilizer market before the validation studies were reported. Although the new formulated fertilizers available on the fertilizer market, there is no national/regional conscience on the importance of those newly formulated fertilizer types. Therefore, this activity was conducted with the objective of identifying major yield-limiting nutrients for bread wheat productivity in North West Amhara Region, Ethiopia.

Materials and Methods

Study Area Description: The experiment was conducted at three major wheat growing districts (Womberema-Burie, Yilmana Densa-Gonje and Deber Eliyas) in Amhara regional state and located in North West direction from the capital city of Ethiopia (Fig 1).

Experimental Materials: Improved bread wheat variety (TAY) with 150 Kgha^{-1} seed rate was used. Urea, TSP, KCl, MgSO4, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Soil auger and core-sampler was used to collect soil samples.

Experimental Methods and Design: The experiment was conducted in 2021 at 18 farmers' field. Randomized complete block design (RCBD) with three replications were used. Row planting method was used. Spacing between rows, plots and blocks was 0.2m, 1m and 1.5m, respectively. Gross plot size used was 4m x 3m and harvested 9.6 m^2 areas. The experimenthad a total of ten treatments as indicated in Table 1. Except Urea, all fertilizers were applied at planting using basal application. Urea fertilizer was applied in three equal splits at different crop stages (planting, tilering and butting).

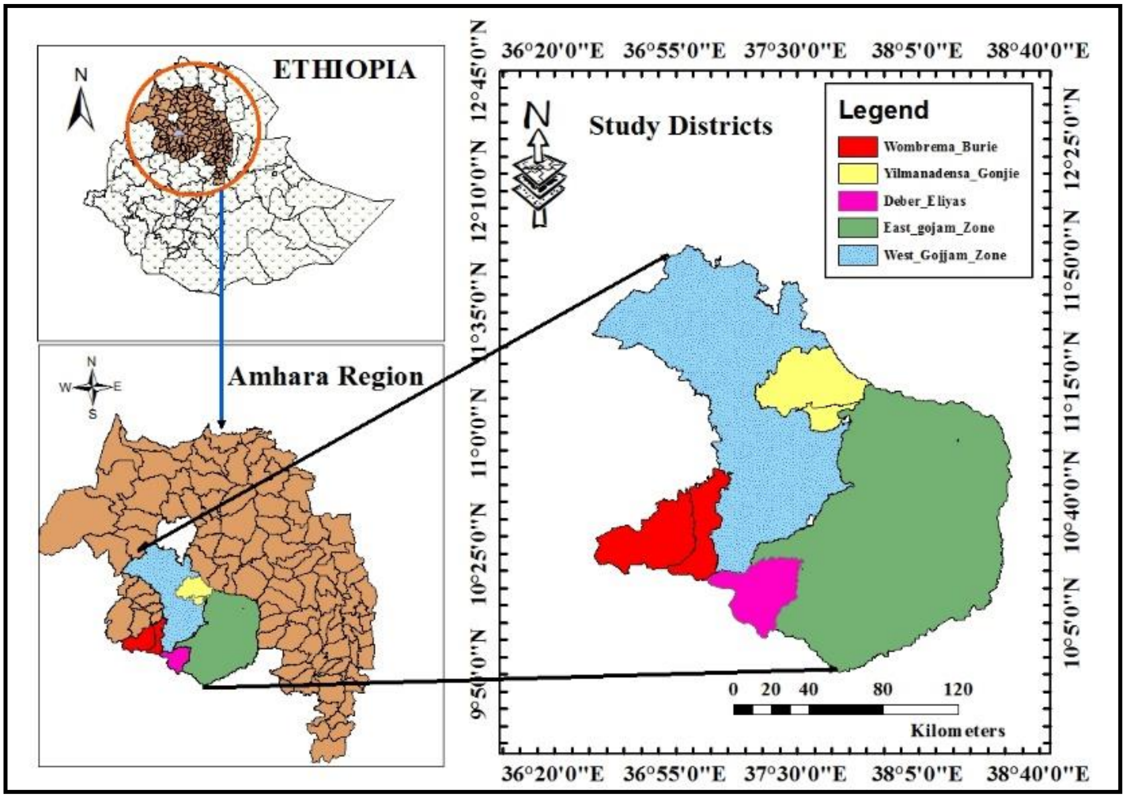

Figure 12.Map of the study districts

Table 1. Treatment setup for the on-farm experiment

No	Treatment	Description	Nutrient application rates ($Kgha^{-1}$)					
			N	P_2O_5	K_2O	S	Zn	B
1	NPSZnBK	All	138	92	60	10.5	5	1
2	NPSZnK-B	B-omitted	138	92	60	10.5	5	-
3	NPSBK-Zn	Zn-omitted	138	92	60	10.5	-	1
4	NPBZnK -S	S-omitted	138	92	60	-	5	1
5	NPSZnB-K	K-omitted	138	92	-	10.5	5	1
6	NSZnBK-P	P-omitted	138	-	60	10.5	5	1
7	NP	NP alone	138	92	-	-	-	-
8	Control	No fertilizer	-	-	-	-	-	-
9	NP+S2	NPS alone	138	92	-	30	-	-
10	PSZnBK -N	N-omitted	-	92	60	10.5	5	1

Soil Sampling, Preparation and Analysis: From each experimental site, one composite soil sample before planting was taken from five points following X-pattern sampling technique at the depth of 0-20 cm. The sample was air dried and sieved using ≤2 mm sieve for the analysis of the required parameters. Soil pH, organic carbon (SOC), cation exchange capacity (CEC), available Phosphorus (AP) and total Nitrogen (TN) were analyzed. All the mentioned parameters were analysed at Adet agricultural research centre's (AARC) soil laboratory. Besides, soil pH was determined using 1:2.5 soil-water suspensions ratios according to Taye *et al.*, 2002. Olsen (1954) was used for AP analysis. TN was analysed following Kjeldahl method (Bremner and Mulvaney, 1982). Soil OC was determined using wet oxidation and CEC determined using ammonium acetate method.

As indicated in Table 2, Soil pH values of the experimental sites found from strongly (4.5-5.2) to moderately acidic (5.3-5.9) ranges based on (Tekalign, 1991). Average soil AP values ranged in medium (5-10) based on Olsen (1954) nutrient rating scale. Based on Tekalign (1991) soil OC and TN values found from low to medium nutrient levels. While, CEC reading from medium (15-25) to high (25-40) $Cmol_{(+)}Kg^{-1}$ rating level according to Hazelton and Murphy (2007).

Table 2. Before planting selected soil properties for experimental sites

Parameters		Wombrema-Burie	Yilmana Densa-Gonje	Deber Eliyas	Reference
pH	min	4.97	5.30	4.85	Strongly-moderately acidic Tekalign (1991)
	max	5.13	5.75	5.27	
	Mean	5.46	5.48	5.06	
AP [Ppm]	min	7.08	4.42	3.09	Medium Olsen *et al.*, (1954)
	max	10.56	8.34	7.79	
	Mean	8.89	6.17	5.61	
SOC [%]	min	1.482	0.437	0.971	Low-medium Tekalign (1991)
	max	2.746	1.673	2.129	
	Mean	2.102	1.142	1.716	
TN [%]	min	0.153	0.055	0.095	Low-medium Tekalign (1991)
	max	0.155	0.164	0.238	
	Mean	0.154	0.101	0.180	
CEC	min	26.40	23.92	20.22	Medium-High, Murphy (2007)
	max	27.70	30.36	33.92	
	Mean	27.05	26.65	27.67	

Data Collection and Analysis: Yield components data like plant height, spike length and all biological yields (grain + biomass) were collected. The grain yield was adjusted to 12.5% of moisture content. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). The least significant difference (LSD) was used for mean comparison at 5% probability.

Results and Discussion

Grain and Biomass Yields: In Wombrema district, grain yield of bread wheat showed a highly significant difference among treatment means except at one site (Table 3). Most of the observed significant differences among treatment means of the grain yield in the growing districts derived due to control and N omission treatments, respectively. In the other saying, significant difference generated due to the presence of control and N omitted treatments. Almost at all trial sites, the minimum grain yield values recorded at control treatments followed by N omitted treatment. However, the maximum values were observed at any one of the treatments which received N and P nutrients together.

In the study district, an automatic response on grain yields of bread wheat was observed when either N nutrient was added or omitted. Even in this district, Phosphorus omission didn't show a significant difference from treatments which received recommended N and P nutrients together. This might indicate us to revise the current P rate to be used in the coming years. This showed that, N still showed its primarily potential on wheat yield-limiting which is in line with the findings of (Tadele *et al*., 2018) as he stated, *the yield-limiting nutrients to produce maize and wheat in major growing areas in Amhara region were N and P, respectively*. With the exception of N nutrient, significant difference didn't occur among the means of bread wheat grain yield either due to addition or omission of other nutrients (S, Zn, B, K and P) in the study district.

Table 3. Grain yield of bread wheat values at Wombrema-Burie

Treatment	Grain yield (Kgha^{-1})								
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
NPSZnBK	5192	4970	4263	4302	2814	3598	3313	3437	3548
NPZnBK-B	5153	5118	4365	4325	2775	2965	3171	3202	3632
NPSBK-Zn	4890	5026	4320	5020	2858	3360	3268	3341	4278
NPSZnK-S	5110	5106	4520	3963	2769	3172	3284	3273	3888
NPSZnB-K	4277	4887	4220	3811	2987	2965	2871	3297	4382
NSZnBK-P	4802	4854	4574	3836	2864	3102	3269	3539	3629
NP	4807	5015	4007	3975	2885	3050	2994	3435	3984
Control	3782	4219	1740	1867	339	1036	1308	1231	1201
NP+S2	4782	4660	4183	4049	2792	2590	2975	3454	3665
PSZnBK-N	2940	4351	1858	2138	865	1510	1735	1279	2057
LSD (0.05)	511**	1019^{NS}	569**	1091**	794**	611**	734**	738**	997**
CV	6.6	12.4	8.8	17.2	19.5	13.1	15.3	14.7	17.1

Note: *** = Highly significant, * = Significant, NS = Non significant*

Similar to Wombrema-Burie, Yilmana Densa-Gonjie and Deber Eliyas domains, grain yield of bread wheat also showed a highly significant difference among treatment means (Table 4). But unlike Wombrema-Burie, P omission also caused for the significant differences among treatment means of bread wheat grain yield in addition to control and N omitting treatments (Table 4). This showed that, P is the second yield-limiting nutrient in these study districts which is in line with the findings of (Tadele *et al*., 2018). As an overall trend in the conducted experiment, N and P nutrients are still the major wheat yield-limiting nutrients in most of North West Amhara.

Table4. Grain yield values of wheat at Yilmana Densa-Gonjie and Deber Eliyas districts

Treatment	Yilmana Densa-Gonjie (Kgha^{-1})				Deber Eliyas (Kgha^{-1})				
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 5
NPSZnBK	3275	3590	4252	4164	2835	2813	1752	2453	3686
NPZnBK-B	3100	3869	4116	4305	2787	2721	1742	2525	3179
NPSBK-Zn	3331	4061	4131	4177	2296	2863	1928	2219	3523
NPSZnK-S	3146	3861	3846	4387	2707	2932	1869	2343	2971
NPSZnB-K	2831	4026	4079	3946	1912	2612	1918	1891	3727
NSZnBK-P	2696	3096	2724	4004	1564	1675	2435	2010	2776
NP	3018	3401	3149	3481	1824	2669	2534	1850	3419
Control	255	300	854	1158	450	410	641	243	1295
NP+S2	2750	3476	3798	3982	2292	3005	2077	2333	3878
PSZnBK-N	695	937	1255	1401	454	655	791	359	1678
LSD (0.05)	572**	845**	597**	358**	486**	505**	1069**	760**	991**
CV	13.4	16.2	10.9	6.0	14.9	13.3	35.5	24.5	19.3

***Note:** ** = Highly significant, * = Significant, NS = Non significant

Except at one site in Wombrema-Burie study area, biomass yield of bread wheat showed significant difference among treatment means (Table 5). Similar to grain yield results, significant difference among treatment means for biomass yield was also generated from N omitting and control treatments in comparison with other remaining treatments. As an exception to the two sites, the minimum biomass yield values recorded at control treatment followed by N omitting treatment in the study domain. However, the maximum values recorded at any one of the treatments which received N and P nutrients together. An automatic biomass yield reduction was observed when either of the two or both of major nutrients (N and P) was omitted. Phosphorus omitting treatment in this domain didn't show a significant difference from a treatment which received recommended N and P nutrients together. Inversely in the study districts, N showed its major impact on determination of bread wheat biomass yield. Similar to grain yield, no significant differences were observed on biomass yields of bread wheat either due to adding or omitting of S, Zn, B and K nutrients.

Table5. Biomass yield of bread wheat values at Wombrema-Burie

Treatment	Biomass yield (Kgha^{-1})								
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
NPSZnBK	11080	9635	9382	9924	7444	7927	6597	9010	9615
NPZnBK-B	10938	10632	9365	10458	7809	7639	7420	9090	9299
NPSBK-Zn	10069	10747	9785	8958	7483	7799	7653	9757	10337
NPSZnK-S	10736	10563	10007	9326	7510	8038	6295	9715	9778
NPSZnB-K	9444	10715	9458	9573	7618	7448	5795	9036	10736
NSZnBK-P	10003	8924	9497	9201	7479	6573	6347	9569	8788
NP	10432	10493	9552	8557	6017	7337	6153	8556	9830
Control	7799	8569	3882	4260	1257	2208	2587	5566	3469
NP+S2	10521	8795	9399	10212	7733	6236	7170	9882	8569
PSZnBK-N	7448	9243	6250	4743	2569	2361	3809	5476	5073
LSD (0.05)	1715**	3296^{NS}	1913**	1547**	2073**	1203**	2350**	2629*	1984**
CV	10.2	19.7	13.0	10.7	19.3	11.1	23.1	18.0	13.6

***Note:** ** = Highly significant, * = Significant, NS = Non significant

Similar to Wombrema-Burie, Yilmana Densa-Gonjie and Deber Eliyas districts, biomass yield of bread wheat also showed a highly significant difference among treatment means. But unlike Wombrema domain, P omitting also caused for the significant differences among treatment means of bread wheat biomass yield in addition to control and N omitting treatments (Table 6). This showed that, P is the second wheat yield-limiting nutrient in the study domains which is in line with the finding of (Tadele *et al.*, 2018).

Similar to the individual experimental sites, all the biological yields (grain and biomass) showed significant difference among treatment means (Table 7). As discussed for the individual sites, in the combined ANOVA, P omitting didn't show a significant difference from treatments which received recommended N and P nutrients together. Except control and N omitted treatments other treatments didn't show any significant difference with each other on both grain and biomass yields. Therefore, N is still the leading yield limiting nutrient in Ethiopian soils followed by P which is in line with (Tadele *et al.*, 2022) finding, as he explained, *the yield-limiting nutrients to produce wheat in major wheat-growing areas in Amhara region were N and P, respectively*.

Table6. Biomass yield values at Yilmana Densa-Gonjie and Deber Eliyas

Treatment	Yilmana Densa-Gonje (Kgha^{-1})				Deber Eliyas (Kgha^{-1})				
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 5
NPSZnBK	8855	9427	9415	9827	8708	5990	4260	6840	7833
NPZnBK-B	8264	9960	9837	10130	8160	5382	5101	6774	6740
NPSBK-Zn	8642	10236	9634	10105	7194	7052	5135	6278	8351
NPSZnK-S	8393	9830	9151	10518	8151	7729	4781	6438	6323
NPSZnB-K	7718	10766	9365	9550	7080	6521	5526	5757	7932
NSZnBK-P	6926	8700	6620	9754	5351	4337	6870	5358	5792
NP	7000	9495	7484	9382	4672	6703	7052	5938	7594
Control	981	1167	2267	2995	2201	1288	1944	858	2910
NP+S2	7806	9332	8696	9660	7314	7583	5285	6670	8597
PSZnBK-N	2043	2588	3299	3197	1896	1646	1538	1153	3354
LSD (0.05)	1405**	2000**	1267**	700**	1120**	1775**	2893**	1448**	1845**
CV	12.4	14.4	9.8	4.8	10.8	19.2	35.8	16.3	16.6

***Note:** ** = Highly significant, * = Significant, NS = Non significant

Table7. Combined grain and biomass yields of bread wheat at each study domain (Kgha^{-1})

Treatment	Wombrema-Burie (Kgha^{-1})		Debre Eliyas (Kgha^{-1})		Yilmana Densa-Gonjie (Kgha^{-1})	
	Grain yield	Biomass yield	Grain yield	Biomass yield	Grain yield	Biomass yield
NPSZnBK	3938	8957	2708	6726	3820	9381
NPZnBK-B	3856	9183	2591	6431	3848	9548
NPSBK-Zn	3862	9176	2566	6802	3917	9647
NPSZnK-S	3898	9108	2564	6684	3810	9473
NPSZnB-K	3744	8869	2412	6563	3720	9349
NSZnBK-P	3830	8487	2092	5541	3130	8000
NP	3740	8496	2459	6392	3262	8340
Control	1858	4400	608	1840	642	1853
NP+S2	3683	8724	2717	7090	3502	8873
PSZnBK-N	2081	5219	788	1917	1072	2782
LSD (0.05)	526**	1031**	497**	1037**	430**	919**
CV	28.5	23.9	32.0	25.7	17.3	14.7

*Note: ** = Highly significant, * = Significant, NS = Non significant

In most of the study districts, omitting of each nutrient contributed yield penalty in comparison to the bench mark treatment (treatment which received all type of nutrients). However, the contribution of each nutrient on the yield penalties didn't show equal magnitude. Even, omitting of some nutrients provided a yield advantage from the bench mark treatment (NPSZnBK). With these remarks, omitting of K, S, B and Zn nutrients contribute insignificant impact from the bench mark treatment. However, impact of omitting N and P nutrients showed high and significant from the treatment which received all type of nutrients, respectively (Figure 2). Especially impact of N omitting is nearly equivalent to zero input treatment.

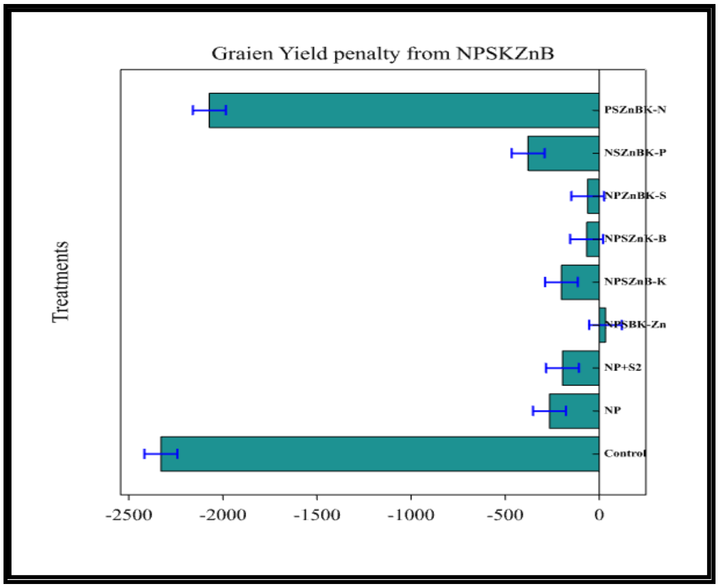

Figure 13.Yield penalty /advantage of bread wheat grain yield due to omitting of nutrients

(*: NPSZnBK is a benchmark treatment for this analysis)

In all study districts, grain yield of wheat showed highly and positive significant correlation with yield components like plant height, spike length and biomass yield. Similarly, yield components by themselves also showed highly and positive significant correlation with each other (Table 8).

Table8. Correlation of bread wheat yield components with grain yield at the three districts

Parameter	Yilmana Densa-Gonjie			Wombrema-Burie		
	PH*	SL	GY	PH	SL	GY
PH	-			-		
SL	0.83**	-		0.63**	-	
GY	0.93**	0.74**	-	0.54**	0.57**	-
BMY	0.96**	0.76**	0.98**	0.55**	0.51**	0.84**
Parameter	Debre Eliyas					
	PH	SL	GY			
PH	-					
SL	0.69**	-				
GY	0.78**	0.58**	-			
BMY	0.77**	0.71**	0.90**			

***PH=plant height, SL=spike length, GY=grain yield, BMY=biomass yield, **=Correlation is significant at $p<0.01$; *=Correlation is significant at $p<0.05$ & ns=Correlation is non-significant ($p\geq0.05$).*

Conclusion

Grain yield of wheat showed a highly significant difference among treatment means at each individual site as well as at all study domains. The study confirmed that, N is the primary wheat yield-limiting nutrient followed by P which is in line with the previous results reported by AARC. However, S, Zn, B and K nutrients had no significant statistical response from the former nutrients used (N and P) on both grain and biomass yields of wheat either when we add or omit them. Therefore, still it is possible to maximize wheat yield by using N and P fertilizer sources with the integration of other improved technologies. However, frequent revision of the soil fertility status is too important for updating nutrient requirements both in types and amounts used for enhancing wheat productivity and production in the study districts.

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12. Improvement of Barley Productivity and Soil Physico-Chemical Properties through Farmyard Manure and Lime Application in Acidic Hot Spot Areas in Northwestern Ethiopia

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Abstract

The experiment was conducted to determine the optimum rates of farmyard manure and lime to increase barley yield and improve soil Physico-chemical properties in Machakel and Guagusa shikudad Districts. The experiment comprised three levels of farmyard manure (0, 2 & 4 tha^{-1}) and four levels of lime (0, 25%, 50% &100%) with one pilot (92N, 69P_2O_5) treatment which was laid out in RBD design with three replications. Data on soil Physico-chemical properties, yield and yield components of barley were collected and subjected to ANOVA using SAS (9.4 version) software. The results revealed that the individual application of farmyard manure and lime significantly affected yield and yield components of barley. Similarly, soil property after planting slightly changed across treatments as compared to before planting. Sole Application of farmyard manure (4 tha^{-1}) and 100% *(8, 8 tha^{-1})* lime *gives the highest grain and above-ground biomass yield (1.7&3.5 tha^{-1}) and (1.6&3.1tha^{-1}) respectively as compared to control and a pilot treatments. Similarly, the application of sole 4 that-1scored the highest plant height (72.9cm) than both control and pilot treatments. On the other hand, the individual supplement of both farmyard manure and lime scored the highest net benefit with acceptable marginal return than control (note receive organic fertilizer). In general, the application of farmyard manure and lime improved yield and yield components of barley and soil properties in the study area. To attain the highest net benefit, within a short period of time application of 4 tha^{-1} and 25% (2.2tha^{-1}) can be preferable for yield improvement in the study area and similar agro-ecological environments.*

Key Words: Lime, Farmyard manure, soil properties, Barley

Introduction

Globally, soil acidity has been known as an important problem, which adversely affects crop production, directly or indirectly, especially in temperate and tropical regions of the world (Brady and Weil 2002). It covers about 30% or 3950 million ha of the land area and occurs mainly in two global belts, the northern belt (cold and temperate climate) dominated by Spodosols, Al*fi*sols, Inceptisols, and Histosols, and the southern tropical belt consisting largely of Ultisols and Oxisols (Sumner and Noble 2003). Acid soils in Ethiopia are widely distributed in highlands under varying climatic and environmental conditions. It covers nearly 40.9 % of the area under cultivation (Geremew et al., 2020). From this 2*7.7*% is moderately acidic (pH 4.5–5.5) and 13.2% is strongly acidic (pH < 4.5) (Taye, 2007). The problem is more expected in areas thathave high rainfall that enable leach exchangeable bases from the soil surface (Achalu *et al*., 2012).

In the case of the Amhara region, about 24% of the cultivated land is affected by acidity (ANRIO, 2006). The severity of soil-related problems affects the agricultural sustainability of cultivated lands. Its problem is known to exert an adverse effect on crop growth directly and indirectly through its effect on nutrient availability. The problem is very acute at Machakel and Guagusa Shikudad woredas, where most of the soils are predominantly acidic in nature with 3.33-5.6 exchangeable acidity. That forced most farmers to grow acid-tolerant crops at the expense of economically important crops or to allocate their cultivated lands to eucalyptus, Acacia decurrens and oat cultivation for the last many years.

Soil acidification is one of the major causes of soil degeneration that come from different sources like addition of acid-forming fertilizers, intensive cultivation, precipitation, and heavy irrigation also result in the development of acidity in these soils. Hence, these soils are poor in basic cations. Poor growth of crops on these soils is attributed to the presence of toxic amounts of iron (Fe), Al, and manganese (Mn), de*fi*ciency of Phosphorus (P), and molybdenum (Mo), and less activity of soil microorganisms (Dhananjaya and Ananthanarayana, 2010). This leads to a decrease in the pH value by increasing exchangeable acidity, which consequently results in a decrease in crop yield. The productivity losses of soils with pH range 5.5– 6.5, 4.5–5.5, and less than 4.5 are up to 10%, 10–25%, and more than 50%, respectively (Jehangir et al., 2013).

Barley is a cool-season crop that is adapted to high altitudes. It is grown in a wide range of agro-climatic ranges between 2200–3000 m a.s.l (Asmare *et al*., 1998). The area allocated to barley reached about 1 million hectares in 2015/16, (CSA, 2016). It is one of the most important crops for food, feed, and income generation for many smallholder farmers in the highlands of Ethiopia (Bayeh and Berhane, 2011) However, the productivity of barley in production fields has remained very low (about 1.3 tha^{-1}) as compared with the world average of 2.4 tha^{-1} (CSA. 2005). Acidity-related soil fertility problem is one of the constraints that contribute to low yield levels of the crop. From our experience, AARC (Adet Agricultural Research Center) was successful with the production of wheat in these acidic hot spot areas (Machakel and Guagusashikudad) through acid soil management by applying only 25% of the lime in rows at planting that was calculated by using exchangeable acidity.

Even if, this method is highly successful for wheat it is not able to achieve for barley production until we add 10.8 tha^{-1} (125% LR). This might be due to the soil being out of production or non-responsiveness related to the severe depletion of soil organic matter beyond the high sensitivity of barley for acidity as compared to wheat (Tigist,2022). Because of this barely yield was low beyond its biological yield potential. Based on this we suggest that in order to produce barley it is important to recover this nonresponsive soil as soil through the addition of organic matter that is the building block of soil.

Liming of acid soils increases soil pH and availability of P, Mo, and N nutrients while it reduces exchangeable acidity (Cairs *et al*., 2005, Nekesa, 2007). Similarly, the application of manure on acidic soils reduces Al^{3+} toxicity and increases the nutrient content of the soils (Hati *et al.*, 2006, Whalen, 2000). But the application of manure is not a complete substitute for lime (Mesfin, 2007). So, it was important to quantify the optimum amount of lime and farmyard manure rate for barely production with the following objectives.

Objective

To assess the economical and biological optimum level of lime and farmyard manure for barley in the highly acidic areas of the Western Amhara region

Materials and Methods

The experiment was conducted in Guagusashikudad and Machakel districts of Amhara Region on farmer's field for two consecutive years 2020/21-2021/22 cropping seasons at Guagusa shinkurta and Debrekelemo Kebles in Awi and East Gojjam zones respectively, Ethiopia. Guagusa shikudad district is located 129km from Bahirdar the capital city of Amhara region and geographically the area lies at 10^0 36' 22" N and 36^0 25' 15" E (Figure 1) with a mean altitude of 2204 m above sea level. It receives a mean annual rainfall of 1356 mm with mean minimum and maximum temperatures of 10 and 28°C, respectively (BoA). Based on the district bureau of Agriculture, the major land use comprises cultivated land (62.6%), forest and bushes (14.6%), grazing land (22.2%), and others (0.6%). Major crops grown in the study area are barley, wheat, potato, and fababean taking the lions share. The major soil types include Andisols, Nitosols, and Cambisols. Generally, the soil types of the study area are characterized by shallow, moderate to deep, and very deep in-depth and sandy clay to clay texture types (Alemayehu, 2015).

Machakel district is located 235 km away from Bahir Dar. Geographically the area lies at 10˚51'40" latitude and 37^{0}61'66"longitude E (Figure 1) with a mean altitude of 2600 m.a.s.l. It receives a mean annual rainfall of 1350 mm with mean annual temperatures of 25°C, respectively (BoA). Based on the district bureau of Agriculture (BoA), the major land use comprises cultivated land (52.3%), and others (47.7%). Major crops grown in the study area includes wheat, potato, barley, tef, triticale, and oat. The major soil types include Andisols and Nitosols

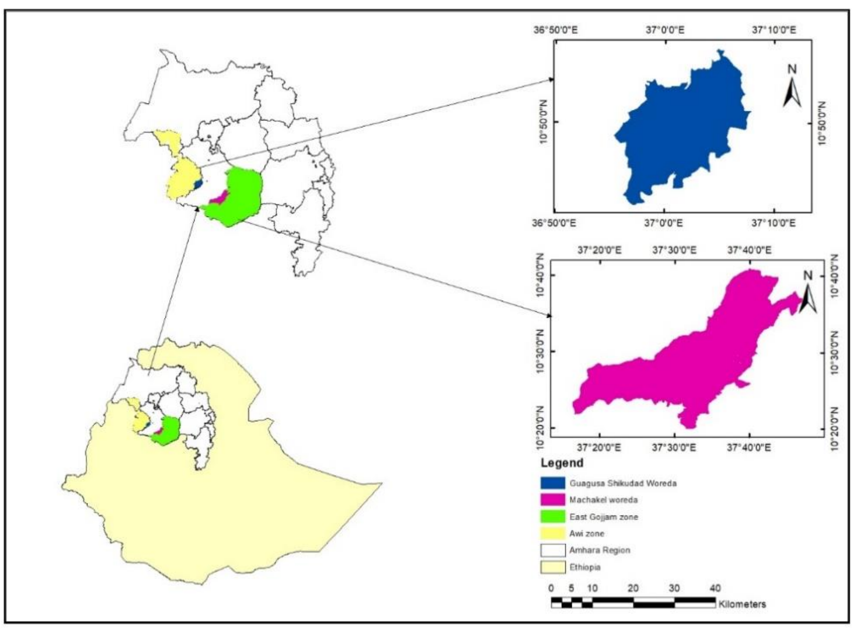

Figure1.The geographical location of the study Areas

Experimental Design and Experimentation: The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Which has thirteen treatments from this the twelve's were obtained from the combination of three levels of farm yard manure (0,2 and 4 tha^{-1}) and four levels of lime (0,25,50,100 % tha^{-1}) in addition to one pilot treatment (92N,69P_2O_5). The experiment was carried out under rain-fed conditions and food barley variety HB-1307 was used as a test crop. The total area of each plot was 4m x 3 m (12 m^2) having 1m space between plots and blocks as well as 0.2m betweenrows . Recommended fertilizer was applied during the growing period in all plots except pilot plots. Soil samples were collected at depths of 0-20 cm beforehand planting. Simultaneously the core samples per each soil sample were collected for the determination of the bulk density which is important for the calculation of the amount of lime using the following formula.

$$\mathbf{Lime(CaCO3)kg^{-1}ha^{-1}} = \frac{\mathbf{Exacidity(cmolkg^{-1}ha^{-1})*0.2m*10000m^2*BD(Mgm^{-3})*1000}}{\mathbf{2000}}\mathbf{*1.5}$$

The soil samples were air-dried, ground, and sieved based on the standard procedures. Analysis of soil chemical properties including exchangeable acidity was done in Adet Agricultural Research Center Soil Laboratory. Bulk density was determined by the core sampling method. Before and after sowing major chemical properties of soil such as exchangeable acidity, OC, pH, CEC, total N, and AvP (available P) were analyzed following the compiled laboratory manual of Sahlemedhin and Taye (2000).

Soil pH was measured in water at the ratio of 1:2.5 using a glass electrode pH meter. The soil OC content was determined following the wet digestion method as outlined by Walkley and Black which involves digestion of the OC in the soil samples with Potassium dichromate ($K_2Cr_2O_7$) in sulphuric acid solution. Available P was determined by Olsen extracting method (ref). Total N content in the soil sample was determined following the Kjeldahl method (ref). CEC was determined by extracting the soil samples with ammonium acetate (1N NH_4OAc) followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution. Percolating the NH_4^+saturated soil with sodium chloride would displace the ammonium ions adsorbed in the soil and the ammonium liberated from the distillation was titrated using 0.1N NaOH.

Agronomic Data Collection: Plant height and Spike length were measured at maturity from randomly selected five plants and averaged for a single reading. Similarly, Grain and Biomass yield was measured by balance from central rows by avoiding both the right and left two rows as borders for single reading

Statistical Analysis: All data were subjected to analysis of variance by using SAS software program version 9.4 (SAS Institute, 2002) proc glm model. A least significant test (LSD) at a 0.05 probability level was employed to separate treatment means where significant differences exist (Gomez and Gomez, 1984).

Economic Analysis: The partial budget and marginal rate of return (MRR) were used for evaluating the change in farming methods that affect partially rather than the whole farm practice and also concerned with a planning tool to estimate the profit change within a farm (CIMMYT, 1988). This was computed by adjusting the yield downward by 10% and multiplying it by the local field price (23 ETBKg^{-1} of Barley). And the cost of farmyard manure and lime was 0.2 and 0.8 ETBKg^{-1} respectively. Net benefits were considered by current fertilizer (Farm yard manure) cost of 0.2 ETBKg^{-1}, cost of lime Kg^{-1} 0.8 ETB, field price of Barley was 20 ETB Kg^{-1}, and cost of labor per man day in the area was 70 ETB. Dominance analysis was done by listing treatments in increasing order of cost thathas net benefit less than or equal to treatments with lower costs that vary dominated (CIMMYT, 1988).

Result and Discussion

*Soil Chemical Properties before Planting and After Harvest***:** Laboratory results of the soil before planting and after harvesting across districts from each experimental site are described in Tables 1 and 2. The analysis result of soil samples before planting indicated that the sites were acidic with a high exchangeable acidity across each site, which is an unsuitable range of soil exchangeable acidity for barley production Tekalign (1991). Similarly the total N, available P, OC, and CEC of the soil in Guagusa shikudadd and Machakel 2020/21 as well as Machakel 2020/22 before planting were (0.188.0.115 & 0.131%), (14.403,5.776 & 4.560 ppm), (2.734,1.509 & 1.450%), (29.64,24.70 & 23.30 cmol (+) Kg^{-1}), respectively (Table1).The total N content of the soil was within the range of low up to medium according to Tekalign (1991) who classified the range of total N < 0.1, 0.1- 0.15, 0.15-0.25, and > 0.25% as very low, low, medium and high, respectively. Based on Olsen *et al*.,1954 classification, available P content ranged < 5 as very low, 5 -15 as low, 15 -25 as medium, and > 25 mgKg^{-1} as high. Hence the available P of the soil before planting across sites lies under very low to low ranges. Similarly, according to Landon (1991) the soil OC content of the study area before planting ranged 1.45-2.7 and rated as low tomedium On the other hand cation exchange capacity (CEC) ranged from 23-30 cmol(+)Kg^{-1} and are rated as medium and high in the study sites before planting. Generally, the nutrient contents of the study sites especially at Machakel are not good in terms of the availability of major plant nutrients besides Guagusa shikudad with nice CEC.

On the other hand, after harvest, all soil chemical properties changed from the initial soil samples (before planting) in values across experimental sites except inconsistency Guagusa shikudad due to the application of lime with farmyard manure as compared to control and pilot treatments (Table2). Numerically the higher value most of selected soil chemical properties displayed in table two was scored by the application of lime and farm yard manure across sites as compared to control. The increment of these soil properties may be related to the releasing of basic cations in soil solution that makes substitute of acid cations and make neutralization in the rhizosphere beyond the supplemented nutrient of the plant. These results were in agreement with the investigation of Endalkachew *et al.* (2017) who reported that the application of compost, lime, and farmyard manure with inorganic P has increased (make a change) the soil chemical properties as compared to control or non-treated plots at Lay Gaint District North Western highlands of Ethiopia.

Table 1. Soil chemical properties before planting across experimental sites

Guagusa shikudad (2020/21)						
BD (gcm^{-3})	TN%	OC%	CEC	AVP (ppm)	Ex. Acidity	LM per site
1.3	0.188	2.734	29.64	14.403	3.33	6.5
Machakel (2020/21)						
BD (gcm^{-3})	TN%	OC%	CEC	AVP (ppm)	Ex. Acidity	LM per site
1.2	0.115	1.509	24.70	5.776	4.81	8.6
Machakel (2021/22)						
BD (gcm^{-3})	TN%	OC%	CEC	AVP (ppm)	Ex. Acidity	LM per site
1.4	0.131	1.450	23.30	4.560	5.60	11.3

Table 2. Soil chemical properties after planting across experimental sites

Treatments	Guagusa shikudad (2020/21)					Machakel (2020/21)					Machakel (2021/22)				
	pH	TN %	OC %	CEC (cmol Kg^{-1})	AVP (ppm)	pH	TN %	OC %	CEC (cmol Kg^{-1})	AVP (ppm)	pH	TN %	OC %	CEC	AVP (ppm)
0,0 (FY*, LM)	5.25	0.07	3.13	31.9	16.01	5.19	0.22	2.52	23.18	9.231	5.04	0.18	1.65	26.94	11.76
0,25% (FY, LM)	5.32	0.11	3.1	34.46	18.14	5.4	0.21	2.17	24.48	12.17	5.33	0.19	1.33	25	11.32
0,50% (FY, LM)	5.45	0.2	3.02	33.18	13.89	5.71	0.19	1.98	30.16	17.94	4.96	0.17	1.31	25.26	12.01
0,100%(FY, LM)	5.48	0.16	2.75	34.5	15.33	6.34	0.22	2.26	29.24	16.32	5.52	0.17	1.36	28.32	10.19
2,0 (FY, LM)	5.2	0.13	3.37	34.96	17.58	5 .18	0.17	2.37	27.66	8.27	5.12	0.18	1.36	25.5	11.26
2,25% (FY, LM)	5.27	0.14	3.06	37.04	19.27	5.22	0.22	1.92	29.28	12.11	5.18	0.19	1.39	30.42	11.76
2,50%(FY, LM)	5.38	0.16	3.19	34.02	16.89	5.43	0.22	2.39	31.64	11.21	5.32	0.18	1.67	30.52	8.88
2,100%(FY, LM)	5.76	0.13	2.94	35.14	17.7	5.48	0.22	2.22	25.94	9.652	5.56	0.18	1.41	29.82	10.63
4,0 (FY, LM)	5.24	0.17	3.44	34.66	19.33	5.07	0.18	2.35	25.32	11.87	4.9	0.13	1.42	20.66	10.51
4,25% (FY, LM)	5.31	0.16	3.21	34.54	17.7	5.18	0.23	1.92	27.5	7.55	4.98	0.14	1.58	28.4	8.755
4,50% (FY, LM)	5.2	0.2	3.19	31.36	19.96	5.73	0.24	2.13	32.16	14.52	5.03	0.18	1.3	29.34	10.13
4,100%(FY, LM)	5.54	0.13	3.08	33.92	16.83	6.14	0.21	2.44	28.6	10.25	5.78	0.16	2.12	31.28	10.82
Pilot	5.08	0.13	3.1	38.4	17.64	5.15	0.22	2.28	28.36	10.91	5.15	0.19	1.07	26.36	9.881

**NB: FY =farmyard manure levels (0, 2, 4 tha^{-1}), LM=lime levels (0, 25, 50,100%) of Lime requirements in each sites, pilot = (92 N, 69 $P2O_5$), pH=concentration of hydrogen, TN=total Nitrogen, OC=organic carbon, CEC=cation exchange capacity, AVP=available Phosphorus*

Plant Height and Spike Length: The combined application of farm yard manure and lime was not significantly ($P < 0.05$) affected plant height (PH) and spike length (SL) across the year and sites (Table 3). Besides the application of farmyard manure (FYM), significantly affected plant height as compared to the control traetment. However, different lime application rates did not show statistical difference with the control treatment in pant hieght. This might be dueto amelroation propertes of lime rather to serves a plant nutrent.. The highest value of plant height (72.9cm) was achieved with the addition of 4 tha^{-1} farmyard manure as compared to both control and pilot treatments that scored (63.1 and 64.8cm) respectively (Table 3). The increase plant height in response to the application of farmyard manure may be due to the improvement of soil properties that enhance good water absorption and nutrient utilization to the plant root system or rhizosphere. Moreover, application of farmyard manure (FYM) may deliver balanced micro and macronutrients as well as enhanced availability of plant nutrients, which would help to boost the metabolic activity of microorganisms and improvement of plant growth. The result is in agreement with the findings of Tolera *et al.,* (2018) who observed that the highest plant height of food barley was obtained by application of 50% vermicompost with 50% conventional compost next to 50:50% conventional with NP. Similarly, the study conducted by Molla *et al*., (2018) indicated that an application of 4 tha^{-1} vermicompost significantly increased food barley height by a value of 6.39 cm as compared to the control.

Table3. The main effect of lime and farmyard manure on plant height and spike length of food barley at Machakel and Guagusa shikudad

Treatment	Guagusa Shikudad 2020/21		Machakel 2020/21		Machakel 2020/22		Combined over years	
	PH (cm)	SL (cm)	PH (cm)	SL (cm)	PH (cm)	SL (cm)	PH (cm)	SL (cm)
0 tha^{-1}FY*	70.7^{b}	6.4	58.8^{b}	6.1	63.4^{b}	5.8	63.1±1.3^{b}	6.1
2 tha^{-1}FY	79.9^{a}	6.6	60.0^{b}	5.9	67.1^{ab}	5.9	69.0±1.6^{a}	6.1
4 tha^{-1}FY	83.0^{a}	6.8	63.5^{a}	6.0	72.1a	6.0	72.9±1.5^{a}	6.2
LSD	**5.0**	**NS**	**3.1**	**NS**	**5.0**	**NS**	**4.5**	**NS**
FY	*****	**-**	*****	**-**	*****	**-**	*****	**-**
0%Lime (0 tha^{-1})	74.5	6.4	57.1^{b}	5.8	64.5	5.6	65.4	6.0
25%Lime (2.2 tha^{-1})	76.8	6.5	61.0^{a}	5.8	67.3	5.7	68.4	6.0
50%Lime (4.4 tha^{-1})	80.2	6.7	62.5^{a}	6.1	67.7	6.3	70.2	6.3
100%Lime (8.8 tha^{-1})	80.0	6.8	62.5^{a}	6.1	70.7	6.0	71.1	6.3
LSD	**NS**	**NS**	**3.6**	**NS**	**NS**	**NS**	**NS**	**NS**
Lime*FY	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV%	**7.7**	**12.5**	**6.1**	**9.0**	**8.7**	**12.6**	**13.8**	**12.1**
Pilot (92N,69P_2O_5)	67.9	5.9	56.4	5.7	70	5.7	64.8	5.8

*NB: *FY=farmyard manure, GY=grain yield, PH= plant height, SL=spike length*

Grain Yield and Above-Ground Biomass: The statistical analysis results in both years across sites indicated that yield and yield component of food barley were not significantly affected at ($P<0.05$) by the combined application of farmyard manure and lime application (Table 4). Rather the sole application of farmyard manure significantly affected both grain yield and above-ground biomass. However, sole lime provided significant biomass yield difference between different lime rates (Table4). Related to this numerically the highest value of both grain yield (1.7 tha^{-1}) and above-ground (3.5 tha^{-1}) was obtained by application 4 tha^{-1} farm yard manure (FY) as compared to control and pilot treatments. This might be due to the positive effect of farmyard manure on soil acidic amelioration or chelation of acid-forming cations which makes to help available plant nutrients in plant root system or rhizosphere beyond its nutrient supplement as organic fertilizer. Moreover, FY results in the release of organic acids that attached Al and Fe, thereby, reducing P retention and enhancing P availability.

The study is in lined with the finding of Getachew *et al*., (2005) who found that the application of 4 and 8 tha^{-1} FYM with 26 $Kgha^{-1}$ P on acid Nitisols of Holetta, Ethiopia, increased faba bean seed yield by 97 and 104%, respectively, compared to the control treatments. In the same way, the study conducted by Mitku and Tamado, (2016) implied that an application of 5 tha^{-1} farmyard manure gives figuratively the highest (2581 $Kgha^{-1}$) grain yield of food barley as compared to control or untreated treatment. In addition, Molla *et al.*, (2017) indicated that the sole application of vermicompost with a rate of 2, 4 & 6 tha^{-1} can increase grain yield and above-ground biomass by 11, 17 & 26% as compared to control or unfertilized treatment.

Similarly, the sole application of lime beyond its combination with farmyard manure significantly affected both grain yield and above-ground biomass of food barley at ($p<0.05$) in table 4. The highest value of both gain yield (1.6 tha^{-1}) and above ground biomass (3.1tha^{-1}) was observed at 100% lime (8.8 tha^{-1}) application as compared to control and the pilot treatment. However, there was no statistical yield difference between different lime rates (Table 4). Similarly, except 25% of the full dose of lime, there no biomass yield difference among lime rates. This might be related to the amelioration of soil acidity as the pH increased thathave reduced the active forms of Al and Fe besides the enhancement of the availability of P, Ca, and Mg and improvement in the physical environment of soil in the plant root system. The study agreed with the findings of Rajneesh (2018) who revealed that the supplying of lime for four decades in wheat-maize cropping system increased grain yield of wheat continuously as compared to control and N alone treatments. Similarly, the result coincides with Asmamaw *et al*., (2020) who observed that an application of 25% lime gives a 90.23% yield advantage over previously wheat production years in highly acidic areas of the northwestern Amhara region.

Table4. Main effect of lime and farmyard manure on grain yield and above-ground biomass of Barley at Machakel and Guagusa shikudad.

Treatment	Guagusa 2020/21		Machakel 2020/21		Machakel 2020/22		Combined over years	
	GYtha^{-1}	BY tha^{-1}	GY tha^{-1}	BY tha^{-1}	GYtha^{-1}	BYtha^{-1}	GYtha^{-1}	BYtha^{-1}
0tha^{-1} FYM*	1.1^{b}	2.3^{c}	0.87^{b}	1.9^{b}	1.1^{b}	2.0^{b}	1.1±0.48^{c}	2.1±0.12^{c}
2tha^{-1} FYM	1.8^{a}	3.4^{b}	1.2^{a}	2.8^{a}	1.1^{b}	2.2^{b}	1.4±0.08^{b}	2.8±0.87^{b}
4tha^{-1} FYM	2.1^{a}	4.0^{a}	1.3^{a}	3.1^{a}	1.7^{a}	3.4^{a}	1.7±0.07^{a}	3.5±0.65^{a}
LSD	**0.28**	**0.58**	**0.21**	**0.44**	**0.24**	**0.4**	**0.20**	**0.31**
FY	*	*	**	*	*	**	**	**
0%Lime (0 tha^{-1})	1.5	3.0	0.82^{b}	1.8^{c}	1.1	2.2^{b}	1.2±0.09^{b}	2.3±0.18^{c}
25%Lime (2.2 tha^{-1})	1.6	3.0	1.1^{a}	2.5^{b}	1.3	2.6^{ab}	1.4±0.09^{a}	2.7±0.18^{b}
50%Lime (4.4 tha^{-1})	1.8	3.3	1.2^{a}	2.9^{b}	1.2	2.6^{ab}	1.4±0.08^{a}	2.9±0.15^{ab}
100%Lime (8.8 tha^{-1})	1.8	3.6	1.3^{a}	3.1^{a}	1.5	2.9^{a}	1.6±0.09^{a}	3.1±0.18^{a}
LSD	NS	NS	0.24	0.5	NS	0.46	0.20	0.40
Lime*FY	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.5	21.4	22.1	20.1	22.6	18.8	26.2	23.6
Lime	-	-	*	**	-	*	**	**
Pilot (92N,69P_2O_5)	1.1	2.2	0.67	1.5	1.1	2.2	1.0	2.1

**NB: FY=farmyard manure, GY=grain yield, BY= above-ground biomass*

Partial Budget Analysis: The marginal rate of returns of 100% was used to determine the acceptability of treatments. This economic analysis indicated that all most all the farmyard treatments give the highest net benefit than control (Table 5). Addition of both 2 and 4 tha^{-1} FY (farmyard manure) scored (24,170 ETB) and (28,540 ETB) net benefit with marginal rate of return of 424.3% respectively. This indicate that for every 1ETB invested for 2 and 4tha^{-1} FY in farm land can enables farmers obtain an additional 4.24ETB (CIMMYT, 1988). Similarly, economical analysis of lime also indicated that addition of 25%lime (2.2 tha^{-1}) numerically gives the highest (21600) net benefit with marginal rate of returns of 55.2% as compared to control and other dominated treatments. This also implies that for every 1ETB invested for 2.2 tha^{-1} (25% lime) in farm land can enables farmers obtain an additional 0.552ETB (CIMMYT, 1988). All Un-dominated treatment for farmyard manure and lime sole application could be acceptable for barley producers in the study area except the dominated one's. So that by considering the residual importance of farmyard manure for soil and crop production application 4 tha^{-1} FY with 25%lime (2.2 tha^{-1}) should be recommended in these acid hot spot areas for barley production.

Table 5. Partial budget and marginal analysis of barley as affected by the main effect of farmyard manure and lime application in acid hot spot areas of northwestern Amhara Region.

Farmyard manure	Actual Grain Yield tha^{-1}	10% Adjusted Grain Yield t ha^{-1}	Total variable Cost ETB ha^{-1}	Net Benefits ETB ha^{-1}	MRR%
0tha^{-1}FY	1.1	0.11	0	19800	0
2tha^{-1}FY	1.4	0.14	1030	24170	424.3
4tha^{-1}FY	1.7	0.17	2060	28540	424.3

Lime	Actual Grain Yield tha^{-1}	10% Adjusted Grain Yield t ha^{-1}	Total variable Cost ETB ha^{-1}	Net Benefits ETB ha^{-1}	MRR%
0%Lime(0tha^{-1})	1.2	0.12	0	21600	0
25%Lime(2.2tha^{-1})	1.4	0.14	2320	22880	55.2
50%Lime (4.4tha^{-1})	1.4	0.14	4640	20560	D
100%Lime (8.8tha^{-1})	1.6	0.16	9280	19520	D

Conclusion and Recommendation

Yield and yield components of barley were significantly affected by the effect of farmyard manure and lime as individual application rather than their combination. Barley that was grown on by sole application of farmyard manure and lime was improved in yield and yield components as compared to control and pilot treatment. The addition of farmyard manure as organic nutrient fertilizer had a positive impact on plant height, grain yield, and above ground-biomass. Application of farmyard manure gives a higher net benefit when compared to control. Treatments with the application of 2- and 4 tha^{-1} of FYM for this experiment give a better net benefit response with over 100% marginal rate of return than the control. Similarly, individual application of lime significantly affected both grain yield and above-ground biomass as compared to control and pilot treatment. Additionally, it also gives a higher net benefit with acceptable marginal returns as compared to control. The study identified that the highest net benefit could be obtained from the individual application of farmyard manure and lime. Related to this application 4tha^{-1}FY and 25% lime (2.2tha^{-1}) gives a higher net benefit with 424.3% and 55.2% marginal returns respectively. Therefore, resource-poor small-scale farmers can be benefited, if they apply these soil improvement rates depending on their convenience. As we see barley yield is low as compared to its biological yield potential and yield of wheat that we have achieved in the lime trial in this area is about 3-4 tha^{-1}. This may be related to its sensitivity to acidity than wheat. So to make barley an alternative crop in the farming system in this non-responsive acid hot spot area soils like Debrekelemo and Guagusa shikudad; It needs high investment to enhance soil organic matter through application such as compost, farmyard manure , vermicompost, and by practicing of agroforestry, soil and water conservation measures.

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13. Integrating Effect of Vermicompost with Nitrogen Fertilizer Equivalent Ratio on Soil Properties and Onion (*Allium Cepa* L.) Bulb Yield in North Western Amhara Region

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Abstract

The experiment was conducted to determine the integrated effects of vermicompost with equivalent nitrogen rates on soil chemical properties and the yield and yield components of onions at the Koga Irrigation Scheme in Northwest Ethiopia. The study comprised six treatments (Control, recommended Nitrogen, 75% recommended Nitrogen + 25% vermicompost, 50% recommended Nitrogen + 50% vermicompost, 25% recommended Nitrogen + 75% vermicompost, and 100% vermicompost) arranged in a randomized complete block design with three replications. Data on soil chemical properties and onion yield components were collected and analyzed using ANOVA with SAS software. The results indicated that different rates of vermicompost combined with nitrogen fertilizer significantly affected the yield components of onions. Soil properties, except for total nitrogen and organic carbon, were not significantly affected by the treatments. The application of 50% vermicompost with 50% nitrogen resulted in the highest bulb yield (23.6 t/ha) compared to the control and achieved the highest net benefit with an acceptable marginal return (above 100%), next to 100% vermicompost. Overall, the integration of vermicompost with nitrogen rates can improve the yield and yield components of onions. For the highest net benefit in a short period, applying 50% vermicompost with 50% nitrogen is preferable for yield improvement in the study area and similar agro-ecological environments. However, to ensure consistency, further research should be conducted widely and repeatedly in permanent plots.

Keywords: nutrient, organic fertilizer, amendement, irrigation, balancing

Introduction

Onion (*Allium cepa* L.) is one of the most important commercial vegetable crops grown intensively in the world. Onion has a significant contribution to the human diet, and economic earnings as well as valued for its medicinal properties (Gessesew et al., 2015). It is consumed primarily for unique flavor or the ability to enhance flavor in food (Yohannes et al, .2013). The common varieties of onion grown in Ethiopia include Han, Robaf, Lambada, Mata Hari, Rio Bravo, Sirius, and others (MAL, 2017). The total area covered by the onion crop is 31673.21ha, with a total production of 293887.585 tons and average productivity of 9.3 tons/ha (CSA, 2018). This is a very low yield compared to the world average of 19.7 tha^{-1} (Haq, 2016). The phenomenon is common in our region (Amhara) as compared to other regions. Low yield is attributed to factors, such as low soil fertility, pests, diseases, and poor storage facilities among others (Zziwa et al., 2015).

Moreover, the lack of fertile soil and the absence of recommended organic fertilizer rates are pertinent problems in any given area (Gessesew et al., 2015). Vermicompost is a product of organic matter degradation through interactions between earthworms and microorganisms (Arancon *et al.*, 2008). In this process earthworms fragment the waste, enhance microbial activity and accelerate rates of decomposition, as in composting, but by a non-thermophilic process (Abduli *et al.*, 2013). Vermicompost is not only the source of organic matter and nutrient but also improve microbial population, physical, biological, and chemical properties of the soil, as well as produce vigorous plants (Mavaddati *et al.*, 2010). Many researchers studied the role of organic fertilizers as a stimulant of plant growth and yield of onion (Shaheen *et al.*, 2007), improving bulb quality and storability (Al-Fraihat, 2016).

In Ethiopia, vermicompost application is getting more emphasis accounted for ease of preparation, input and labor availability, better nutrient composition as well as low cost as compared to inorganic fertilizer (Shanu *et al*., 2019). The principles of integrated nutrient management are the maintenance and possible management of soil fertility for sustaining crop productivity on a long-term basis. Judicious and proper use of organic and inorganic fertilizers is very essential not only for obtaining higher yield and quality but also to maintain soil health and sustainability for a longer period. *Therefore, to improve onion production, a number of inputs are required, including adequate soil fertility management through integrated organic and inorganic fertilizers.* Since integrated nutrient management for the crop is lacking in the study area, therefore, this study aimed to evaluate the effectiveness of vermicompost and N fertilizer rate on soil chemical properties and determine the optimum agronomic and economical rate of vermicompost and N fertilizer for the production of onion at the Koga irrigation scheme

Materials and Methods

Description of the Study Area: The experiment was conducted for two consecutive growing seasons (2020 and 2021) at the Koga irrigation scheme in the Mecha district on a farmer's field in North West Amhara region Ethiopia. It is one of the irrigation schemes developed by the government of Ethiopia to enhance the production and productivity of horticultural crops in northwestern Ethiopia. The irrigation scheme is about 7,000 ha large and is mostly used for the production of vegetables including onion, tomato, pepper, cabbage, carrots and etc. Moreover, cereal crops like wheat and maize are also produced during both irrigation and the main rainy season in the scheme. The topography of the irrigation scheme is a gentle slope and the soil type of the area is Nitosol. The area is located at 11° 23′ latitude and 37° 05′E to 37° 06′E longitude with an average altitude of about 1972 meters above sea level with an annual mean rainfall of about 1,395.23 mm. The mean maximum and minimum temperatures of the area are 27 and 12.8°C, respectively.

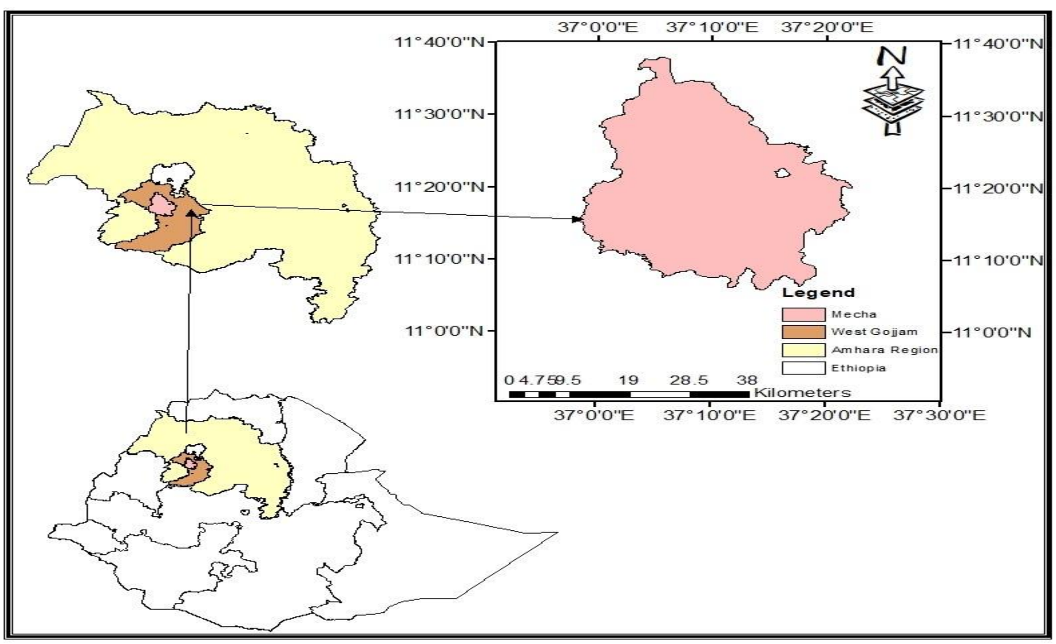

Figure 1. The geographical location of the study area

Experimental Design and Procedure: The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications which has six treatments control (without N), recommended N (137N $Kgha^{-1}$), 75% recommended N (103N $Kgha^{-1}$)+25% VC (2.65 tha^{-1}), vermicompost 50% equivalence (5.3 tha^{-1})+50% recommended N (68.5N $Kgha^{-1}$), 25% recommended N (34.3)+75% VC (7.95 tha^{-1}) and 100% VC (10.6 tha^{-1}). The equivalence vermicompost rates were adjusted based on recommended Nitrogen. Urea and TSP were used as a source of synthetic N and P_2O_5 during the transplanting period. The experiment was carried out under irrigation and the onion variety Red Bombey was used as a test crop. The total area of each plot was 11.55 m^2 having 1.5m space between plots and blocks with 0.4m furrow width. Plants and rows were spaced 0.05 and 0.15m respectively. Vermicompost was incorporated in ridges during the transplanting. P_2O_5 was applied as basal on all plots at planting time while inorganic N was applied in two splits, half at transplanting planting and the remaining half 30 days after transplanting planting.

Data Collection, Preparation and Analysis:

Vermicompost Analysis: Representative composite sample vermicompost was taken from the whole collected vermicompost from well-prepared pits for analysis of (pH), total Nitrogen (TN%), cation exchange capacity (CEC), organic carbon (OC%), available Phosphorus (avP) and carbon-Nitrogen ratio (C: N ratio) by following laboratory procedures (Sahlemedhin and Taye, 2000).

Table 1. Chemical analysis of vermicompost before planting

PH	TN%	CEC(cmol Kg^{-1})	OC%	avP($mgKg^{-1}$)	C:N
7.61	1.3	65.71	18.16	477.63	14

OC%=organic carbon percent, TN%=total Nitrogen percent, C: N=carbon to Nitrogen ratio, CEC = cation exchange capacity, avP=available Phosphorus, and pH= Power of hydrogen concentration.

Soil Sampling and Analysis before Sowing: Before transplanting, representative soil samples were collected from 0-20 cm depth in a random sampling method from 10 spots in the field by using an auger. All samples were mixed together and one composite sample was formed. The composite sample was grounded using a mortar and passed through a 2mm sieve to analyze soil texture, CEC, pH, and available P; a 0.5 mm sieve was used to determine the organic carbon (OC) and total N.

Table 2. Soil Physico-chemical properties before transplanting

Texture	PH	TN%	CEC (cmol Kg^{-1})	OC%	avP ($mgKg^{-1}$)	C:N
Clay	5.11	0.185	31.32	2.48	20.60	13.41

Similarly, before transplanting and after harvesting soil samples were collected from 0-20 cm depth in a random sampling method from 10 spots in each experimental unit based on treatments through an auger. Determination of particle size distribution was done using the hydrometer method (procedures) compiled by Sahlemedhin and Taye (2000) and the sand, silt, and clay percent were calculated and identified using FAO textural triangle. The major chemical properties of soil such as OC, pH, CEC, total N, and available P were analyzed following the compiled laboratory manual of Sahlemedhin and Taye (2000). Soil pH was measured in water at a ratio of 1:2.5 using a glass electrode pH meter. The soil OC content was determined following the wet digestion method as outlined by Walkley and Black (1954) which involves the digestion of the OC in the soil samples with Potassium dichromate ($K_2Cr_2O_7$) in a sulphuric acid solution. The avP was determined by Olsen (1954) extracting method. The total N content in the soil samples was determined following the Kjeldahl method. CEC was determined by extracting the soil samples with ammonium acetate (1N NH_4OAc) followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution. Percolating the NH_4^+ saturated soil with sodium chloride would displace the ammonium ions adsorbed in the soil and the ammonium liberated from the distillation was titrated using 0.1N NaOH (sodium hydro oxide).

Crop Data Collection

Plant Height: it was measured at the maturity stage by taking five randomly selected plants from ground level to the top apex and averaged for a single reading.

Leaf Number: it was taken by counting all leaves randomly from five middle rows at the maturity stage and computed for the mean value.

Leaf Length: it was measured at the maturity stage by taking five randomly selected plants from each randomly measured leaf and averaging for a single reading.

Bulb Diameter: it was done by taking three plants bulb atharvest from middle rows measured by caliper then the values were averaged for a single reading.

Marketable Bulb Yield and Un-Marketable Bulb Yield: it was determined by personal judgment by considering all diseased attacked, shriveled, and sizes below 20mm bulbs could be un-marketable while the others are marketable

Total Bulb Yield: it was measured atharvesting by using both marketable and non-marketable bulbs from the net middle plot area (six ridges) of 3.3m x 3m.

Economic Analysis: Economic analysis was performed to make a rational choice among the applied variables in the production of onion. The partial budget and marginal rate of return (MRR) were used for evaluating the change in farming methods that affect partial rather than the whole farm practice and also concerned with a planning tool to estimate the profit change within a farm (CIMMYT, 1988). This was computed by adjusting the yield downward by 10% and multiplying it with the local field price (20 Ethiopian ETB per Kg of onion). Dominance analysis was done by listing treatments in increasing order of cost and thathave net benefit less than or equal to treatments with lower costs that vary dominated (CIMMYT, 1988).

Statistical Analysis: All data were subjected to analysis of variance through GLM procedure by using the SAS software program version 9.4 (SAS Institute, 2002). A list significant test (LSD) at 0.05 probability level was employed to separate treatment means where significant differences exist (Gomez and Gomez, 1984).

Results and Discussion

Effect of Vermicompost with Nitrogen on Soil Chemical Properties after Harvest: Soil chemical properties analysis after harvest from each experimental site were indicated in Table 3. Except for soil Nitrogen (@Y1S1 (year one site one) and organic carbon (@Y2S1 (year two site one) the other soil properties were not affected by the application of vermicompost with N equivalence rates (Table 3). The non-significant effects of the applied treatments on these parameters might be due to the slow release of nutrients from vermicompost, which was applied during the experimentation period to soil solution related to short cropping season onion cultivation. However, applied vermicompost and N rates had a significant ($P < 0.05$) effect on Nitrogen at site Y1S1 (year one site one) and organic carbon at Y2S1 (year two site one) (Table 3). Numerically the highest Nitrogen and organic carbon content were obtained by the application of (75% N with 25%VC) and (50%N+50%VC) respectively as compared to the control (Table 3). The increment of soil organic carbon in treated plots might be due to the improvement of soil organic matter by the application of vermicompost. These results were in agreement with the investigation of

Geremew *et al.*, 2019 who reported that the application of dry bio-slurry (14tha^{-1}) with blended fertilizer increased the soil OC content after harvest by scoring the highest value as compared to the control. Similarly, Tilahun *et al*., 2013 also, indicated that soil OC content just after the rice harvest responded significantly to the application of FYM, and the highest carbon (8.7%) was recorded from the application of FYM at the rate of 15 tha^{-1}. Similarly, the integration effect of both vermicompost and Nitrogen on total Nitrogen may be due to the addition of mineral N from vermicompost and urea fertilizer sources into the soil solution which makes increased the nutrient availability in the soil root system. The results agreed with the investigation of Iqbal *et al*., 2021 who reported that the combined application of vermicompost with inorganic Nitrogen (25%VC+25%N) on onion increased the soil total Nitrogen and other nutrient content after the harvest of onion as compared to the control.

Table 3. Integration effect of vermicompost and Nitrogen fertilizer on selected soil properties

Y1S1						
Treatment	pH	TN %	CEC (cmolKg^{-1})	OC%	avP (ppm)	C: N
Control (0,0)	5.08	0.15c	26.75	2.17	24.39	14.45
RN (100%) (137N Kgha^{-1})	5.17	0.20ab	27.61	2.30	24.37	11.60
75%RN (103N Kgha^{-1}) +25% VC (2.65tha^{-1})	5.12	0.21a	28.05	2.23	24.69	10.73
50%RN (69NKgha^{-1}) +50% VC (5.3tha^{-1})	5.09	0.17bc	27.45	2.08	27.32	11.96
25%RN (34NKgha^{-1}) +75% VC (7.95tha^{-1})	5.12	0.19ab	27.68	2.02	26.92	10.82
100% VC* (10.6tha^{-1})	5.08	0.19ab	27.82	2.19	27.82	11.31
LSD	NS	0.03	NS	NS	NS	NS
CV%	2.29	7.95	11.70	7.36	18.05	12.40
Y1S2						
Treatment	pH	TN%	CEC (cmolKg$^{-1)}$	OC%	avP (ppm)	C: N
Control (0,0)	4.95	0.17	27.52	2.17	29.21	12.51
RN (100%) (137N Kgha^{-1})	4.79	0.20	28.29	2.15	30.91	10.49
75%RN (103N Kgha^{-1}) +25% VC (2.65tha^{-1})	4.85	0.17	26.71	2.04	28.14	11.92
50%RN (69NKgha^{-1}) +50% VC (5.3tha^{-1})	4.99	0.19	29.99	1.94	31.55	10.54
25%RN (34NKgha^{-1}) +75% VC (7.95tha^{-1})	4.94	0.21	28.91	2.08	32.34	10.22
100% VC (10.6tha^{-1})	4.89	0.20	29.38	1.98	33.02	9.91
LSD	NS	NS	NS	NS	NS	NS
CV%	2.12	9.56	6.57	11.41	10.75	11.35
Y2S1						

Treatment	pH	TN%	CEC ($cmolKg^{-1)}$	OC%	avP (ppm)	C: N
Control (0,0)	5.08	0.21	29.07	2.26bcd	39.52	10.66
RN (100%) (137N $Kgha^{-1}$)	5.01	0.21	29.63	2.40abc	41.12	11.70
75%RN (103N $Kgha^{-1}$) +25% VC (2.65tha^{-1})	5.13	0.21	27.45	2.21cd	41.76	10.46
50%RN (69N$Kgha^{-1}$) +50% VC (5.3tha^{-1})	5.11	0.22	26.31	2.53a	42.36	11.62
25%RN (34N$Kgha^{-1}$) +75% VC (7.95tha^{-1})	5.19	0.20	25.75	2.43ab	40.14	12.10
100% VC (10.6tha^{-1})	5.17	0.23	25.51	2.15d	41.08	9.48
LSD	NS	NS	NS	0.21	NS	NS
CV%	4.53	8.20	10.13	5.01	11.46	10.73

*NB: VC= vermicompost, RN = recommended Nitrogen, Y1S1 = year one site one, Y1S2 = year one site two and Y2S1= year two site one

Integrated Effect of Vermicompost with Nitrogen on Onion Growth Parameters: Integrated application of vermicompost and inorganic Nitrogen significantly affected on plant height of onion ($p<0.05$) beyond leaf number and leaf length. Numerically, the highest value of plant height of onion was observed by application 50%VC (5.3tha^{-1}) with 50%N (69KgN) as compared to the control (untreated plots). Increasing plant height in response to the application of vermicompost (VC) with Nitrogen (N) fertilizer may be due to the improvement of chemical properties of the soil that resulted from the mineralization of vermicompost and release of N from urea fertilizer into soil solution for easy uptake by plant for its growth. In addition, it might be a positive effect of vermicompost in increasing water absorption and holding capacity that helps for nutrient utilization of the plant root system (rhizosphere).

Moreover, application of vermicompost may deliver balanced micro and macronutrients as well as enhanced availability of plant nutrients, which would help to enhance the metabolic activity of microorganisms and improvement of plant growth. The result is in agreement with the findings of Melkamu *et al.,* (2020) who observed that longer plants when onion plants were applied with farm yard manure (13.5tha^{-1}) and NPS (245.1Kgha^{-1}). lt is also harmonized with the findings of Bhavana *et al.,* 2022 who recorded maximum plant height of onion from the application of 50% vermicompost with 50% inorganic fertilizer while the minimum value was recorded from the control treatment. Another study that was conducted by Muhammad *et al*., 2017 reflected that the highest value of mung bean plant height (78.08 cm) was recorded from the treatment which received 20:50 NP Kgha^{-1} with inoculation Rhizobium as compared to the lowest value 68 cm on control treatment

Table 4. Response of onion growth parameters for vermicompost and inorganic fertilizer application at Koga irrigation scheme

Treatment	Leaf Number	Leaf Length (cm)	Plant height (cm)
Control (0,0)	8.9	27.8	32.8b
RN (100%) (137N $Kgha^{-1}$)	8.9	29.5	35.2ab
75%RN (103N $Kgha^{-1}$) +25% VC (2.65tha^{-1})	8.9	30.9	36.5a
50%RN (69N $Kgha^{-1}$) +50% VC (5.3tha^{-1})	8.7	31.1	37.3a
25%RN (34N $Kgha^{-1}$) +75% VC (7.95tha^{-1})	8.5	29.2	35.0ab
100% VC (10.6tha^{-1})	8.7	29.6	35.0ab
LSD (0.05)	NS		2.8
CV%	7.9	8.2	8.4

**NB: VC= vermicompost, RN= recommended Nitrogen*

Integrated Effect of Vermicompost with Nitrogen on Onion Yield Parameters: The bulb diameter and yield of the onion were significantly affected ($p<0.05$) by the application of vermicompost and inorganic Nitrogen fertilizer (Table 5). Due to this, the highest value of bulb diameter and yield was observed by the application of 50% VC (5.3tha^{-1}) with 50% inorganic Nitrogen (69N $Kgha^{-1}$) as compared to control (untreated plots) (Table 5). This may be due to the application of organic manures which provide major and micronutrients resulting in increased photosynthetic activity, chlorophyll formation, Nitrogen metabolism, and auxin contents in the plants ultimately improving the diameter of the bulb. The higher total bulb yield might be due to an increase in plant height, number of leaves, and other yield attributes for the fresh weight of the whole plant bulb. Moreover, it might be due to the release of N from vermicompost (VC) and Urea to soil solution that makes for plant better growth and development.

Moreover, it could be due to the addition of both macro and micronutrients from the vermicompost by improving soil Physico-chemical properties. Similar results have been reported by Sioflo *et al*., (2020) who reported that the highest value of onion bulb yield (19,8tha^{-1}) was observed through the application of 20tha^{-1} vermicompost before transplanting of onion as compared to control by folding 7.9 times. Another study conducted by Bosco *et al*., (2017) also indicated that the amendment of experimental plots by farmyard manure gives the highest bulb yield of onion (12tha^{-1}) than untreated plots (control). Kirose *et al*., 2018 also reported that an application of 75%

recommended fertilizer with 2.5tha^{-1} vermicompost gives the highest onion seed yield (1462.5Kgha^{-1}) which was 263% higher than control (untreated) treatments.

Table 5. Response of onion yield parameters for vermicompost with inorganic Nitrogen application at Koga irrigation scheme

Treatment	Bulb Diameter (mm)	Bulb Yield (tha^{-1})
Control (0,0)	45.5c	15.6c
RN (100%) (137N Kgha^{-1})	50.1ab	23.2a
75%RN (103N Kgha^{-1}) +25% VC (2.65tha$^{-1)}$	49.2b	19.3b
50%RN (69N Kgha^{-1}) +50% VC (5.3tha^{-1})	51.8a	23.6a
25%RN (34N Kgha^{-1}) +75% VC (7.95tha^{-1})	49.5ab	18.6b
100% VC* (10.6tha^{-1})	50.4ab	17.3bc
LSD (0.05)	2.3	2.7
CV%	4.9	14.4

**NB: VC= vermicompost, RN =recommended N*

Partial Budget Analysis: Net benefits were calculated by the current fertilizer (Urea) cost of 13.643 ETBKg^{-1}, cost of vermicompost Kg^{-1} 0.2 ETB, field price of onion was 20 ETBKg^{-1}, and cost of labor per man day in the area is 70 ETB. The marginal rate of returns of 100% was used to determine the acceptability of treatments. This economic analysis indicated that un-dominated treatments give high net benefit than the control (Table 6). The addition of 50% vermicompost with 50% RN and 100% vermicompost gives (420587.2 ETB) and (308160.0 ETB) net benefits with marginal rates of return of 18403.2 % and 844.4% respectively. This indicates that for every 1ETB invested for 50% vermicompost with 50% RN and 100% vermicompost in the field, farmers can obtain an additional 184.032 and 8.444 ETB respectively (CIMMYT, 1988). All Un-dominated treatment rates could be acceptable for onion producers in the study area except the dominated ones. Therefore, the most economical rate for producers with low costs and higher benefits was 50% vermicompost with 50 %RN. As the second option farmers can be used 100% vermicompost only for onion production because it also has a promising net benefit with an acceptable marginal rate of return.

Table 6. Partial budget and marginal analysis of onion as affected by the application of vermicompost with Nitrogen.

Treatments	Actual yield tha^{-1}	10% Adjusted Bulb Yield tha^{-1}	Total variable Cost $ETBha^{-1}$	Net Benefits $ETBha^{-1}$	MRR%
Control (0,0)	15.6	14.04	0	280800.0	0
100% VC* (10.6tha^{-1})	17.3	15.57	3240	308160.0	844.4
25%RN (34N $Kgha^{-1}$) +75% VC(7.95tha^{-1})	18.6	16.74	3726.4	331073.6	D
50%RN (69N $Kgha^{-1}$) +50% VC (5.3tha^{-1})	23.6	21.24	4212.8	420587.2	18403.2
75%RN (103N $Kgha^{-1}$) +25% VC (2.65tha^{-1})	19.3	17.37	4699.2	342700.8	D
RN (100%) (137N $Kgha^{-1}$)	23.2	20.88	5185.6	412414.4	D

**NB: VC = vermicompost, RN =recommended Nitrogen, D = dominated*

Conclusions and Recommendations

Applied vermicompost with N (Nitrogen) had a positive impact on plant height, bulb diameter, and Total bulb yield. Among treatments used for this experiment undominated once gave a better net benefit response with over 100% marginal rate of return than the control. Therefore, resource-poor producers or small-scale farmers can be benefited, if they apply these soil improvement rates depending on their convenience. The study identified that the highest net benefit could be obtained from the application of vermicompost with N fertilizers. Related to this application 50% vermicompost with 50% N gives a higher net benefit with 184.032% marginal return. As a result, small-scale farmers could use it for onion production in the area (for an irrigation scheme). In the future, similar studies should be done in different locations, crops, and years in permanent plots in order to confirm the current findings and to give a concrete recommendation for crop production and soil health amendment in the Koga irrigation scheme.

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14. Dry Bio-Slurry with Nitrogen Fertilizer Application and Its Residual Effect on Soil Physico-Chemical Properties and Crop Yield under Potato-Wheat Cropping System in North West Amhara Region, Ethiopia

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Abstract

The experiment aimed to determine the effect of dry bio-slurry with equivalent nitrogen (N) rates on soil physico-chemical properties and the yield of potato and wheat in a potato-wheat cropping system at Yelmana Denesa District. The study included ten treatments (Control, recommended NP, 50% dry bio-slurry, 100% dry bio-slurry, 75% dry bio-slurry, 75% dry bio-slurry + 25% recommended NP, 50% dry bio-slurry + 50% recommended NP, 25% dry bio-slurry + 75% recommended NP, 100% dry bio-slurry + 25% recommended NP, and 100% dry bio-slurry + 50% recommended NP) in a randomized complete block design (RCBD) with three replications over three years. Data on soil physico-chemical properties, yield, and yield components of potato and wheat were collected and subjected to ANOVA using SAS software. The results revealed that the application of different rates of dry bio-slurry with N fertilizer significantly affected the yield and yield components of both potato and wheat. Soil properties, except pH, were not significantly affected by dry bio-slurry. Application of 25% dry bio-slurry with 75% recommended NP resulted in the highest tuber yield (27.6 t/ha) compared to the control. Similarly, sole application of 100% and 75% dry bio-slurry yielded the highest grain yield (3.85 t/ha) and above-ground biomass (9.59 t/ha) of wheat, respectively, due to the residual effect. The 25% dry bio-slurry with 75% recommended NP treatment achieved the highest net benefit with an acceptable marginal return (above 100%), next to 50% dry bio-slurry with 50% recommended NP. Overall, the application of dry bio-slurry with nitrogen rates improved the yield and yield components of potato and wheat in the study area. For the highest net benefit within a short period, a rate of 50% dry bio-slurry with 50% recommended NP is preferable for yield improvement in the study area and similar agro-ecologies. Given the study's three-year duration, further research should be conducted extensively and repeatedly in permanent plots.

Keywords: dry bio-slurry, Nitrogen, soil properties, potato, wheat

Introduction

Potato (*Solanum tuberosum L.*) is the world's third most important food crop after wheat and rice (Birch et al., 2012). In Ethiopia, the area coverage for potato cultivation reached about 73,677.64 ha and *its* production was 1,044,436.359 *tons (CSA, 2020).* The productivity of potato in Ethiopia is 13.9tha^{-1} (CSA, 2018), which is relatively low compared to other African countries (FAOSTAT, 2017). Bread wheat (*Triticum aestivum* L.) is also one of the major cereal crops grown in the highlands of Ethiopia, and regarded as the largest wheat producer in Sub-Saharan Africa (Efrem *et al*, .2000). Out of the total area allocated for cereals, wheat ranked 4th after tef (Eragrostis tef), maize (Zea mays) and sorghum (Sorghum bicolor), while third in total production after maize and tef (CSA, 2016). Despite the long history of wheat cultivation and its importance to Ethiopian agriculture, its average yield is still very low, not exceeding 2.4tha^{-1} (CSA,2014) which is below the world's average of 3.4tha^{-1} (FAOSTAT,2015) which is the same phenomenon in Amhara region.

Low level of potato and wheat productivity is mainly due to soil fertility degradation, improper fertilization, poor pest management practices, use of the low-quality seed, and soil nutrient depletion (Chanie *et al*., 2017). Enhancing soil fertility is a precondition for improving crop production and productivity through organic manure like bio-slurry that can achieve sustainability soil fertility and crop production (Shankarappa *et al*., 2012; *Khan et al*., 2015). The bio-slurry obtained after extraction of the energy content of animal manure is an excellent fertilizer, rich in major nutrients (Nitrogen, Phosphorous and Potassium) and organic matter that determine the soil fertility and yield of different crops and vegetables (Yalemtsehay and Fisseha, 2016). It also improves the physical and biological quality of soil besides providing both macro and micro-nutrients to crops and vegetables. The application of bio-slurry also helps in the reduction of dependence on mineral fertilizers (Karki, 1997). *Both Potato and wheat are* highly responsive to N fertilization; it is usually the most limiting essential nutrient for growth and development (Errebhi *et al*., 1998). In addition, Nitrogen plays an important role in the balance between vegetative and reproductive growth for both crops (Alva, 2004; White *et al*., 2007). The studies have shown that N fertilizer applications can increase the dry matter-protein content of wheat and potato tubers (Zelalem *et al*., 2009). Furthermore, most of the time the available Nitrogen in most organic source fertilizers including bio-slurry is high as compared to other nutrients in concentration (Gupta, 2000). Due to this, dry bio-slurry and Nitrogen fertilizers were applied through Nitrogen equivalence. Neither organic manure nor chemical fertilizer alone is not enough to meet the demand for crops in the different cropping systems via soil-plant interaction (Rahman, 2016). Because of this, the study was done with flowing objectives to determine the optimum rate of dried bio-slurry and Nitrogen fertilizer on potato and wheat yield and Physico-chemical properties improvement in northwestern Amhara region Ethiopia

Materials and Methods

Description of Study Area: The experiment was conducted at Yilemana Densa district on farmer's field for three consecutive years 2019/20-2021/22 cropping seasons at Debremewi Keble, West Gojam zone, northwestern Ethiopia, Amhara region. The site is located at 33km east direction from Bahirdar. Geographically the area lies at 11^0 21' 22" N and 37^0 25' 43" E (Figure 1) with a mean altitude of 2304 meters above sea level. It receives a mean annual rainfall of 1421 mm with mean minimum and maximum temperatures of 12.29 and 27.56°C, respectively (Bureau of Agriculture (BOA unpublished). The landforms of the area are characterized by undulating to rolling plateaus, scattered moderate hills, dissected side slopes, and river gorges (Eyasu, 2016). Based on the district office of agriculture, the major land use comprises cultivated land (57%), forest and bushes (2%), grazing land (33%), and others (8%). Major crops, grown in the study area are Maize, Tef, wheat, barley, potato, and field pea which take the lion's share. Soil types in the area are Nitisols (45%), Vertisols (30%) and Luvisols (25%). This on-farm experiment was conducted on Luvic Nitisols which is the most dominant soil in the study area.

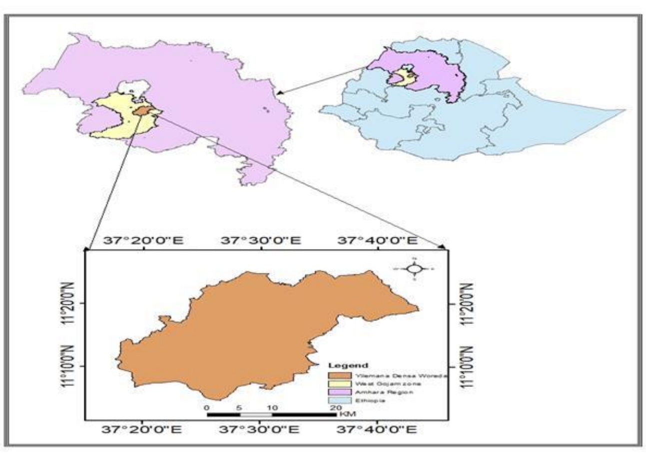

Figure 1. The geographical location of the site

Experimental Design and Experimentation: The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in permanent plots for three years. Treatments include control (without N), recommended N (138N),dry-bio slurry 50% equivalence (5.3tha^{-1}),dry-bio slurry 100% equivalence (10.6 tha^{-1}), dry-bio slurry 75% equivalence (7.95 tha^{-1}), dry-bio slurry 75% equivalence (7.95tha^{-1})+25% recommended N (34.5N), dry-bio slurry 50% equivalence (5.3tha^{-1})+50% recommended N (69N), dry-bio slurry 25% equivalence (2.65tha^{-1}) +75% recommended N (103.5N), dry-bio slurry100% equivalence (10.6tha^{-1})+25% recommended N (34.5N) and dry-bio slurry 100% equivalence (10.6 tha^{-1}) +50% recommended N (69 N). The rates of dry-bio slurry were adjusted based on recommended rate of N equivalency corresponding to its N content. Urea was used as a source of synthetic N whereas TSP was applied as sources of P to all plots. The experiment was carried out under rain-fed conditions. *Gudenie* and Tay varieties were used as test crops for Potato and wheat respectively. Total area of each plot was 13.5 m^2 having 1m space between plots and 1.5m between blocks. Potato was spaced 0.3m between plants and each plot consisted of six rows at 0.75m intervals and the data were collected from the middle four rows. Wheat was planted as a rotated crop in 0.2m row spacing and harvested from middle rows by avoiding four rows as a border. Dry bio-slurry and P_2O_5 were applied during the planting period of time as basal whereas inorganic N for potato was applied in three splits; one-third at planting, one-third about 30 days after planting, and the remaining one-third at the beginning of the flowering. While for wheat recommended NP was applied in all plots except control which only received P_2O_5 to see the residual effect of dry bio-slurry in the next crop. Nitrogen was supplied, in two splits for wheat crop.

Data Collection, Preparation, and Analysis

Dry- Bio Slurry Analysis: Representative composite sample dry-bioslurry was taken from the whole collected dried pit of slurry that was collected from different biogas plants across individual and make them composite for analysis of (pH), organic carbon (OC%), cation exchange capacity (CEC), total Nitrogen (TN%) and available Phosphorus (P) by following laboratory procedures (Sahlemedhin and Taye, 2000).

Table 1. Physico-chemical analysis of dry-bio slurry before incorporation in to the soil in year1and 2 and its average

Dry bio-slurry	Concentration
Year 1	
Dry matter%	11.2
*OC%	27.8
TN%	1.2
Av P ($mgKg^{-1}$)	112.1
pH (H_2O;1:2.5)	7.9
C:N ratio	22.9
CEC ($cmolKg^{-1}$)	59.8
Year 2	
Dry matter%	11.8
OC%	16.3
TN%	1.4
Av P ($mgKg^{-1}$)	91.6
pH (H_2O;1:2.5)	7.7
C:N ratio	11.6
CEC ($cmolKg^{-1}$)	67.4
Average result of Year1 and Year 2	
Dry matter%	11.5
OC%	22.1
TN%	1.3
Av P ($mgKg^{-1}$)	101.9
pH (H_2O;1:2.5)	7.8
C: N ratio	17.3
CEC ($cmolKg^{-1}$)	63.6

**OC%=organic carbon percent, TN%=total Nitrogen percent, C: N=carbon to Nitrogen ratio, CEC = cation exchange capacity, AvP=available Phosphorus, and pH= Power of hydrogen concentration.*

Soil Sampling and Analysis: Before planting, representative soil samples were collected from 0-20 cm depth in a diagonaly zigzag sampling method from 10 spots in the field by using an auger. All samples were mixed together and one composite sample was formed for each site. The composite samples were grounded using a mortar and pistel and passed through a 2 mm sieve for analysis of soil texture, CEC, pH, and available P; whereas a 0.5 mm sieve was used for determining the organic carbon (OC) and total N. Bulk density was determined by the core sampling method.

Determination of the particle size distribution was done by using the hydrometer method (procedures) compiled by Sahlemedhin and Taye (2000) from each site and the sand, silt, and clay percent's were calculated and identified using FAO textural triangle. The major chemical properties of soil such as OC, pH, CEC, total N and available P were analyzed following the compiled laboratory manual of Sahlemedhin and Taye (2000). Soil pH was measured in water at the ratio of 1:2.5 using glass electrode pH meter. The soil OC content was determined following the wet digestion method as outlined by Walkley and Black which involves the digestion of OC in the soil samples with Potassium dichromate ($K_2Cr_2O_7$) in a sulphuric acid solution. AvP was determined by Olsen extracting method. The total N content in the soil samples was determined following the Kjeldahl method. CEC was determined by extracting the soil samples with ammonium acetate ($1NNH_4OAc$) followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution. Percolating the NH_4^+ saturated soil with sodium chloride would displace the ammonium ions adsorbed in the soil and the ammonium liberated from the distillation was titrated using 0.1N NaOH.

Crop Data Collection: Plant height, number of plants per hill, and spike length were measured for both potato and wheat at the maturity stage by taking five randomly selected plants from ground level to the top apex and averaging for a single reading.

The number of tubers per plant was taken by counting tubers from five randomly taken plants at the maturity stage from the middle rows of experimental plots and averaged for a single estimation of the mean value. While thousand seed weight for wheat was taken from each treatment plot by counting of 1000 seeds. Total tuber yield, grain yield, and above-ground biomass were measured atharvesting from the middle plot area by avoid border effects.

Economic Analysis: Because potato is the main crop in this experimenting system the economic analysis was done based on its. Economic analysis was performed to make rational choice among the applied variables in the production of potato. The partial budget and marginal rate of return (MRR) were used for evaluating the change in farming methods that affect partially rather than the whole farm practice and also concerned with planning tool to estimate the profit change within a farm (CIMMYT, 1988). This was computed by adjusting yield downward by a 10% and multiplying it with the local field price (6 Ethiopian ETB per Kg of potato). Dominance analysis was done by listing of treatments in an increasing order of cost and thathas net benefit less than or equal to treatments with the lower costs that vary is dominated (CIMMYT, 1988).

Statistical Analysis: All data were subjected to analysis of variance through GLM procedure by using SAS software program version 9.4 (SAS Institute, 2002). List significant test (LSD) at 0.05

probability level was employed to separate treatments means where significant differences exist (Gomez and Gomez, 1984).

Results and Discussion

Soil Chemical Properties before Planting and after Harvesting of Potato: The analysis result of soil chemical properties before planting in each site and after harvest from each main and residual experimental site were indicated in Table 2, 3 & 4. Soil analysis results before-planting showed that the soil was acidic in reaction with a pH (H_2O 1:2.5) value of 5.1 for Y1S1 and 5.2 for Y2S1, which is within the range of soil pH for potato production Tekalign (1991) (Table 2). The total N, available P, OC, C: N ratio and CEC of the soil for Y1S1 and Y2S1 before planting were 0.16%, 6.9 $mgKg^{-1}$, 1.8%, 11.1^{-} and 33.9 cmol (+) Kg^{-1} and 0.16%, 6.3 $mgKg^{-1}$, 1.5%,9.3 and & 30.3 cmol (+) Kg^{-1}, respectively (Table 2). The total N content of the soil was within the range of medium category according to Tekalign (1991) who classified the range of total N < 0.1, 0.1- 0.15, 0.15-0.25 and > 0.25% as very low, low, medium and high, respectively. Olsen *et al*., (1954) classified available P content of the soil with < 5 $mgKg^{-1}$ as very low, 5 -15 $mgKg^{-1}$ as low, 15 -25 $mgKg^{-1}$ as medium and > 25 $mgKg^{-1}$ as high. Hence the available P of the soil before planting lies under the low range. According to Landon (1991) the soil OC content ranged 1-2, 2-4, and 4-6% are rated as low, medium and high, respectively. Based on these ratings the OC (1.4 & 1.5%), of the experimental fields were in the low. while cation exchange capacity (CEC) ranges of 5-15, 15-25 and 25-40 $cmolKg^{-1}$ are rated as low, medium and high, Hence, the CEC of (33.9 & 30.3 $cmolKg^{-1}$) the experimental site before planting was ranged in high category.

Generally, the nutrient contents of the study site Y2S1 is not good in terms of availability of major plant nutrients beside its nice CEC. On the other hand, on Y2S2 pH, TN, avP, OC, C: N and CEC before planting were 5.5, 0.17%, 6.8ppm, 2.4%, 14.1 and 33.9, respectively. Based on Tekalign (1991) rating the pH value was under moderate while total Nitrogen was medium. Similarly, according to olsen *et al*. (1954) available P was under low while OC and CEC were medium and high respectively landon (1991). The soil fertility status of Y2S2 was better than Y1S1and Y2S1 based on its soil chemical properties. However, the acidity of the soil Y1S1 and Y2S2 may cause sorption of available P. Thus, application of OM like bio-slurry is very essential in order to neutralize soil solution for the availability of nutrients. On the other hands, after harvest all soil chemical properties except soil pH (on Y2S2) were not affected by the application of dry bio-slurry with N equivalence rates (Table3).

The non-significant effects of the applied treatments on these parameters might be due to the slow release of nutrients from dry bio-slurry that was applied during the experimentation period. This might be due to short cropping season of potato cultivation which might not get enough time to decompose the dry bio-slurry to release these nutrients to the soil solution. However, applied dry bio-slurry and N rates had a significant ($P < 0.05$) effect on pH at site Y2S2 after harvest as compared to the control (Table 2). Numerically the highest soil pH content was obtained by the application of 100% and 100%+25%N dry bio-slurry as compared to the control (Table 3). The increment of soil pH in treated plots may be related due to the releasing of basic cations from dry bio-slurry into soil solution that makes substitute of acid cations. These results were in agreement with the investigation of Workineh *et al.,* (2021) who reported that the combined application of compost with inorganic NPSB in maize increased the soil pH content after harvest as compared to control.

Residual Effect of Dry Bio-Slurry on Soil Chemical Properties after Harvesting Of Wheat

The residual effect of dry bio-slurry on selected soil chemical properties was significantly explained at (p<0.05) across sites and years in Table 4. Related to this, addition of 100% (10.6tha^{-1}) dry bio-slurry gives the highest TN% (0.207 and 0.223) on Y1S1 and Y2S2 respectively than the control. This might be due to the gradual releasing of Nitrogen by dry bios-slurry into soil solution beyond its chelating capacity. The finding was in lined with Geremew *et al*., 2019 who found that an application of dry bio-slurry with inorganic fertilizers gives the maximum value of total Nitrogen than control. Similarly, the study conducted by Tsegaye *et al*., 2018 also indicated that an application of 70cm^3 scored the highest (1.36%) TN as compared to the control which gives 0.07%.

On the other hand, OC, C: N and CEC are significantly affected at Y2S1 (Table 4) in addition Y2S2 only CEC is significant at (p<0.05) Table 4. Based on this, numerically the highest value of CEC (34.6), C: N (12.82) & OC% (2.20) was observed by application 50% DBS and 100% DBS with 25%N as compared to control on Y2S1. On Y2S2 the maximum value of CEC (cmolKg^{-1}) 36.06 was obtained in plots that receive 100% DBS with 25%N than control plots. This might be due to the positive effect of applied DBS that enables increasing organic matter and holding capacity of positive cation in the soil exchangeable site. The finding agreed with Zelalem *et al*., 2020 who revealed that an application of $41.3m^{-3}$ liquid bio-slurry with $20.5Kgha^{-1}$ N significantly increased soil organic carbon than untreated plots. The study conducted by Sandeep and Salwinder (2019) also indicated that an application of $10tha^{-1}$ with 50% N $Kgha^{-1}$ significantly increased OC% by scoring the maximum value of 0.67 than the control. Organic amendments significantly enhanced SOC which had a considerable effect on soil microbes and nutrient availability and uptake that may alter the C: N ratio. This makes Nitrogen trapped by organic matter; a phenomenon known as the priming effect (Shahzad *et al*., 2015). The application of the 50% DBS and 100% DBS with 25% N gives the highest CEC at Y2S1 and Y2S2 respectively as compared to the control (Table 1). Such increment in CEC might be due to the application of DBS on soil that makes a negatively charged colloidal site and storehouse of basic cations. The finding agreed with Tamado and Mitiku (2017) who reported that the use of organic FYM and inorganic fertilizers significantly increased CEC over the control.

Table 2.Soil physico-chemical properties before planting

				2019-20 site1 (Y1S1)			
Texture	BD	pH	TN%	Av P (ppm)	CEC (cmol Kg^{-1})	C:N	OC%
SCL	1.22	5.1	0.16	6.9	33.9	8.8	1.4
				2020-21 site1 (Y2S1)			
Texture	BD	pH	TN%	Av P (ppm)	CEC (cmol Kg-1)	C:N	OC%
SCL	1.33	5.2	0.16	6.3	30.3	9.3	1.5
				2020-21 site2 (Y2S2)			
Texture	BD	pH	TN%	Av P (ppm)	CEC (cmol Kg-1)	C:N	OC%
SCL	1.26	5.5	0.17	6.8	33.9	11.8	2.0

***NB:** *SCL= sandy clay loam; BD= bulk density*

Table 3. Main effect of dry bio slurry with Nitrogen on soil chemical properties after harvest of potato

Treatment	pH	TN%	Av P (ppm)	CEC (cmol Kg^{-1})	C:N	OC%
2019-20 site1 (Y1S1)						
Treatment	pH	TN%	Av P (ppm)	CEC (cmol Kg^{-1})	C:N	OC%
Control (0,0)	5.13	0.12	9.3	29.1	11.6	1.4
RN (138NKgha^{-1})	5.11	0.12	7.8	29.9	11.61	1.3
50% DBS (5.3tha^{-1})	5.19	0.13	8.8	29.6	11.59	1.4
100% DBS (10.6tha^{-1})	5.18	0.13	9.6	29.7	11.58	1.5
75%DBS(7.95tha^{-1})	5.19	0.13	10.2	29.1	11.62	1.5
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.22	0.16	10.1	28.3	11.57	1.9
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.10	0.15	9.1	28.7	11.59	1.7
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.18	0.15	7.5	29.2	11.61	1.7
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.12	0.13	12.3	28.3	11.62	1.5
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.15	0.13	11.2	27.6	11.60	1.5
LSD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV%	**1.2**	**14.3**	**22.43**	**3.3**	**0.21**	**14.19**
2020-21 site1 (Y2S1)						
Treatment	pH	TN%	Av P (ppm)	CEC (cmol Kg^{-1})	C:N	OC%
Control (0,0)	5.2	0.15	4.4	27.3	11.59	1.7
RN (138NKgha^{-1})	5.3	0.16	4.3	27.7	11.59	1.8
50% DBS (5.3tha^{-1})	5.3	0.14	6.5	30.8	11.61	1.7
100% DBS (10.6tha^{-1})	5.4	0.15	6.2	27.4	11.60	1.8
75%DBS(7.95tha^{-1})	5.4	0.15	5.8	28.6	11.58	1.7
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.3	0.14	5.4	24.4	11.63	1.7
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.3	0.14	4.5	26.7	11.61	1.6
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.2	0.14	4.6	27.5	11.59	1.7
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.4	0.17	4.4	28.4	11.59	1.9
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.4	0.16	4.4	28.5	11.61	1.9
LSD	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV%	**2.12**	**13.5**	**21.6**	**9.0**	**0.17**	**13.5**
2020-21 site2 (Y2S2)						
Treatment	pH	TN%	Av P (ppm)	CEC (cmol Kg^{-1})	C:N	OC%
Control (0,0)	5.3^{cd}	0.17	12.2	30.6	12.10	2.1
RN (138NKgha^{-1})	$5.4b^{cd}$	0.17	7.1	31.9	11.60	1.9
50% DBS (5.3tha^{-1})	5.5^{abc}	0.18	11.5	30.4	11.60	2.0

100% DBS (10.6tha^{-1})	5.6^{ab}	0.18	9.5	32.1	12.62	2.3
75%DBS(7.95tha^{-1})	5.6^{ab}	0.17	13.2	32.1	12.00	2.0
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.5^{abc}	0.18	13.3	33.5	11.60	2.1
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.5^{abcd}	0.17	13.1	32.6	12.01	2.1
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.3^{d}	0.16	9.5	30.9	11.60	1.9
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.6^{a}	0.18	11.6	31.8	11.80	2.1
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.4^{bcd}	0.17	15.3	33.4	11.60	2.1
LSD	**2.3**	**NS**	**NS**	**NS**	**NS**	**NS**
CV%	**0.22**	**9.9**	**29.1**	**6.1**	**5.9**	**13.8**

**Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$). RNP=percent of recommended Nitrogen and Phosphorus, DBS =dry bio-slurry, pH= power of hydrogen concentration, TN% = total Nitrogen percent, AvP = available Phosphorus, OC% = organic carbon percent, C: N *ratio = carbon to Nitrogen ratio, CEC = cation exchange capacity, OM% = organic matter percent, Y1S1= year one site one, Y2S1= year two site one and Y2S2 = year two site two.*

Table 4. The residual effect of dry bio-slurry on soil chemical properties after wheatharvesting in the potato-wheat cropping system

2020-21 site1 (Y1S1)						
Treatment	pH	TN%	Av P (ppm)	CEC (cmolKg^{-1})	C:N	OC%
Control (0,0)	5.40	0.174bcd	8.97	21.39	9.68	1.69
RN (138NKgha^{-1})	5.40	0.196a	10.12	21.69	10.01	1.95
50% DBS (5.3tha^{-1})	5.40	0.197a	9.25	26.13	9.64	1.88
100% DBS (10.6tha^{-1})	5.38	0.168d	11.04	23.51	11.81	1.98
75%DBS(7.95tha^{-1})	5.40	0.192ab	9.34	25.60	9.42	1.82
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.42	0.172cd	9.07	24.51	11.98	2.06
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.36	0.188abc	10.06	22.09	9.61	1.80
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.35	0.202a	10.08	25.11	10.14	2.04
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.31	0.194ab	10.46	21.81	11.01	2.13
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.37	0.205a	10/76	23.78	9.35	1.89
LSD	NS	0,020	NS	NS	NS	NS
CV%	1.3	6.2	12.7	11.9	14.8	13.3
2021-22 site1 (Y2S1)						
Treatment	pH	TN%	Av P (ppm)	CEC (cmolKg^{-1})	C:N	OC%
Control (0,0)	5.61	0.178	10.15	27.70d	7.61d	1.36b

RN (138NKgha^{-1})	5.53	0.179	10.22	30.52bc	10.31abc	1.85a
50% DBS (5.3tha^{-1})	5.69	0.180	11.56	34.67a	12.25abc	2.20a
100% DBS (10.6tha^{-1})	5.67	0.160	9.85	31.77bc	12.42ab	1.98a
75%DBS(7.95tha^{-1})	5.64	0.194	9.85	31.09bc	9.74cd	1.88a
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.70	0.178	11.76	29.56cd	10.79abc	1.90a
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.62	0.167	10.69	30.63bc	11.38abc	1.90a
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.54	0.186	9.59	30.37bc	10.00bcd	1.86a
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.58	0.172	9.88	31.99bc	12.82a	2.20a
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.44	0.185	10.19	32.91ab	11.78abc	2.17a
LSD	NS	NS	NS	2.60	2.61	0.41
CV%	2.0	6.7	14.4	4.8	14.1	12.6

2021-22 site2 (Y2S2)

Treatment	pH	TN%	Av P (ppm)	CEC (cmolKg^{-1})	C:N	OC%
Control (0,0)	5.51	0.176de	10.03	29.43c	12.03	2.12
RN (138NKgha^{-1})	5.65	0.190bcd	8.76	30.69bc	12.19	2.29
50% DBS (5.3tha^{-1})	5.62	0.186bcde	13.49	35.92 a	12.78	2.38
100% DBS (10.6tha^{-1})	5.62	0.209ab	14.08	33.68ab	11.63	2.43
75%DBS(7.95tha^{-1})	5.76	0.178cde	11.74	34.47a	13.41	2.39
75%DBS+25%N (7.95tha^{-1}+34.5NKgha^{-1})	5.68	0.207ab	12.93	34.81a	12.29	2.54
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	5.57	0.202abc	13.08	35.88a	11.47	2.30
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	5.59	0.164e	11.07	33.27ab	13.52	2.19

100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	5.66	0.223a	11.51	36.06a	10.09	2.24
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	5.66	0.207ab	11.21	35.95a	11.75	2.42
LSD	NS	0.025	NS	3.78	NS	NS
CV%	2.3	7.6	17.8	6.5	10.5	7.3

*Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$). RNP=percent of recommended Nitrogen and Phosphorus, DBS =dry bio-slurry, pH= power of hydrogen concentration, TN% = total Nitrogen percent, AvP = available Phosphorus, OC% = organic carbon percent, C: N ratio = carbon to Nitrogen ratio, CEC = cation exchange capacity, OM% = organic matter percent, Y1S1= year one site one, Y2S1= year two site one and Y2S2 = year two site two.

Main and Residual Effects of Bio-Slurry on Potato and Wheat Yield and Yield Components in the Potato-Wheat Cropping System

Plant Height and Number of Stem per Hill of Potato: Combined analysis of dry bio slurry with N rates significantly ($P < 0.05$) affected plant height (Table5).,The highest values of plant height (52.1 and 48.8cm) was achieved with addition of RNP and 25% DBS with 75% N recpectively as compare control and 50%DBS that gives minimum values (Table 5). Increasing of plant height in response to application of DBS with N fertilizer may be due to the improvement of physico- chemical properties of the soil that resulted increased water absorption and nutrient utilization of the plant.Moreover, application of DBS may deliver balanced micro and macronutrients as well as enhanced availability of plant nutrients,which would help to enhance the metabolic activity of microorganisms and improvement of plant growth.The result was in agreement with the findings of Melkamu *et al*., (2020) who observed longer potato plants when farm yared manure (13.5tha^{-1}) and NPS (245.1Kgha^{-1}) were applied. lt is also in confirmity with the findings of moniruzzaman *et al.,* (2009) who recorded maximum plant height of french bean from the application of 120 Kgha^{-1} N while, the minimum value was recorded from the control treatment. Another study conducted by Muhammad *et al.,* (2017) reflected that the highest value of mung bean plant height (78.08 cm) was recorded from the treatment which received 20:50 NP Kgha^{-1} with inoculation Rhizobium as compared to the lowest value 68 cm on control treatment. On the other hand, a combined analysis of variance revealed that DBS with N fertilizers had not significant effects on the stem numbers of potato per hill (Table 5). This may be due to the parameter more favors genetic makeup, physiological age and tuber seed size rather than a nutrient supplement. This finding was in line with finding of De La, Guillen, & Del Moral (1994) who reported shoot number of potato is mostly determined by the genetic makeup, the physiological age, and the size of potato seed tubers rather than mineral nutrients added in the form of fertilize

Plant height and spike length of wheat: After a year of DBS application, the residual dry bio-slurry significantly affected at ($P < 0.05$) both plant height and spike length of bread wheat (Table 5). The highest values of plant height and spike length of wheat (93.2 and 9.3 cm) were achieved by application of 100% DBS as compared to control, RN and 25% DBS

+75% N plots (Table 5). This might be from the positive effect of DBS for delivering balanced micro and macronutrients as well as enhanced availability of plant nutrients via improving of soil properties. The result agreed with the findings of Balasubramanian, *et al.*, 2016 who observed that the longer plants were in plots which received 75% cow dung with 25 % vermicompost than non-treated plots. the result was also in harmony with Bilkis *et al*., 2017 who recorded maximum plant height (101.5cm) of Boro rice from the application of 5tha^{-1} tricho compost while the minimum value (78.6) was recorded from control treatment .The result related to spike length also much with Pandey *et al*., 2020 who said that an application of 15tha^{-1} bio-gas slurry gives the highest spike length of wheat than checked treatment or control

Table 5. Main and residual effects of dry bio-slurry with equivalence N on growth parameters of potato and wheat over years

Treatments	Potato		Wheat	
	PH (cm)	NSPH	PH (cm)	SL (cm)
Control (0,0)	29.4^{de}	3.3	68.2d	6.7d
RN (138NKgha^{-1})	52.1^{a}	4.8	89.1c	8.5c
50% DBS (5.3tha^{-1})	28.2^{e}	4.4	92.3ab	8.7bc
100% DBS (10.6tha^{-1})	30.4^{de}	4.4	93.2a	9.3a
75%DBS(7.95tha^{-1})	36.6^{cd}	4.5	93.0ab	9.0abc
75%DBS+25%N (7.95tha^{-1} + 34.5 N Kgha^{-1})	41.9^{bc}	4.6	92.1abc	9.0abc
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	42.7^{bc}	3.7	90.2bc	8.9abc
25%DBS+75%N (2.65tha^{-1} + 103.5 N Kgha^{-1})	48.8^{ab}	4.0	90.2bc	8.7bc
100%DBS+25%N (10.6tha^{-1} + 34.5NKgha^{-1})	44.0^{bc}	4.3	92.1ab	9.0abc
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	47.1^{ab}	4.2	90.6abc	9.1ab
LSD	7.9	NS	3.0	0.5
CV%	20.9	30.1	3.6	6.6

**Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$). DBS= dry bio slurry, N= Nitrogen, PH= plant height, NSPH = number of stems per hill, SL=spike length.*

Number of Tubers per Plant and Total Tuber Yield of Potato: The combined analysis result in both years across sites indicates that yield and yield component of potato was significantly differ at ($P<0.05$) due to the effects of DBS with equivalence N (Table 6). The application of 75% N with 25% DBS gives the highest fresh total tuber yield (27.6tha^{-1}) while the lowest fresh tuber yield (8.6tha^{-1}) was observed at control. This might be due to the release of N from dry bio-slurry (DBS) and urea to soil solution. This condition created favorable environment for plant growth and development. Moreover, the application of

DBS could provide both macro and micro nutrients to plants. This study is in line with the findings of Yalemtsehay and Fisseha (2016) who revealed that, the supplying of recommended inorganic fertilizer (100Kg DAP, 50Kg Urea and 50Kg Murate potash per hectare) with 8tha^{-1}bio-slurry gives maximum (266.7 tha^{-1}) yield of cabbage as compare to the lowest (160 tha^{-1}) from the control treatment which gave about 66.7% yield increment due to the combination of both bio-slurry and recommended fertilizers over control. On the other hand the study done by Tsegaye *et al*., (2020) revealed that the lowest value of fresh shoot biomass and marketable yield of potato tuber were achieved from control while the highest values were obtained in plots that recieved both farm yard manure and recommended Nitrogen and Phosphorus.

Similarly, number of tubers per plant (NTPP) was significantly affected at ($P<0.05$) by the application of DBS with equivalence Nitrogen. Maximum value of NTPP was observed through the application of recommended NP followed by 100% DBS+50%N as compare to control treatment (Table 6). Even if the maximum value occurs at Recommended NP, the other dry bio slurry-Nitrogen combination treatments also give better yield advantage than control. This might be due to; the harmonization of organic and inorganic fertilizers for uptake and assimilation of nutrients to potato tubers by increasing the availability of native soil nutrients through higher biological activities. The result coincides with Suh *et al*., (2015) who observed that an application of combined organic and inorganic fertilizers increasing number of tubers per plant in treated plots than control or untreated plots. Another study done by Geremew *et al*., (2019) showed that an addition of dry bio-slurry with recommended Nitrogen Phosphorus increase 40 to 73% number of fruits per plant on tomato.

Grain Yield and Above Ground Biomass of Wheat: Yield and above ground biomass of wheat was significantly differed at ($P<0.05$) (Table 6) by residual effect of dry bio slurry. The application of 100% DBS gives the highest grain yield (3.85tha-1) while the lowest was recorded on control plots. Similarly, addition of 75%DBS gives the highest above ground biomass yield of wheat (9.59tha-1) as compare to control (Table 6). Releasing N from dry bio-slurry (DBS) to soil solution may make favorable for better plant growth and development. Moreover, it could be due to the release of both macro and micro nutrients from the dry bio-slurry in to soil solution that can be used by wheat; Beyond its positive effect on soil improvement by increasing the availability of native (inherit) soil nutrients. The result coincides with Pandey et al., 2020 who reported the supplement of 10 and15 tha-1 of significantly increased grain yield of wheat. Similarly study done by Shahid et al., 2016 revealed that he application of combined use of biogas slurry and chemical fertilizer @ 50% has a good strategy for sustainable crop yield by improving soil health. Beside to this, Mercy et al. (2022) also showed an addition of 100% dry bio-slurry increase stover and stalk yield of maize by 45.5 and 42.2% than control treatments through biological activities.

Table 6. Response of potato and wheat yield parameters for dry bio slurry and equivalence Nitrogen main and residual effect

Treatments	DBS on Potato		Wheat		
	NTPP	TYD tha^{-1}	GY (tha^{-1})	BY (tha^{-1})	1000 SW(g)
Control (0,0)	4.2^{e}	8.6^{d}	1.23d	3.11d	30.1
RN (138NKgha^{-1})	10.9^{a}	26.2^{ab}	3.17c	7.9c	32.4
50% DBS (5.3tha^{-1})	5.0^{de}	12.0^{cd}	3.33bc	8.37bc	32.8
100% DBS (10.6tha^{-1})	6.4^{cd}	13.4^{c}	3.85a	9.52ab	33.6
75%DBS(7.95tha^{-1})	7.3^{bc}	14.9^{c}	3.83a	9.59a	33.9
75%DBS+25%N (7.95tha^{-1} + 34.5 N Kgha^{-1})	6.5^{bcd}	23.0^{b}	3.47abc	9.08ab	33.2
50%DBS+50%N (5.3tha^{-1}+69NKgha^{-1})	6.4^{cd}	24.6^{ab}	3.47abc	8.53abc	32.1
25%DBS+75%N (2.65tha^{-1}+103.5NKgha^{-1})	6.8^{bc}	27.6^{a}	3.28bc	8.43abc	32.6
100%DBS+25%N (10.6tha^{-1}+34.5NKgha^{-1})	7.0^{bc}	25.2^{ab}	3.70ab	9.56a	33.0
100%DBS+50%N (10.6tha^{-1}+69NKgha^{-1})	8.1^{b}	26.8^{a}	3.59abc	9.06abc	32.4
LSD	1.7	3.7	0.5	1.2	NS
CV%	25.6	19.4	15.6	14.8	10.1

Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$). DBS= dry bio-slurry, N= Nitrogen, PH= plant height, NTPP = number of tubers per plant, TYD, = total tuber yield, GY= grain yield, BY= above-ground biomass and SW = seed weight.

Partial Budget Analysis: Net benefits were calculated by current fertilizer (urea) cost of 13.643 ETB Kg^{-1}, cost of DBS Kg^{-1} 0.2ETB, field price of potato was 6 ET Kg^{-1}, and cost of labor per man day in the area is 70 ETB. The marginal rate of returns was used to determine the acceptability of treatments with 100% as acceptable. This economic analysis indicated that most of treatments give high net benefit than control (Table 7). Addition of 50%DBS with 50%RN and 25%DBS with 75%RN gives (128613.6 ETB) and (144460.3 ETB) net benefit with marginal rate of return of 8461.1% and 4486.3% respectively. This indicate that for every 1ETB invested for 50%DBS with 50%RN and 25%DBS with 75%RN in field, farmers can be obtain an additional 84.611 and 44.863 ETB respectively (CIMMYT, 1988). All un-dominated treatment rates could be acceptable for potato producers in the study area. Even if enough un-dominated alternatives treatments have been available as choice for potato cultivation farmers in the study area. Application of 25%DBS with75%RN and 50%DBS and 50%N scored the most promising result 144460.3 and 128613.6 ETB net benefit respectively as compare to other treatments (Table 7). Therefore, the most economical rate for producers with low cost and higher benefit was 25%DBS with 75%RN. As second option farmers can be used 50%DBS with 50%RN for potato production because it also has promising net benefit with marginal rate of return

Table 7. Partial budget and marginal analysis of potato as affected by the application of dry bio-slurry with Nitrogen at Yilemana Densa District.

Treatments (RN +DBS Kgha^{-1})	10% Adjusted tuber Yield tha^{-1}	Total variable Cost ETBha^{-1}	Net Benefits ETBha^{-1}	MRR%
Control	7.74	0	46440	0
50% DBS	10.8	1760	63040	943.2
75%DBS	13.41	2640	77820	1679.6
100% DBS	12.06	3520	68840	D
50%DBS+50%N	22.14	4226.45	128613.6	8461.1
25%DBS+75%N	24.84	4579.675	144460.3	4486.3
100%DBS+25%N	22.68	4753.225	131326.8	D
RNP*	23.58	4932.9	136547.1	D
100%DBS+50%N	24.12	5986.45	138733.6	D
75%DBS+25%N	20.7	10873.23	113326.8	D

**RNP=percent of recommended Nitrogen and Phosphorus in Kg per hectare, DBS=dry bio-slurry in kilogram per hectare, MRR= marginal rate of return; D= is dominated treatments*

Conclusion and Recommendation

Yield and yield components of potato and wheat were significantly affected by main and residual effect of dry bio slurry with Nitrogen fertilizer. Both Potato and wheat was improved in yield and yield components as compared to control. Applied dry bio-slurry with N (Nitrogen) had a positive impact on plant height, number of tubers per plant, total tuber yield, grain yield and above ground biomass of potato and wheat. Addition of Dry bio-slurry with N rate in most treatments gives higher net benefit when compared to control. Among treatments used for this experiment undominated once gave better net benefit response with over 100% marginal rate of return than control in the main crop (potato). Therefore, resource poor producers or small scale farmers can benefited, if they apply these soil improvement rates depending on their convenience. Related to this application 50%DBS with 50% N gives a higher net benefit with 8461.1% marginal return. As a result, small-scale farmers could use it for potato-wheat production system in the area. In a mixed farming system like the Yilemana Densa district livestock production is a component of their livelihood; cattle manure and bio digester plantation is available. Hence, farmers should be encouraged to practice these fertilizers in order to produce vegetables and cereal crops in their back yards and nearest farms. Finally, similar studies should be done in different locations, crops, years and forms of bio-slurry in order to provide more evidence on the current findings and to give a concrete recommendation for crop production and soil health amendment in the study area.

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15. Enhancing Yield and Yield Components of Food Barley (*Hordeum vulgare* L.) through Optimum Nitrogen and Phosphorus Levels in Gazo District, Eastern Amhara, Ethiopia

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Abstract

The correct application of plant nutrients depends on understanding the nutrient requirements of crops and the nutrient supply capacity of the soil. There is no updated nutrient management package for barley production in the rainy season for Gazo district and similar environmental areas in Eastern Amhara. This study was conducted during 2019 and 2020 main cropping seasons, in order to determine the economical optimum rates of urea and TSP (phosphorus) fertilizer for improved food barley. The experiment had 9 treatments. i.e. three levels of nitrogen (46, 69, and 92 Kg N ha^{-1}) and three levels of phosphorous (46, 69, and 92 Kg P_2O_5 ha^{-1}) in a factorial Combination. The design of the experiment was RCBD with three replications per site. The five random sampled plant height, biomass and adjusted grain yield were collected and analysis of variance was conducted using SAS version 9.0. The results indicated that applications of N and P nutrients significantly improved the grain and biomass yield of food barley. There was statistically significant yield difference ($p < 0.05$) between different rates of P and N nutrients. The yield data clearly showed that food barley yield increased with increased N and P rates. The highest biomass yield (5466.2$Kgha^{-1}$) and the highest grain yield (2884.6 $Kgha^{-1}$) were obtained with the application of 92 $Kgha^{-1}$ N and 92 Kgha-1 P_2O_5 which were significantly superior to other treatments. However, the application of 92 Kg of N and 69 Kg of P_2O_5 ha^{-1} gave the maximum economic benefit (53,592.3) with a marginal rate of return (1597.1%) resulting in higher net benefits than the other treatments. So, an application of 92 Kg N and 69 Kg P_2O_5 ha^{-1} can be recommended for food barley production in the study area and similar agro-ecologies.

Keywords*: biomass, food barley, grain yield, plant nutrient*

Introduction

Maintaining soil fertility and increasing crop yields in agricultural productivity is a key challenge for Ethiopia's agriculture. Plants use nutrients in different ways, and each plant has different nutrient requirements (Gruhn, *et al.,* 2000). The way plants use nutrients can greatly affect the overall performance and yield of the plant (Hutchings et al., 2003). For farmers who want to maximize crop yields and reduce input costs, it is important to understand the nutritional needs of crops. The application of balanced fertilizers is an important practice that can increase crop yields on existing arable land and increase the nutrient requirements of crops according to their physiological needs and expected yields (Ryan, 2008).The correct application of plant nutrients depends on the understanding of the nutrient requirements of crops and the nutrient supply capacity of the soil (Dagne Chimedessa, 2016). S*oils in the highlands of Ethiopia usually have low levels of essential plant nutrients, especially low availability of nitrogen and it is the major constraint to cereal crop production (Assefa* et al.*,.2017).*

Nitrogen is an essential nutrient for crops and is consumed by the roots of crops during the growing season. It is an extremely important phytonutrient and its supply can be controlled through proper management practices Due to its mountainous terrain and an intensive agricultural system based on small grains, Ethiopia is considered to be one of the countries most affected by soil fertility depletion. The national average nutrient balance is estimated to be -41 Kg N, -6 Kg P, and -26 Kg K ha^{-1} $year^{-1}$, which are the highest nutrient consumption rates (Smaling *et al*., 1992). However, the soil nutrient balance between different crops, agricultural systems, and agro-ecological zones may vary greatly (Sommer *et al*., 2014). Therefore, restoring soil fertility and increasing crop yields is a key priority for researchers, by applying balanced nutrients for each crop and site-specific fertilization recommendations and improved management practices to increase crop yields and maintain soil sustainability.

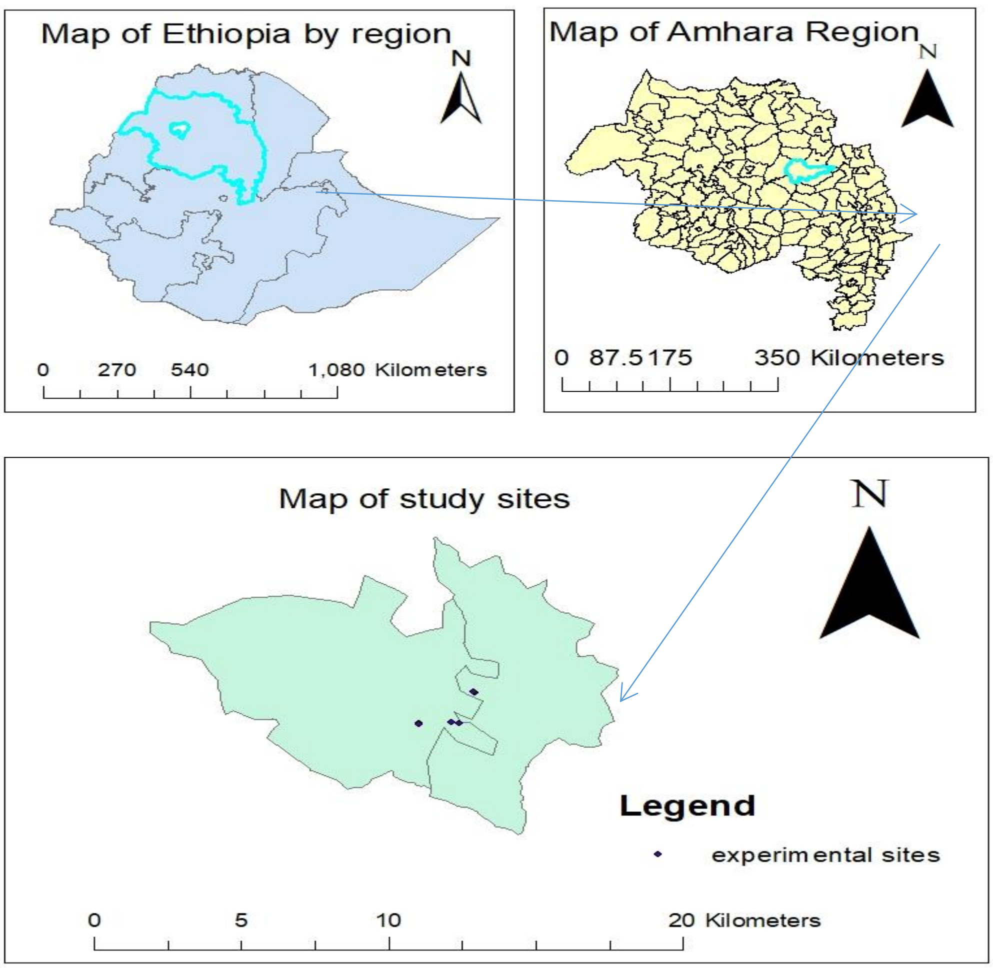
Barely is one of the most important crops for the production of food, feed, and income for many small farmers in the Ethiopian highlands (Bayeh and Berhane, 2011). In Ethiopia, barley is the fifth most stable crop after teff, maize, wheat, and sorghum (CSA, 2019/20). It is a cool-season crop adapted to high altitudes. It grows in a wide range of agro-climatic areas under various production systems. But it grows in Ethiopia, mainly between 2200 and 3000 masl (Asmare *et al*., 1998). Since barley is an early harvest crop, it is a popular hunger nemesis during the lean season in some parts of the country (Bayeh and Berhane, 2011). It also has the advantage of dual crop production. Ethiopia is the second-largest producer of barley (Hordeum vulgare L.) in Africa, only surpassed by Morocco, and represents approximately 25% of the total barley production on the African continent (FAO, 2014). The land area allocated for barley production in 2015/16 was approximately 1 million hectares, with an average national productivity of 25 qt/ha (more than 23 million qt of production) and more than 4 million smallholder farmers producing it (CSA, 2016). It also covers a considerable amount of cultivated land in the Amhara region (321,515.21 ha) and in the north Wollo zone (35,222.50 ha), with 23.3 and 17.4 qt/ha productivity, respectively (CSA, 2019/20).

Nutrient management (agronomic rtial) for barley began in the late 1960s (Tamene *et al*., 2017). However, in Ethiopia, especially in the Amhara region, food barley was produced with little or no fertilizer application, mainly in eroded areas and steep slopes (Getachew *et al*., 2001). Therefore, its national average yield (2.11 t ha^{-1}) is very low (Daniel Tadese and Beyene Derso, 2019). Among the factors that affect barley production, low soil fertility and low input (fertilizer) application are the major constraints in Ethiopia (Getachew *et al*., 2001; Gete *et al*., 2010). Nitrogen and phosphorus are the nutrients that most limit barely performance (Wakene *et al*., 2014). However, there is no updated nutrient management package for barley production in the rainy season for the study area. So, this research was designed to determine optimum nitrogen and phosphorus rates for barley in the Gazo district of the North Wollow Zone.

Objective: To determine the economic optimum rates of nitrogen and phosphorus nutrients for food barley

Materials and Methods

Description of the Study Area: The experiment was conducted in the main cropping season of 2019 and 2020 at different locations (farmers field) in Gazo district. The district is located at 781 km North of Addis Ababa, the capital city of Ethiopia 282 km far from Bahir Dar (the capital city of Amhara region) and 79 km North of Woldia town. Geographically the experimental site (the district) is located at 11°50‘N latitude and 39°08‘E longitude with an elevation of 3298 meters above sea level. The district is characterized by mixed farming (that is crop and livestock production). The most commonly produced crops are Food barley (*Hordeum vulgare* L.) Potato (*Solanum tuberosum* L.), Wheat (*Triticumaestivum* L.) and pulse crops like Faba bean (*Vicia fabae* L.), and Lentil (*Lens culinaris*).



Figiure 1. Location map of the study district

Experimental procedures: The experimental sites were prepared using standard cultivation practices before planting. Trial fields were plowed using oxen-drawn implements by farmers as usual. The experiment includes three levels of nitrogen (46, 69, and 92 $Kgha^{-1}$) and three levels of phosphorous (46, 69, and 92 $Kgha^{-1}$ P_2O_5) with a factorial Combination similar with below

Treatments used were: -

1. Control
2. (46,46) N, P_2O_5
3. (46,69) N, P_2O_5
4. (46,92) N, P_2O_5
5. (69,46) N, P_2O_5
6. (69,69) N, P_2O_5
7. (69,92) N, P_2O_5
8. (92,46) N, P_2O_5
9. (92,69) N, P_2O_5
10. (92,92) N, P_2O_5

Treatment sequencing was randomized using Randomized Complete Block Design (RCBD) on a plot size of 3m×3m ($9m^2$) with three replicates for each site and three sites per location. The spaces between plots and blocks were 0.5m and 1m, respectively and spacing between rows was 20cm. Sowing was done in the first week of July. Phosphorus was applied as triple superphosphate and nitrogen was also applied in the form of Urea. Nitrogen was applied half at planting and the other half was applied just after weeding with the presence of moisture while, Phosphorous was applied immediately before planting. Recommended agronomic practices such as weeding, cultivation, and fertilizer application (except negative control) were carried out uniformly during the growing season of the barley.

Methods of Data Collection

Growth, Yield and Yield Components

Plant Height (cm): Heights of five randomly selected plants from the ground level to the tip of the spike grown in net plot area using meter were measured at maturity stage and the average values were used for further analysis.

Biomass Yield (t/ha)**:** It was determined by weighing the total air-dried aboveground biomass harvested from net plot areas rows and biomass yield per plot and per hectare was recorded.

Grain Yield (t/ha): Weight of grains were separated from the straw by threshing and seeds/grains were cleaned, weighed, and adjusted to a moisture content of 12.5% using grain moisture tester and grain yield per plot and per hectare was recorded (the collected plant-based data were changed plot and hectare bases).

Straw Yield (t/ha); It was estimated as the difference between biomass yield and grain yield.

Soil Sample Collection and Analysis: Surface soil samples were collected randomly in a zigzag pattern before sowing from the 0 to 20 cm deep plough layer using an auger in the entire experimental field of each site and composited. The sampled soil was air-dried; ground using pestle and mortar to pass through a 2-mm sieve. Soil pH was determined in a1:2.5 soil to water suspension following the procedure outlined by Sertsu and Bekele (2000). Soil organic carbon content was determined by the wet digestion method using the Walkley and Black procedure (Nelson and Sommers, 1982) and total N using Kjeldhal's method (Bremner and Mulvaney, 1982). The available phosphorus was determined following the Olsen procedure (Olsen,.1954).

Data Analysis: The effect of the different treatments was statistically analyzed through Analysis of Variance (ANOVA) for Randomized Complete Block Design (RCBD) using SAS Version 9.0 computer software. Comparisons among means were done using Duncan's Multiple Range Test (DMRT) to determine the specific significant differences among treatment means.

Partial Budget Analysis: The partial budget was calculated to compare gain and losses between one treatment and another. It was considered the analysis of gross benefit (GB), total variable cost (TVC), the net benefit (NB) and finally the analysis of the marginal rate of return (MRR).

$GB = (YA \times PA) + (YB \times PB)$

TVC = (The sum of all the costs which vary between treatments

NB = GB-TVC

Where, GB= Gross benefit, TVC=Total variable cost, NB=Net benefit, MRR=Marginal rate of return, YA=Grain yield, PA =Price per unit kilogram, YB=Straw yield, PB =Price of straw per unit kilogram.

Variable Costs (ETB/Kg): Nitrogen (Urea) 14 ETB/Kg, Phosphorus (TSP) fertilizer 12ETB/Kg, costs were the price of the fertilize in the time of the experiment conducted.

The farmer gate price of straw and grain was 2.5 ETB per Kg and 20 ETB per Kg, respectively.

Results and Discussion

Physico-Chemical Properties of the Soil: The experimental site analysis results indicated that soil particle size distribution of the experimental sites was in proportions of 29.2% of sand, 40.8% of silt, and 30% of clay with the textural class of clay loam. According to Tekalign (1991) the pH of the study site (5.5) was moderately acidic. The analysis result shows that the mean available P content was 13.93 ppm (Table 1.) which is rated as medium to adequate according to (Cottenie, 1980). The mean total nitrogen content was 0.28 % which is ranged at high according to Tekalign's (1991) classification. Similarly, organic carbon content was 1.54% which is ranged at a low level according to Tekalign's (1991) classification.

Table 4. Result of soil parameters taken at planting.

pH*	OC	T.N (%)	Avail P(ppm)	%clay	%silt	%sand
				30	40.8	29.2
5.5	1.54	0.28	13.93	Clay loam		

***** pH=Power of Hydrogen; OM=Organic matter; OC= Organic carbon T.N= Total nitrogen; P Avail P =Phosphorus;

Yield and yield components of Barley

Effects of Nitrogen and Phosphorus rates on Plant height: The combined statistical analysis showed that the interactions between nitrogen and phosphorous rates were found to be significant ($P < 0.05$) to plant height. Plant height was significantly affected by the application of different rates of nitrogen and phosphorous, as shown in (Table 2.0) ($P < 0.05$). The highest plant height (98.3) was obtained from applications of 92Kgha^{-1}N and 69 Kgha^{-1}P_2O_5 and the lowest plant height (85.8 cm) was observed in plots receiving 46Kgha^{-1}N and 92Kgha^{-1}P_2O_5 (Table 2.). Such an increase in plant height in conjunction with an increase in NP rate could be attributed to the action of nitrogen, which increases vegetative growth when other growth factors are present. The application of N and P also resulted in an increase in plant height as its rate increased from 46 Kgha^{-1}to 92 Kgha^{-1} for both fertilizer sources.

These findings are comparable to those of (Rashid *et al*., 2007: Melesse,2007), who indicated that plant height was linearly increased with increasing levels of N and P fertilization and found that increasing nitrogen fertilizer rates improved barley plant height. This research result also similar with the Deshbhratar (2010) found that the role of macronutrients, primarily nitrogen (N) and phosphorus (P), in chlorophyll formation, and nutrient movement within the plant boost vegetative growth, resulting in an increase in plant height. The plant heights obtained from all NP fertilized plots were significantly higher than the blanket. This is because the applications of NP fertilizers have great roles in plant growth. Many studies revealed significant influence of N on plant height as it plays a vital role in vegetative growth of plants. This result is in line with the report of Wakene et al. (2014) who stated that plant height of barely increased with increasing rates of NP from 0/0 to 69/30 Kgha^{-1}.

Table 2. Effect of N and P rate on Plant Height (cm) of food barley combined over years (2019 and 2020)

N rate ($Kgha^{-1}$)	P rate ($Kgha^{-1}$)		
	46	*69*	*92*
46	87.4^{cd}	86.0^{d}	85.8^{d}
69	88.3^{cd}	89.4^{bcd}	94.1^{abc}
92)	89.9^{bcd}	98.347^{a}	96.2^{ab}
Sig.	**		
CV (%)	10.4		

Effects of Nitrogen and Phosphorus Rates on Biomass Yield of Barley

According to the combined statistical analysis (Table.3) above ground biomass yield of barely were statistically significant ($p < 0.05$) between the different rates of nitrogen and phosphorus. The highest biomass yield ($5466.2Kgha^{-1}$) was obtained from the application of $92Kgha^{-1}$ N & $92Kgha^{-1}$ P_2O_5 which was significantly superior over other treatments (but not with 92-69). The lowest biomass yield ($2969.5Kgha^{-1}$) was obtained from the plots which received $46Kgha^{-1}$ N & $46Kgha^{-1}$ P_2O_5 (Table3.). The highest biomass yield obtained with the application of higher rate of NP was due to cumulative increase measured in different yield contributing characters (plant height and thousand seed weight). An increase in biomass yield might have been because of overall improvement in the vegetative growth of the plant due to the application of higher rate of NP.

This result was in conformity with Mesfin Kassa and Zemach Sorsa (2015) who reported that Total above ground dry mass of barely increased significantly when NP rates increased up to 69 $Kgha^{-1}$ N with combination of $30Kgha^{-1}$ P_2O_5. These finding shows that the increment of NP rates from $46Kgha^{-1}$ to 92 $Kgha^{-1}$ the biomass yield were increased by 54%. Similarly, Melesse (2007) reported that wheat cultivars produced higher straw yields in response to the combined application of higher rates of N and P. The output of this research was in contrast with the study WakeTigre *et al*., (2014) who stated that interaction effect of NP was not significant on biomass yield of barley.

Table 3. Effect of N and P rate on Biomass (Kgha^{-1}) of food barley combined over years

N rate (Kgha^{-1})	P rate (Kg ha^{-1})		
	46	*69*	*92*
46	2969.5^{d}	2978.6^{d}	3696.5^{bcd}
69	3569.7^{bc}	4096.3^{bc}	4398.6^{b}
92)	4410.7^{b}	5420.3^{a}	5466.2^{a}
Sig.	**		
CV (%)	26.10		

Effects of N and P rates on Barely Grain Yield: Grain yield is the result of many complex morphological and physiological processes occurring during the growth and development of crops (Khan et al., 2008). The combined analysis (Table 4.) indicates that the grain yield of barley was significantly ($p \leq 0.05$) respond to different nitrogen and phosphorus rates. Accordingly, the highest grain yield (2884.6 Kgha^{-1}) of barely were recorded with the application of 92Kgha^{-1} N & 92Kgha^{-1} P_2O_5 without statistical significance difference with the application of 92 Kgha^{-1} N& 69 Kgha^{-1} P_2O_5(table 4.). Similar result was observed (Sebnie, and Mengesha, 2018) they reported that there is significant increase in grain yield of sorghum when supplied with higher rates of NP fertilizer. The linearly increment of grain yield of barley with the increment of NP is due to Synergistic effects of the nutrient. This result is in agreement with the finding of Benedicta *et al*., (2016) who stated that increasing N rates significantly increased grain and total dry biomass production, whereas the application of inorganic P fertilizer increased the efficient utilization of inorganic N fertilizer by the plants in grain yield.

In the other hand application of 46 Kgha^{-1} N with 46 Kgha^{-1} P_2O_5 resulted in lowest grain yield (1560.1 Kgha^{-1}) (Table 4.) than others. As observed in table 1 below when N/P rate increased from 46Kgha^{-1}/ 46Kgha^{-1} to 92Kgha^{-1}/92 Kgha^{-1} except 69 Kgha^{-1}/92 Kgha^{-1} the grain yield of barely was increase with the mean of 11.7% (table 4.). This result is contrast with Tewold *et al*., (2020) reported that the increase in the levels of N/P from the control (0/0 N/P) to 46 Kg N ha^{-1} along with 10 Kg P ha^{-1}, increased the grain yield of tef but decreased with further increase in applied N and P fertilizer. As indicated in the result, grain yield increasing when the Nitrogen and Phosphorus rates increase. Generally, these findings show that the application of nitrogen and phosphorus fertilizer increases the yield of food Barley. This may be because the plants may have been able to take up sufficient amounts of nitrogen and phosporous throughout the major growth stages due to enhanced availability of the nutrient in the root zone over the growth stages.

This result was in agreement with the finding of Taye Bekele *et al.,* (1996) and Woldeyesus Sinebo (2005) reported that the yield of barley increase with increasing N/P fertilizer application at many locations. Wake Tigre *et al*., (2014), who reported N and P fertilizers, are very important nutrients in limiting the growth and development of crops which has direct effect on productivity of barely.

Table 4. Effect of N and P rate on Grain yield (Kgha^{-1}) of food barley combined over years

	P rate (Kgha^{-1})		
N rate	46	*69*	*92*
46	1560.1^{d}	1564.7^{d}	1720.1^{d}
69	1788.8^{cd}	2168.1^{bc}	2144.3^{bc}
92)	2241.0^{b}	2733.7^{a}	2884.6^{a}
Sig.	**		
CV (%)	27.50		

Partial Budget Analysis: Partial budget analysis was done to investigate the economic feasibility of the treatments with acceptable marginal rate of return by assuming total variable cost (TVC), which was a cost incurred due to the application of inputs (fertilizes). In doing the partial budget analysis, the average grain yield was adjusted to 10% downwards to reflect the difference between the experimental plot yield and the yield expect from farmers with the same treatment. The average open market price (ETB Kg^{-1}) for barley and the prices of nitrogen and phosphorus containing fertilizers were used for analysis. For a treatment to be considered a worthwhile option to farmers, MRR should be 100% (CIMMYT, 1988), which is suggested to be realistic. Accordingly, when all the comparable treatments showed more than 100% MRR value in the experiment, treatment having the highest NB value can be taken as an economically profitable and recommendable to the users. The current result revealed that 46-46, 69-46, 46-92, 69-69, 69-92, 92-69 Kgha^{-1} N and P_2O_5 respectively gave more than 100% MRR value than others which were more than the minimum acceptable value (Table 5). Therefore, from those treatments which had MRR value more than

100%, the treatment that received 92 Kg N ha^{-1} and 69 Kg P_2O_5 ha^{-1} (Table 5.) gave the highest net benefit (NB) which can be taken as economically acceptable and recommendable for the users.

Table 5. Partial budget analysis of mean grain and straw yields of Barley in Gazo district

Trt	AGY	GYP	ASY	SYP	TR	TVC	NB	D	MRR (%)
0,0	631.8	20	1614..3	2.5	16671.8	0	14171.8		0
46, 46	1404.09	20	3077.8	2.5	34763.2	5500	28553.2		2187.2
46, 69	1408.23	20	2576.6	2.5	34866.5	6190	28521.5	D	-488.9
69, 46	1548.09	20	3501.9	2.5	39278.9	6310	32968.9		753.1
46, 92	1609.92	20	2834.4	2.5	40230.2	6880	33350.2		317.7
69, 69	1951.29	20	3817.9	2.5	48242.5	7000	41242.5		6576.9
92, 46	1929.87	20	3926.2	2.5	48494.3	7120	41374.3		23.1
69, 92	2016.9	20	4210.9	2.5	50262.1	7690	42572.1		998.2
92, 69	2460.33	20	4387.1	2.5	61402.3	7810	53592.3		1597.1
92, 92	2596.14	20	4725.1	2.5	64221.8	8500	55721.8	D	-25.1

Where:- All costs are expressed in ETB; AGY=Adjusted grain yield (Kgha-1), GYP=Grain yield price Kg-1 (ETB), ASY=Adjusted straw yield (Kgha-1), SYP=Straw yield priceKg-1 (ETB), TR=Total revenue (ETB), TVC=Total variable cost, NB=Net benefit (ETB); DA = Dominance Analysis, MRR=Marginal rate of return

Conclusion and Recommendation

The result of this study clearly indicates that using a different NP rate of fertilizer had significant effect on plant height, above ground biomass and grain yield of barely. Application of the different rate of nitrogen and phosphorous was affected grain yield and yield related traits. Therefore, from this finding, it is possible to conclude that 92 N $Kgha^{-1}$ with 69 $Kgha^{-1}$ phosphorous rate was better in terms of attainable yield and net benefit as compared to the blanket recommendation and other treatment combinations. Therefore, based on the above data most parameters and grain yield were statically significantly affected by interaction effect of nitrogen and phosphorous.

Based on the partial budget analysis and biological data, applications of 92 Kg N and 69 Kg P_2O_5 ha^{-1} gave the highest net benefit 53592.3 $ETBha^{-1}$ with MRR of 1597.1%.and 2460.33 Kg grain yield ha^{-1}. Therefore, application of 92 Kg N and 69 Kg P_2O_5 ha^{-1} can be recommended for Food barley production in the study area and similar agro-ecologies.

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II) Agricultural Water Management

1. Effects of Micro-Dosing Fertilizer and Irrigation Water under Drip Irrigation for Onion (*Allium cepa* L.) in Northern Ethiopia

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Abstract

*The most significant variables affecting bulb yield in Ethiopia's irrigated agriculture onion production systems are irrigation water amount and irrigated fertilizer application rates. Due to significant water savings and improved water and fertilizer use efficiencies, drip irrigation has gradually been adopted in North Ethiopia for onion farming. However, it is still unknown what the best irrigation water and fertilizer application rates should be for drip-irrigated onions. Field experiments were conducted in 2019/2020 and 2020/2021 to investigate the effects of irrigation water and fertilizer application rates on onion production and productivity. The trial consisted of four recommended Nitrogen (N) and Phosphorus (P_2O_5) micro dosing fertilizer rates (F_1-125%, F_2-100%, F_3-75%, and F_4-50%) and three irrigation water levels (I_1-100%, I_2-75%, and I_3-50%). The interaction of water amount and micro-dosing fertilizer rates significantly ($P \leq 0.01$) affected onion yield, yield-related components, and water productivity. Based on the combined analysis of variances, the yield, yield-related components, and water productivity had a highly significant (($P \leq 0.01$)) influence on the interaction effects of irrigation water amount and micro-*dosing fertilizer *rates. Onion production and water use efficiency (WUE) increased significantly with higher irrigation water amount and micro-dosing fertilizer application rate. However, applying less than 100% of the irrigation water amount was not beneficial to the above parameters. In the two-season study, the maximum onion yields of 39.22 tha^{-1} were obtained in F_1I_1, which had a WUE of 8.20 Kgm^{-3}. Considering all growth, yield, and yield-related components, the combination of 172.5 N & 86.25 P_2O_5 $Kgha^{-1}$ micro dosing fertilizer rate and 100% irrigation water amount per irrigation was the best drip-irrigated onion pattern. These findings may provide a scientific basis for drip-irrigated onion irrigation water and micro dosing fertilizer management in northern Ethiopia.*

Keywords: Drip irrigation, Micro dose fertilizer, Nitrogen, Onion Phosphorus, Water,

Introduction

Onion is one of the most important cash crops grown by small-scale farmers, allowing them to enhance their income and consequently improve their standard of living (Dessalegn and Aklilu, 2003). It is commonly used as a condiment to enhance food flavor (Enchalew *et al.*, 2016). Almost all spicy foods include onion as a vital element for culinary purposes (Halvorson *et al.*, 2008). It is regarded as an essential component of the human diet (Raber *et al.*, 2022, Metrani *et al.*, 2020). It is high in various minerals and vitamins (Raemaekers, 2001, Shahrajabian *et al.*, 2020). It is also very significant in Ethiopian cuisine for the creation of traditional meals. Some plant parts are edible; the bulbs and lower section of the stem are the most commonly used as a flavoring or vegetable in stews (Griffiths *et al.*, 2002). According to CSA data (2018/19), the production and productivity of onions in Ethiopia and the Amhara region are predicted to be 9.3 and 13.1 tha^{-1}, respectively.

Micro-dosing fertilizer application increases fertilizer efficiency and yields while lowering input and investment costs (Blessing *et al.*, 2017, Kubheka, 2015, Nouri *et al.*, 2017). This is an efficient method of fertilizer application since the fertilizer is administered next to the plants, ensuring a high rate of uptake (Sime and Aune, 2020, Vandamme *et al.*, 2018). When compared to traditional application methods, it was found to enhance yields by 44% to 120% and farmers' revenue by 52% to 134% (Tabo *et al.*, 2011, Fatondji *et al.*, 2011). It is especially significant in irrigated agriculture, where huge amounts of fertilizer must be applied to meet crop requirements while preventing leaching loss (Ibrahim *et al.*, 2016, De Baerdemaeker, 2013). According to Sathya *et al.*, (2008), the appropriate combination of water and nutrients is the key to enhancing produce both quantity and quality.

Efficient water utilization in any irrigation system is becoming increasingly crucial, particularly in arid and semiarid regions where water is scarce (Deng *et al.*, 2006, Girma and Jemal, 2015). Drip irrigation is one of the most efficient irrigation technology methods that will allow the application of light and the way of watering plants regularly and with a volume of water approaching plant consumptive use (Fereres *et al.*, 2003, El-Hendawy *et al.*, 2008, Eranki *et al.*, 2017). Many countries' experience has shown that switching from surface irrigation to drip systems can reduce water use by 30% to 60% while increasing crop yields at the same time (Kifle *et al.*, 2022). Several researchers (Deshmukh and

Hardaha, 2014, El-Hendawy *et al.,* 2008, Feleafel and Mirdad, 2013, Vijayakumar *et al.,* 2010) have observed that drip irrigation offers various advantages. It saves water and labor by reducing traditional losses such as deep percolation, runoff, and soil water evaporation; fertilizer application is more exact and uniform; and nutrient uptake by roots is improved (Munir *et al.,* 2021, Munir *et al.,* 2019, Bravdo and Proebsting, 1993). It is not a replacement for other tried and true watering systems. The objectives of this study were to identify the suitable micro-dosing fertilizer application and the amount of water to be irrigated, as well as to analyze the effect of water and fertilizer amount interaction under drip irrigation for onion production.

Materials and Methods

Description of Study Area: The experiment was conducted in two consecutive irrigation seasons (2019/20 and 2020/2021) at the Aybra main research site in sekota woreda. The location is at latitude 12.72568 and longitude 39.02004 in the northeastern Amhara region (Figure 1). The elevation of the study area is 1929 m.a.s.l. The long-term average precipitation in the area is receives 689.6 mm/year, with peak precipitation from July to the end of August, accounting for more than 90% of the annual precipitation (Figure 2). Average daily temperatures range from 12.6 $^{o}{}_{C}$ to 27.4 $^{o}{}_{C}$, with an average temperature of 20$°_{C}$ (Figure 2).

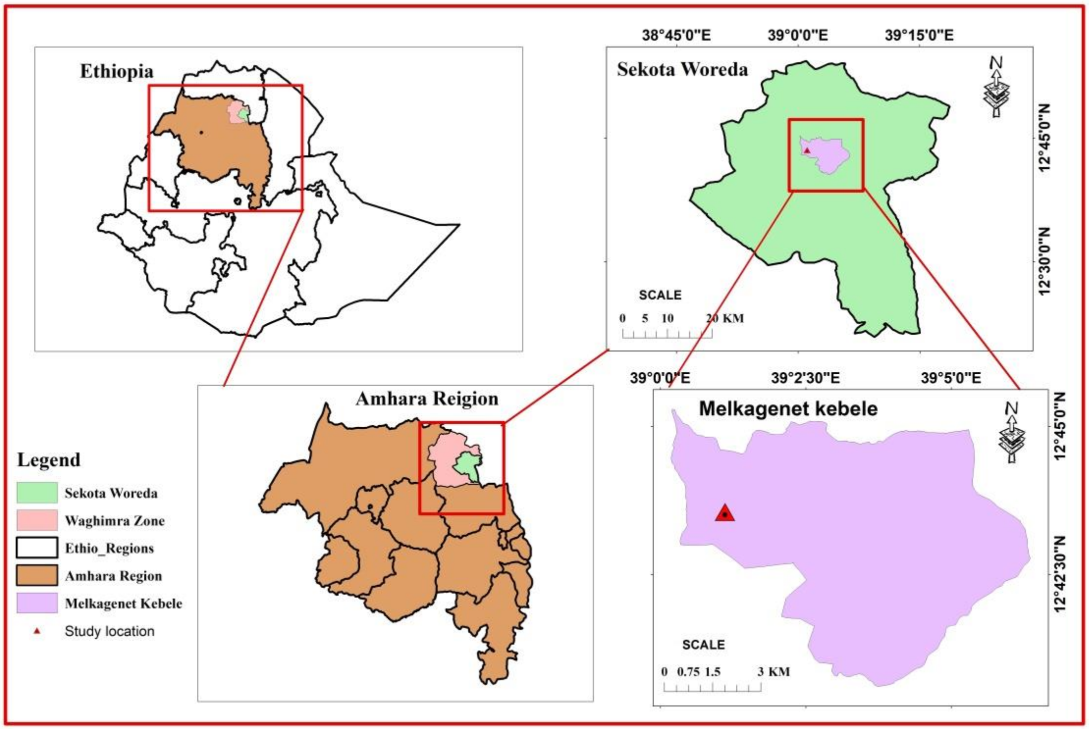

Figure 1. Location map of study area

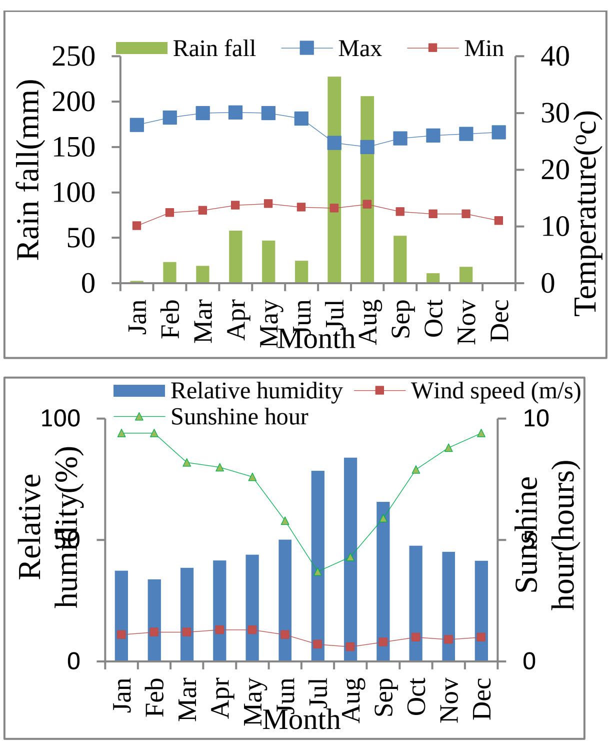

Figure 2. Weather conditions for the crop growing season (2019/20-2020/21)

Experimental Design: The experimental design was a randomized completed block design with three replications in a factorial arrangement. The experiment was designed with twelve treatments that included two factors such as three irrigation levels (100, 75, and 50% , refered as I_1, I_2, & I_3 respectively) and four micro-dosing fertilizer application levels like 172.5Nitrogen (N) & 86.25 Phosphorus (P_2O_5), 138 N & 69 P_2O_5, 103.5 N & 51.75 P_2O_5, and 69 N & 34.5 P_2O_5 Kgha^{-1} or 125, 100, 75, & 50% of recommended Nitrogen and Phosphorus fertilizer rates, refered as F_1, F_2, F_3, & F_4 respectively.

To achieve equal stands of onion seedlings, each treatment receives an equivalent amount of irrigation water up to seedling establishment. Irrigation water was applied at three-day intervals. The drip irrigation system was employed to apply the necessary amount of irrigation water. Each irrigated treatment consisted of six 3 m long lateral lines. The emitters on the lateral line were spaced 20 cm apart. For 45 days, the Bombay red onion variety was raised in a nursery bed. The transplanting to field plots of 1.2 m x 3 m row planting with 20 cm x 10 cm spacing (between rows in the lateral line x plants in rows) was used respectively. Treatment Combination:

T1 = F_1-172.5 N & 86.25 P_2O_5 Kgha^{-1} + I_1-100% ETc with drip irrigation system
T2 = F_1-172.5 N & 86.25 P_2O_5 Kgha^{-1} + I_2-75% ETc with drip irrigation system
T3 = F_1-172.5 N & 86.25 P_2O_5 Kgha^{-1} + I_3-50% ETc with drip irrigation system
T4 = F_2-138 N & 69 P_2O_5 Kgha^{-1} + I_1-100% ETc with drip irrigation system
T5 = F_2-138 N & 69 P_2O_5 Kgha^{-1} + I_2-75% ETc with drip irrigation system
T6 = F_2-138 N & 69 P_2O_5 Kgha^{-1} + I_3-50% ETc with drip irrigation system
T7 = F_3-103.5 N & 51.75 P_2O_5 Kgha^{-1} + I_1-100% ETc with drip irrigation system
T8 = F_3-103.5 N & 51.75 P_2O_5 Kgha^{-1} + I_2-75% ETc with drip irrigation system
T9 = F_3-103.5 N & 51.75 P_2O_5 Kgha^{-1} + I_3-50% ETc with drip irrigation system
T10 = F_4-69 N & 34.5 P_2O_5 Kgha^{-1} + I_1-100% ETc with drip irrigation system
T11 = F_4-69 N & 34.5 P_2O_5 Kgha^{-1} + I_2-75% ETc with drip irrigation system
T12 = F_4-69 N & 34.5 P_2O_5 Kgha^{-1} + I_3-50% ETc with drip irrigation system

Water productivity (WP) was calculated as the ratio of crop production per unit area in terms of onion bulb to crop evapo-transpiration (mm), and was expressed in kilograms of onion bulb per m^3 of used water (Kahlon, 2017, Wakchaure *et al.,* 2018).

$$WP(Kg/m^3) = \frac{\text{Total yield of onion bulb}}{\text{Water delivered up to harvesting}}$$

Water is applied directly to the plot, with no consideration for conveyance or distribution losses (Bhalage *et al.,* 2015, Battikhi and Abu-Hammad, 1994), and an irrigation application efficiency of 90% is assumed.

Data Collection and Analysis: Meteorological data, including rainfall, temperature, humidity, wind speed, and sunshin hour, were obtained from the closest climatic stations to the experimental sites. Soil texture, bulk density (Bd), pH, organic matter (OM), total Nitrogen (TN), available Phosphorus (AP), electrical conductivity of soil (ECe), field capacity (FC), permanent wilting point (PWP), and moisture content were all determined. Data on onion plant growth and yield parameters were measured and recorded in real time from a net plot area of 2.4 m^2 using the standard protocols outlined below.

Plant Height **(cm):** At physiological maturity, the plant heights of five randomly selected plants were measured from the soil surface to the top of the tallest leaf, and the mean values were computed for further investigation (Nigatu, 2016, Nigatu *et al.*, 2018).

Bulb Weight **(g):** The weight of five randomly selected bulbs was weighted per plot using sensitive balance, and the mean bulb weights were computed and used for further analysis (Tekle, 2015).

Bulb Diameter **(cm):** The average bulb sizes atharvest from each plot were determined by measuring the diameters of five randomly selected bulbs with a caliper (Ketema *et al.*, 2013).

Total Bulb Yield **(t ha^{-1}):** Total onion yield was calculated by adding marketable and unmarketable bulb yields (Tekle, 2015). The weight of such bulbs obtained from the net plot area was measured in kilograms using a sensitive balance and expressed as tonnes per hectare.

Data Analysis: The collected onion growth and yield parameters were subjected to analysis of variance (ANOVA) using R 4.2.2 software. Based on the variance analysis results, the mean separation was done using Least Significant Difference (LSD) at 1% level of significance (Gomez and Gomez, 1984).

Partial Budget Analysis (PBA): A partial budget analysis was used to determine the economic benefit of just using fertilizer, drip material, and irrigation water for onion production. It can be used to compare the effect of a technology change on farm costs and returns. This budgeting method is referred to as partial since it does not include all production costs, but only those that alter or vary between the farmer's existing production methods and the planned on-farm production practices (CIMMYT, 1988).

The following data were used for PBA: Variable costs (NP fertilizers and water depths which vary between treatments). Onion yield per hectare resulting from each treatment and it was adjusted by 10% decrement for each treatment. Farm price - prices of harvested onion which is currently about 15 Ethiopian ETB per Kg. The fixed costs included: drip materials, land preparation, planting, weeding, seed, chemical and harvesting costs which have invested equally for each treatment.

The main components of PBA, such as total revenue, net income, change in variable cost, change in return, and marginal cost of return should be greater than 100%, were calculated, and a decision on which fertilizer rate and water depth is more profitable for farmers was made based on net income and marginal rate of return.

Results and Discussions

Soil Characteristics: The water content of the soil at field capacity and permanent wilting point are determined to be 26.22 and 14.85%, respectively (Table 1). The volumetric water content at field capacity ranged from 26.59 to 25.86%. The top 0 to 30 cm had a higher average water content of field capacity of 26.59%, whereas the subsurface soil 30 to 60 cm had a lower field capacity value of 25.86%. The moisture content of the soil at the permanent wilting point varied with depth, reaching as high as 16.10% at the top (0 to 30 cm) and as low as 13.61% at the subsurface soil (30 to 60 cm).

Total available moisture (TAW), which is the depth of water that a crop can absorb through its root system of onion, is directly related to the difference in field capacity and the permanent wilting threshold. The total available soil moisture was 113.7 mmm^{-1} of soil depth, with a maximum infiltration rate of 40 mmh^{-1}. As a result, topsoil contains the highest concentration of TAW, while subsurface soil contains smaller quantities (Table 1).

Table 1 Soil properties

Soil parameters	Soil depth (cm)		
	0 - 30	30 - 60	Average
Bd (gcm^{-3})	1.38	1.57	1.47
OM (%)	1.12	1.01	1.06
pH	6.60	6.70	6.65
TN (%)	0.07	0.06	0.06
AP (ppm)	13.56	18.13	15.85
ECe (ds/m)	0.12	0.22	0.17
Water content			
FC (vol. %)	26.59	25.86	26.22
PWP (vol. %)	16.10	13.61	14.85
TAW (mm/m)	104.90	122.50	113.70
Irrigation water			
pH		6.90	
ECw (ds/m)		0.22	

***(*)** ECw = Electrical conductivity of water*

The interaction effects of irrigation water amount and NP fertilizers were highly significantly ($P \leq 0.01$) affected by plant height, bulb diameter, bulb weight, yield, and water productivity, according to the combined analysis of variances (Table 2).

Table 2. Mean square effects of water and fertilizer amounts on onion yield and related indicators

Source of variation	DF	Mean square values				
		PH	BD	BW	YL	WP
Frequency (F)	3	139.12**	0.39**	243.01**	318.28**	33.87**
Irrigation (I)	2	196.77**	0.23**	10.51**	692.80**	40.10**
F*I	6	21.80**	0.22**	48.62**	23.72**	5.51**
Error	22	0.66	0.01	0.60	0.54	0.07

***(*)** F = Fertilizer, I = Irrigation water, PH = Plant height, BD = Bulb diameter, BW = Bulb weight, YL = Yield.*

Plant Height: The interactions among fertilizer and irrigation water amounthave a significant impact on onion plant height. The plant's height varied between 59.68 and 48.16 cm (Figure 3). The treatments with the highest and lowest plant heights received the recommended fertilizer applications of F_1 with I_1 and F_4 with I_3, respectively.

The addition of nutrients essential for onion plant growth and development resulted in an increase in plant height (Nigatu *et al.,* 2018). However, applying F_4, F_3, and F_2 of the recommended fertilizer rate and obtaining I_3 resulted in plant heights that were lower than the average.

The increase in plant height with proper soil moisture application is due to water's role in sustaining the turgid pressure of the plant cells, which is the primary cause of growth (Enchalew *et al.,* 2016). On the other hand, shortening of plant height under decreased soil moisture stress may be connected with stomata closure to conserve soil moisture evaporation, which leads to reduced CO_2 and nutrient uptake.

As a result, photosynthesis and other metabolic reactions are hampered, ultimately inhibiting plant growth (Vaux Jr and Pruitt, 1983). This study's findings are consistent with the findings of El-Noemani *et al.,* (2009), who discovered that soil water supply is directly proportional to plant height growth.

Bulb Diameter: The amount of irrigation water and fertilizer applied had an effect on the size of onion bulb diameters. The I_1 and F_1 fertilizer applications produced the largest bulb diameter, which was much greater than all other treatments (Figure 3). The treatment that received I_3 and F_3 of the required fertilizer delivery had the smallest bulb diameter. Water deficits of up to I_3 resulted in bulb diameters less than the mean value of 6.04 cm.

This finding is consistent with those of Tolossa (2021), Bhasker *et al.*, (2018), Enchalew *et al.*,(2016), who found that a high amount of soil moisture application leads to a high photosynthetic area, plant height, and a large number of leaves, resulting in a large bulb diameter.

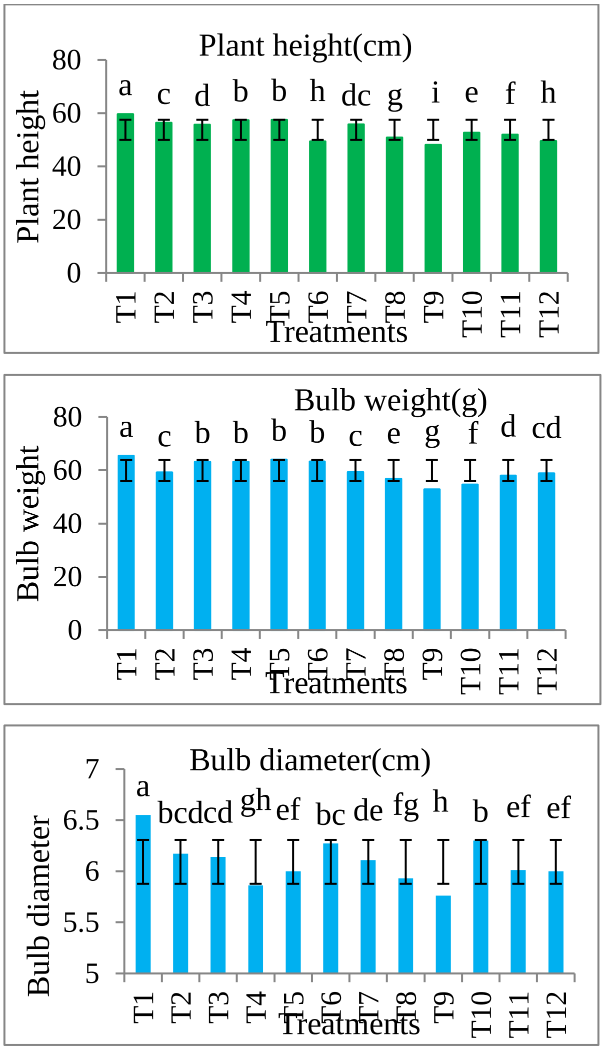

Figure 3. Comparison of the yield related components in different irrigation and fertilizer management (in each column, averages with the same letter, do nothave a significant difference at the 1% level based on the LSD).

Yield and Water Productivity of Onion: The two years combined analysis revealed that applying F_1 of the recommended Nitrogen and Phosphorus from among the applied fertilizer rates increased onion bulb yield (Figure 4). Because onion is a shallow-rooted crop, it requires a high Nitrogen amount during the growing season (Halvorson *et al.*, 2008); nevertheless, if the amount of N provided lowers, the plant P need decreases as well. The water intake and nutrient absorption in plants are highly associated. When plant roots absorb water, dissolved nutrients are transported to the onion's root surface. On the other side, water intake is reduced, as is nutrient supply to the root system.

The use of I_1 at three-day irrigation intervals resulted in a better yield than the applications of I_2 and I_3, although there is no significant difference between the deficit treatments. Though the soil moisture status was not monitored during irrigation, the moisture difference between the two water depths used is not significant. As a result, applying these two treatments should result in about comparable soil moisture conditions.

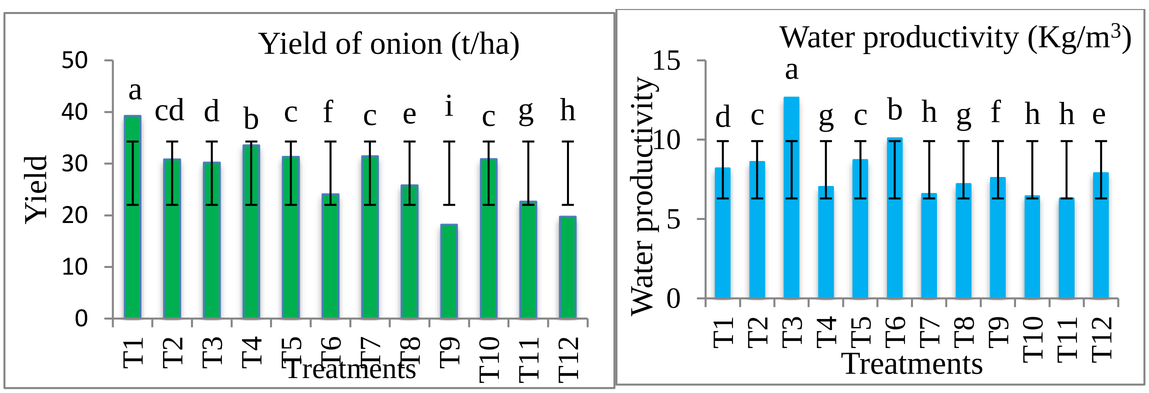

Figure 4. Comparison of the bulb yield, water productivity under different irrigation and fertilizer management.

The interaction effects between irrigation and fertilizer treatments had significant ($P \leq 0.05$) influence on water productivity of onion (Figure 4). The water productivity, however, decreased with increasing depth of irrigations, whereas fertilizer application significantly increased water productivity at all irrigation levels. Thus, F_1 recommended fertilizer rate with I_1 decreased water productivity of onion as compared to the application of F_1 fertilizer rate with I_3.

A significant depth of water was saved 50% in the application of F_1 recommended micro dosing fertilizer rate with I_3 irrigation water amounts. The result showed that a significant depth of water (2382.25 m^3ha^{-1}) was saved without significant yield reduction in 50% deficit as compared to full demand irrigation (Table 3). Hence diverting this saved water to another irrigable land to increase the area irrigated may compensate for decreases in crop yields. This could be used to irrigate an additional land of 0.99 ha with a yield benefit of 29.85 tha^{-1} of onion crop production.

The experimental results from field trials confirmed that with deficit irrigation strategies and appropriate micro dosing fertilizer application it is possible to increase crop productivity, WUE and save water for irrigation. This could be especially important for areas facing drought and limited water resources for agricultural production of onion. Similar findings reported that the photosynthesis could be improved by optimizing water and fertilizer applications (Zhang *et al.,* 2017, Wang *et al.,* 2014) and biomass yield (Mon *et al.,* 2016), can ultimately increase crop yield and crop water and fertilizer use efficiency (Albrizio *et al.,* 2010, Dar *et al.,* 2017, Li *et al.,* 2010). Mansouri-Far *et al.,* (2010) reported that irrigation water can be conserved and yield maintained (as a sensitive crop to drought stress) under water-limited conditions.

Table 3. Amount of water saved and yield reduction of onion

Treatments	Irrigation water (m^3ha^{-1})	Tuber yield (tha^{-1})	Water saved (%)	Yield reduction (%)
T1	4776.00	37.18	0	0
T2	3582.50	31.59	25	15.03
T3	2393.75	30.15	50	18.90
T4	4776.00	35.12	0	0
T5	3582.50	28.64	25	18.45
T6	2393.75	23.41	50	33.34
T7	4776.00	28.88	0	0
T8	3582.50	27.13	25	6.06
T9	2393.75	18.93	50	34.45
T10	4776.00	27.01	0	0
T11	3582.50	21.15	25	21.69
T12	2393.75	18.96	50	29.80

Partial Budget Analysis: Partial budget analysis was done for combined result on the bulb yield of onion. The result showed that, I_1 irrigation water application at 3 days with F_1 recommended Nitrogen and Phosphorus fertilizers rate has the highest net benefit, this could be considered profitable only if its rate of return is higher than 100% (CIMMYT, 1988). But as Table 4 below shows its marginal rate of return (MRR) is 42.92 % which is much less than 100%. Other rates such as (F_1:I_2); (F_1:I_3); (F_2:I_2); (F_2:I_3); (F_3:I_2); (F_3:I_3); (F_4:I_1); (F_4:I_2); (F_4:I_3) micro dosing fertilizer rates and irrigation water depths 3 days interval is marked as dominated. Because as their costs increased against F_3 recommended fertilizer rate with I_1 irrigation water at 3 days interval, their net benefit did not increase, therefore all these rates are rejected. Hence, the partial budget analysis result revealed that F_3 recommended micro dosing fertilizer rate with I_1 irrigation water depth at 3 days interval applications gave a maximum benefit for farmers over the other rates (Table 4).

Table 4: Partial budget analysis for the effects of irrigation and fertilizer on onion yield (tha^{-1}).

Treatments	Unadjusted yield	Adjusted yield	Total benefit	Cost that vary	Net benefit	MRR (%)
T1	39.22	35.298	529470	8789	520681	42.92
T2	30.82	27.738	416070	8789	407281	D
T3	30.22	27.198	407970	8789	399181	D
T4	33.51	30.159	452385	7034	445351	14.92
T5	31.31	28.179	422685	7034	415651	D
T6	24.08	21.672	325080	7034	318046	D
T7	31.44	28.296	424440	5279	419161	3.38
T8	25.81	23.229	348435	5279	343156	D
T9	18.20	16.38	245700	5279	240421	D
T10	30.87	27.783	416745	3524	413221	D
T11	22.62	20.358	305370	3524	301846	D
T12	19.70	17.73	265950	3524	262426	D

Conclusions and Recommendation

The effects of Nitrogen and Phosphorus and irrigation levels were assessed by examining their effects on yield and yield components of onion. Irrigation water amount and micro dosing fertilizer rate is the major limiting factor for increased production and productivity of onion. Therefore, the combined interaction of irrigation water amount and micro dosing fertilizer rate application practices under drip irrigation is a suitable and most efficient practice for sustainable production in water scarce area like Wag-himra, Ethiopia. The maximum bulb diameter, bulb weight, plant height, and total bulb yield associated with application of F_1 recommended micro dosing fertilizer rate with I_1 irrigation water amount. However, to maximize water productivity of onions, F_1 recommended micro dosing fertilizer rate and I_3 water deficit irrigation should be used together. As a result of the partial budget analysis, the F_1, F_2, and F_3 recommended micro dosing fertilizer rates combined with the irrigation water amount given at I_1 applications sound economically and can be recommended for onion production in the studied area and similar agro-ecologies.

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2. Response of Wheat (*Triticum aestivum* L.) to Nutrient Omission under Irrigation in Sekota District of Amhara Region, Ethiopia

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Abstract

The Ethiopian governmenthas imported multinutrient fertilizers and distributed them to farmers recently. Hence, the selection of appropriate types of fertilizer based on the actual limiting plant nutrients is timely to give policy direction to import only fertilizers that could limit crop yield. A field study was carried out to identify the yield-limiting plant nutrients for wheat under irrigation at two farmer's fields in the Woleh irrigation scheme of the Amhara region of Ethiopia in the 2022 irrigation season. A total of nine treatments, including control, NPSKZnB (all), NPSKZn (all-B), NPSKB (all-Zn), NPKZnB (all-S), NPSZnB (all-K), NKSZnB (all-P), PKSZnB (all-N), and RNP (all-KSZnB), were arranged in a randomized complete block design (RCRD) with three replications. The Kekeba wheat variety was used as a test crop. The collected grain and biomass yield data were analized by SAS software following the procedure. The analysis of result showed that the application of fertilizer had a significant effect on wheat grain yield. The highest grain yield (4443.5 Kgha^{-1}) was obtained from NPKZnB (All-S). While the lowest grain yield was obtained from the control and Nitrogen omission. There was no significant difference between and among the treatments except Control, All-N, and All-P. The grain yield was reduced by 3181.6 Kgha^{-1} when N was omitted and 1817.8 Kgha^{-1} when P was omitted over All-S (NPKZnB). This clearly showed that Nitrogen and Phosphorous are the most yield-limiting plant nutrients for wheat under irrigation in the study area. Therefore, the government should give emphasis to Nitrogen- and Phosphorous-containing fertilizers to increase wheat yield.

Key words: Nitrogen, nutrient, omission, Phosphorous, wheat,

Introduction

Wheat is the second most important staple crop in Ethiopia and a major pillar for food security (CIMMYT, 2022). It is one of the strategic crops for food security and the supply of raw materials for the agro-processing industry (Endalew *et al.,* 2020). Due to rapid population growth, massive urbanization and increasing disposable incomes, the consumption of refined wheat breads is rapidly increasing and displacing traditional meals (Noort *et al.,* 2022). But average wheat productivity in Ethiopia is much lower than the world average and far below research yield (CSA 2021). To meet the demand of ever-increasing population growth the yield of wheat should be increased by double.

Irrigated agriculture is a prime sector to ensure food security, alleviate poverty, and promote economic development in the developing world (Fraiture *et al.,* 2010). It is one of the best options to increase production. Nowadays, irrigated wheat farming has expanded into all regions of Ethiopia. It is a new scenario fo Mer wheat under irrigation and it needs some sort of improvement in agronomic, breeding and irrigation efficiency. Even the areas of wheat irrigation farming should also be the lowland and large-scale irrigation schemes.

Mineral fertilizers are considered to be one of the most reliable and readily available inputs for increasing crop yields. They have a positive impact on the yield and yield components of the crop. The type of fertilizer, time of application and amount to apply are the major constraints for production. Understanding the principles of soil fertility is vital to efficient nutrient management, crop production, as well as environmental protection (Pagani *et al.*, 2013). Therefore, identification of limiting plant nutrients in the soil, and providing them to the crops is very important and possible to increase production and reduce costs and environmental pollution. Hence, targeting that liming nutrient is a means of solution to boost the production and productivity of the crops.

In the last 10 years, fertilizer use in Ethiopia has changed from urea and DAP to a multi-nutrient approach. But research conducted on omission trials shows that Nitrogen and Phosphorous are the most yield-limiting nutrients (Amare *et al.,* 2021; Alemayehu *et al.*, 2022). Similarly, Teshome *et al.,* (2022) and Getinet *et al.,* (2022) reported that Nitrogen is the most yield-limiting nutrient for sorghum and maize yields. There is limited research on omission trials under irrigation of wheat in the study areas. Therefore, the objective of the study was to identify the yield-limiting nutrients for wheat under irrigation in the Woleh irrigation scheme.

Materials and Methods

Study Area: The study was conducted at the Woleh irrigation scheme in two farmer fields (Figuer. 1). The scheme has an area of 137.75 ha. In the irrigation season, farmers produce horticultural crops and cereals like Tef wheat and maize. Currently, wheat is the major irrigation crop in all irrigation schemes in the country, including the Woleh irrigation scheme.

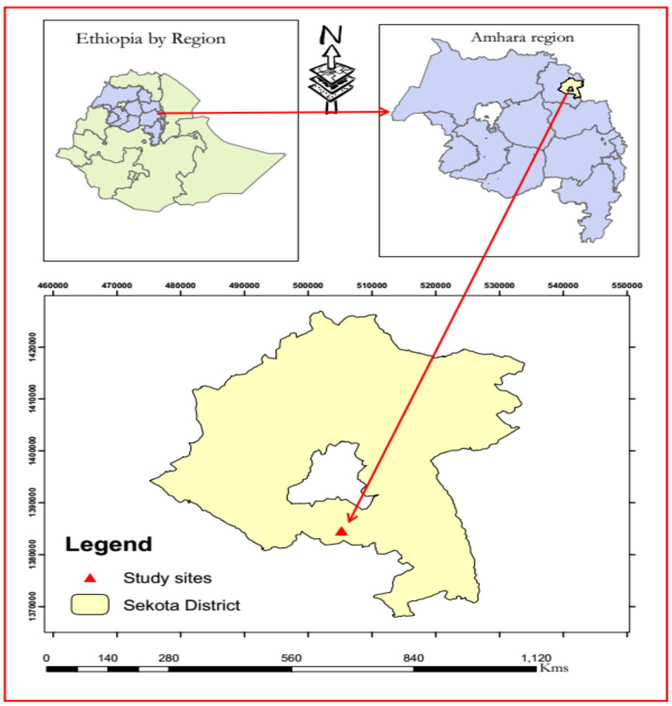

Figure 1 study area map

Experimental Design: The experiment consisted of ten treatments, as described in Table 1 and arranged in a randomized complete block design (RCBD) with three replications. The test crop wheat Kekeba variety was used and planted on a 2.4m x 6 m plot size. The spacing between rows, plots and blocks were 0.2, 0.5 and 1m respectively. The source of nutrients were triple super phosphate for Phosphorous, urea for Nitrogen, *Muriate of potash* for

Potassium, borax for Boron, Zn-EDTA (granular) for Zinc and $MgSO_4$ for Sulphur applied at planting except urea. Urea was applied half at planting and half at 35 days after planting.

Table 1 Treatment setup

Treatment	Treatment description	Applied nutrient $Kgha^{-1}$					
		N	P	S	K	Zn	B
Control	No fertilizer	0	0	0	0	0	0
NPSKZnB (All)	All nutrients	138	92	10	30	5	2
NPSKZn (All-B)	Boron omitted to see the effect of B	138	92	10	30	5	0
NPSKB (All-Zn)	Zinc omitted to see the effect of Zn	138	92	10	30	0	2
NPKZnB (All-S)	Sulphur omitted to see the effect of S	138	92	0	30	5	2
NPSZnB (All-K)	Potassium omitted to see the effect of K	138	92	10	0	5	2
NKSZnB (All-P)	Phosphorous omitted to see the effect of P	138	0	10	30	5	2
PKSZnB (All- N)	Nitrogen omitted to see the effect of N	0	92	10	30	5	2
RNP (All-KSZnB)	Recommended NP alone	138	92	0	0	0	0

Data Collection

Grain and Biomass Yield: Grain yield was determined by harvesting and threshing from the middle centeral rows of the netharvest area of each plot and expressed in $Kgha^{-1}$. The grain yield was determined after adjusting the moisture level of the grain to 12.5%. Above-ground biomass yields were recorded by weighing all the plants collected from the center rows of each plot that were harvested close to the ground surface and expressed in $Kgha^{-1}$.

Soil Sampling and Analysis: Before planting, ten subsamples of soil from the plough depth (0–20 cm) of the experimental site were collected and made into a composite. The composite soil was subjected to air-dried ground by a pestle and mortar and sieved with the required sieve size (0.5 and 2mm). The prepared soil samples were subjected to analysis for total Nitrogen (TN), soil organic carbon (SOC), available Phosphorus (P), available Boron (B), and Zinc (Zn). TN and SOC were determined by the combustion method and P, B, and Zn were analyzed with the method Mehlich 3 (Mehlich, 1984).

Statistical Analysis: The analysis of variance (ANOVA) was performed using R soft wear (R 4.2.2). There were significant treatment effects; the mean separation was done by least significance difference (LSD) at the $p<0.05$ level of significance.

Results and Discussion

Soil Nutrient Status of the Experimental Site: The results of the soil analysis shows that the soil pH of the experimental sites was 8. The soil organic carbon content of the soil from farms 1 and 2 was 0.7 and 1.2%, respectively. The average total Nitrogen was 0.1, and the available Phosphorous of the experimental sites ranged from 10.9 to 16.7 ppm. The available Zinc of the respective sites was also 0.7 to 1.8 ppm, and the available Boron of the experimental site was 0.5 ppm (Table 2).

The pH of the soil was moderately alkaline (Jones, 2003), implying that wheat yield could be maximized by fertilizer applications. Hence, alkalinity could not be considered a yield-limiting factor. The SOC contents of the study site were very low; it required activities that increased SOC to increase crop yield and improve the use efficacy of the fertilizer, as the critical value is 2% (Murphy, 2014). This SOC showed that the yield of wheat is impractical without the application of mineral fertilizer. The lab report also showed that the total Nitrogen content of the experimental site was 0.1 (poor) because the critical values of soil TN are above 0.2%; this amount of soil Nitrogen limits the productivity of wheat (Landon, 1991). In addition to the application of NP-containing fertilizer, the application of other soil management practices that increase total Nitrogen content in the soil should be prevalent. The available P of the experimental site was above the critical value, which was 16.7. This amount of Phosphorus is ideal for the wheat crop (Zamuner *et al.*, 2006) when other factors like soil pH and moisture are in good condition. The range of available Zn content at the experimental site was 0.7 to 1.8, grouped from low to high levels for wheat crops (Cakmak, 2008).

Table 2. Soil nutrient satus of experimental farms

Sites	TN*	SOC	Av. P	Zn	B
	%	%	ppm	ppm	ppm
Farm 1	0.1	0.7	10.9	0.7	0.5
Farm 2	0.1	1.2	16.7	1.8	0.5

**TN: total Nitrogen, SOC: soil organic carbon, Av.P: available phosphorous, Zn: Zinc and B: Boron.*

Effects of Applied Nutrients on Grain Yield of Wheat: The analysis revealed that the application of various fertilizer nutrient sources significantly influenced the grain yields of wheat (Table 3). The highest grain yield was achieved with the application of NPKZnB (-S) nutrients, while the lowest yields were observed in the Nitrogen-omitted, control, and Phosphorous-omitted treatments. The grain yield from the positive control (All-KSZnB) or RNP was comparable to other nutrient-applied treatments, as indicated in Fig. 2. Interestingly, the yield from RNP fertilizer was superior to all treatments except the NPKZnB (-S) treatment. By applying NPKZnB (-S) nutrients, the yield increased by 150.9 Kgha^{-1} compared to the RNP received treatment, but statistically at par. This showed that Nitrogen and Phosphorous are the major yield-limiting nutrients. The highest grain yield reduction occurred when Nitrogen was omitted, followed by Phosphorous omission. Omitting other nutrients (Boron, Zinc, Sulphur, and Potassium) did not significantly affect the grain yield compared to the recommended NP, underscoring the crucial role of Nitrogen and Phosphorous in wheat yield. This suggested that the application of other nutrients without the application of N and P together has less effect on wheat grain yield. Hence, optimizing Nitrogen and Phosphorous in fertilizer formulations can be key to maximizing wheat yields. The results align with previous studies by Abebe *et al.*, (2020), Rawal *et al.*, (2018), Singh (2018), and Teshome *et al*., (2023), who reported that the highest yield reduction was observed from the N-omitted treatment. Similarly, a study conducted on maize and tef in north-western Ethiopia by Amare *et al.*, (2022), Getinet *et al.*, (2022), and Alemayehu *et al.*, (2022) confirmed that Nitrogen and Phosphorous are the most yield-limiting plant nutrients among others. The yield reduction due to Nitrogen and Phosphorous omission is associated with the fertility status of the study farmland soils (Table 2), and it confirms that nutrient depletion is a common and serious problem in Ethiopian soils (Smaling *et al.*, 1997; FAO, 2001; Sanchez, 2010).

Table 3. Grain yield of wheat (Kgha^{-1}) as affected by different nutrient sources

Treatment	Farm 1	Farm 2	Combined
Control	915.6^{c}	1490.8^{d}	1203.2^{c}
NPSKZnB (all)	3665^{a}	4266.7^{b}	3965.8^{a}
NPSKZn (-B)	3459.3^{a}	4418.9^{b}	3939.1^{a}
NPSKB (-Zn)	3718.9^{a}	4516.7^{b}	4117.8^{a}
NPKZnB (-S)	3442.5^{a}	5444.4^{a}	4443.5^{a}
NPSZnB (-K)	3393.3^{a}	4308.3^{b}	3850.8^{a}
NKSZnB (-P)	1561.1^{b}	3698.3^{c}	2629.7^{b}
PKSZnB (- N)	765.6^{c}	1608.3^{d}	1261.9^{c}
RNP	3436.1^{a}	5149.2^{a}	4292.6^{a}
LSD (0.05)	353.65	349.42	869.25
CV (%)	7.35	5.21	22.62

Effects of Omitted Nutrients of Nitrogen and Phosphorous on Yield of Wheat Over the Applied RNP: The result showed that the omission of Nitrogen (N) and Phosphorus (P), as well as no fertilizer treatment, resulted in the highest reduction in grain yield over the recommended Nitrogen and Phosphorus (NP) treatment (Figure 2). Omitting Nitrogen and Phosphorus resulted in a significant reduction in grain yield, with a 70.60% and 38.74% decrease over the recommended NP. This showed that Nitrogen is the primary yield-limiting nutrient, as omitting it resulted in the highest reduction in grain yield. Phosphorus follows Nitrogen as the second most crucial nutrient affecting yield. The current study aligns with findings from other studies, providing additional support for the importance of Nitrogen and Phosphorus in different crop yields. Buah *et al.,* (2012) and Xu *et al.,* (2016) reported that Nitrogen and Phosphorous omission resulted in a 47% and 27% reduction in sorghum and rice grain yield, respectively. Similarly, Aliyu *et al.,* (2021) reported that about 59 and 56% of maize grain yield reductions were due to the omission of Nitrogen and Phosphorus, respectively. Alemayehu *et al.,* (2022) also reported that about 81.6% and 80.7% of the tef yield reduction was due to omissions N and P. Similarly, Getahun *et al.*, (2022) reported that the highest yield reductions of 34% and 27% were obtained from Nitrogen and Phosphorous-omitted treatments. A study conducted by Amare *et al.*, (2022) confirms that the maximum yield penalty was recorded from the omission of N, followed by P, and they also reported that the omission of other nutrients did not show a high yield reduction. Similarly, Desta *et al.*, (2022), who did an experiment on sorghum crops, found that the highest yield reduction was due to N omission, followed by P nutrients. Likewise, Teshome *et al.*, (2022) reported that the omission of the N nutrient significantly reduced the yield of sorghum.

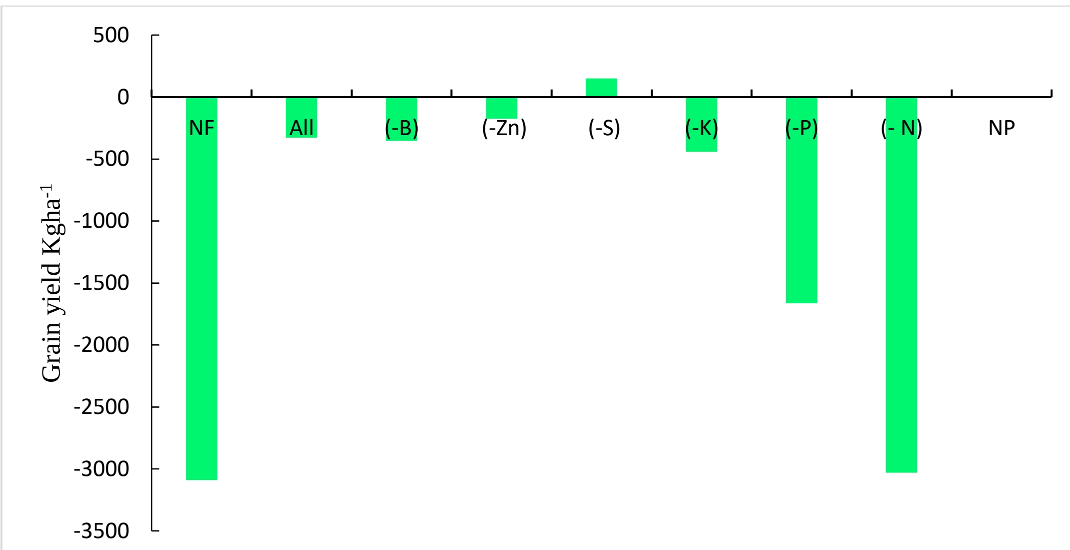

Figure 2 effects of omited nutrient on yield of wheat

Effects of Applied Nutrients on Biomass Yield of Wheat: The applied nutrienthad a significant effect on the biomass yield of wheat (Figure 4). The highest biomass yield was observed in treatments where NPKZnB-S (Nitrogen, Phosphorus, Potassium, Zinc, and Boron) and NP (Nitrogen and Phosphorus) were applied. The lowest biomass yield was recorded in the control and Nitrogen-omitted treatments. Omitting Sulphur, Zinc, Boron, and Potassium did nothave a significant effect on the biomass yield of wheat. However, omitting Nitrogen and Phosphorus had a notable impact, resulting in a lower biomass yield. Among the applied nutrients, Nitrogen and Phosphorus were identified as more critical for biomass yield. There was no significant difference in biomass yield when Sulphur, Zinc, Boron, and Potassium were omitted, suggesting that these nutrients are not as crucial as Nitrogen and Phosphorus for wheat biomass production. This result was in accordance with the findings of Buah *et al.*, (2012) reported that application of Nitrogen and Phosphorus increased sorghum biomass yield by 58 and 26%, respectively. Similarly Abebe *et al.*, (2020) confirmed that Omission of Nitrogen and Phosphorous reduced total biomass yield of wheat by 66.4 and 20.6%, respectively. Study conducted on maize by Atnafu *et al.*, (2021) showed that the highest biomass yield reduction was obtained from Nitrogen, Phosphorous and Potassium omitted treatmens.

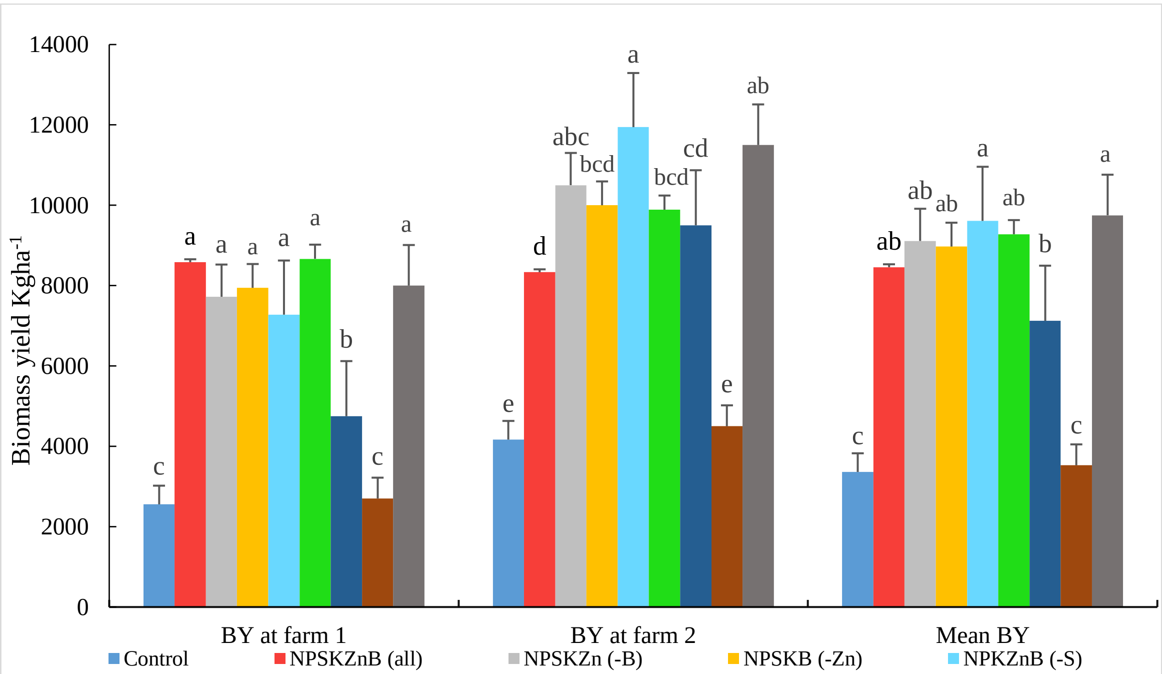

Figure 3 effects of applied nutrient on biomassyield of wheat

Conclusion and Recommendation

Proper nutrient supply through fertilizers enhances both the yield and quality of wheat grains. Omission of Nitrogen and Phosphorous had significant effect on the yield of wheat. The highest yield penality was observed when Nitrogen and Phosphorus were omitted. Hence Nitrogen is identified as the most yield limiting plant nutrient followed by Phosphorous for wheat under irrigation at Woleh irrigation scheme. The highest grain yield was obtained from NPKZnB (-S) nutrient received treatment but did nothave a significant effect over recommended Nitrogen and Phosphorous applied. This shows that Nitrogen and Phosphorous contained fertilizers are the most important than K, S, Zn, and B contained fertilizers. Hence, it is advisable to emphasize onNitrogen and Phosphorus containing fertilizers to obtain higher wheat yield in the study area and similar agroecologies.

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3. Identifying Major Yield- Limiting Nutrients for Bread Wheat (*Triticum aestivum* L.) and Enhancing its Productivity under Irrigation System in Amhara Region

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Abstract

Application of soil nutrients in the form of synthetic fertilizers is the primary option to improve crop productivity and feeding over increased populations. On-farm research was conducted in 2021 under irrigated condition at Mecha and Ayehu Shekudad districts with the objective of identifying the major yield limiting nutrients for bread wheat (Triticum aestivum L.) productivity for western Amhara Region. The experimenthad a total of nine treatments [NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, sole NP, control (no input)] with a randomized complete block design (RCBD) replicated thrice. Improved bread wheat variety (Kekeba) with 150 Kgha^{-1} seed rate was used. Urea, TSP, KCl (muriate of potash), $MgSO_4$, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Furrow irrigation method was used using 40cm furrow width. The four rows were irrigated by one furrow every 10-14 days irrigation interval. Except urea, all fertilizer sources were applied at planting using basal application. While, Urea fertilizer was applied in three equal splits at different crop stages. One composite soil sample was taken from each experimental site before plating at 0-20 cm depth and analysed for selected soil physisco-chemical properties. In most of the experimental sites, grain yield, biomass and yield components showed significant responses for Nitrogen followed by Phosphorus. However, either adding or omitting Sulphur, Zinc, Boron and Potassium nutrients didn't show any significant differences on yield and yield components. In West Amhara Nitrogen is still the primary yield-limiting nutrient followed by Phosphorus under irrigation systems which confirms the rainy season production. Yield without Nitrogen is nearly equal with the yield attended on the control treatment even if all other nutrients existed at optimal levels.

Keywords: Nutrient, bread wheat, Mecha and Ayehu Shekudad

Introduction

Agriculture plays an important role in the Ethiopian economy. It contributes over 35% to the annual GDP, about 80% to the export earnings and it employs over 75% of the population (CSA, 2018). Of the agricultural GDP, the contribution from crop production takes the lion's share which is about 70% or more. Within the crop production system, the share of cereals in area coverage and production potential is about 80% and 85%, respectively (CSA, 2017). The most important three crops (wheat, maize and tef) consume about 60% of the fertilizer inputs, cover 55% of the production area and provide 60% of the annual production potential (CSA, 2017).

Wheat is the most widely cultivated cereal crop in the world, and provides 20% of the protein and calories consumed by the world population (FAOStat, 2013). It is currently the staple food for more than 35% of the global human population (FAOSTAT, 2013). Continues nutrient depletion, newly emerging diseases and pests and unstable weather conditions deriving from climate change are the major threats for declining wheat productivity globally (CIMMYT, 2016). Ethiopia is the second-largest producer of wheat in sub-Saharan Africa, following South Africa (White *et al.,* 2001). The crop covers an area of 1.7 million ha and production of 4.6 million tons (CSA, 2018). From the country, Amhara Region accounts 32.7% of area coverage and 30.3% of volume of production (CSA, 2018). However, average wheat productivity in the Amhara region is about 2.53 tha^{-1} which is below the national average of 2.74 tha^{-1}. Up to 2025, the Ethiopian government plans to save 3 billion USDs of foreign currency that would have been used to import wheat for domestic consumption. To boost wheat productivity and production, Ethiopian governmenthas been striving to produce wheat under irrigation to fulfil national wheat demand through country's production and terminating imported wheat from abroad.

Due to increased use of agricultural inputs (improved seeds, fertilizers and pesticides), agriculture showed a dramatic progress with the annual growth rate of over 8%. Particularly, fertilizer consumption has shown a linear increment from below 37 tons in 1985 jumped to over 134 tons at the end of 1994. Following the RSDEP and PASDEP consecutive five-year plans from 1995 through 2009, fertilizer consumption was increased by 10 tons every year for 16 years. During the subsequent growth and transformation plan of the country (GTP I, 2010 to 2015), the import and consumption rate of fertilizers had grown several folds to 78,000 tons per year. After the introduction of the soil fertility mapping by the Ethiopian Soil Information System (EthioSIS,

2015) and the second growth and transformation plan (GTP II, 2016-2020), the country has increased the fertilizer types from two to over five. For this reason, the annual import and consumption raised to over 100,000 tons per year. Currently, the country imports about 1.4 million tons of multi nutrient fertilizers and projected to use over 2 million tons at the end of 2025 (in GTP III).

In targeting the right fertilizers to the right places, the EthioSIS project team has mapped the soil nutrient status of agricultural lands in Ethiopia and identified that a number of essential nutrients are deficient and critically required for enhancing crop productivity in the country. Based on the map developed by the project team, N, P, K, S, B, Zn, Fe and Cu are the deficient nutrients identified and recommended for enhancing crop production. Even though the newly formulated blended fertilizers needed validation and verification studies, direct demonstration trials were conducted at about 60,000 trial sites by different agricultural scholars and supported EthioSIS project team decision. The country already customized to use multi nutrient fertilizers and made available to farmers through imported market though there is no national or regional conscience on the importance of the fertilizers. Therefore, this activity was designed to validate the EthioSIS based soil nutrient deficiencies and identify the major yield limiting nutrients for bread wheat production under irrigation system in West Amhara Region.

Materials and Methods

Study Area Description: The field experiment was conducted in Mecha and Ayehu Shekudad districts. Both districts are located in North West Ethiopia. Based on Ethiopian traditional agro-ecological classification, Mecha is found under *Weyina dega* (1800 to 2400 m.a.s.l) while, Ayehu Shekudad is found under Dega classification (Mekonen, 2015).

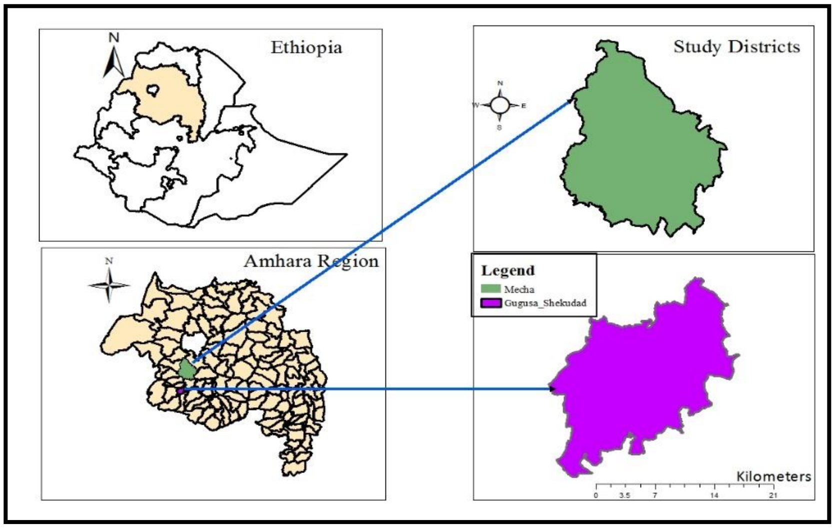

Figure 1. Location of the study districts

Experimental Material: Improved bread wheat variety (Kekeba) with 150 Kgha^{-1} seed rate was used. Urea, TSP, KCl (muriate of potash), MgSO4, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Soil auger and core-sampler was used to collect soil samples.

Experimental Methods and Design: The experiment was conducted for one irrigation season in 2021 at a total of four farmers' field. The experiment was conducted using randomized complete block design (RCBD) in three replications. Spacing between rows, plots and blocks were 0.2m, 1m and 1.5m, respectively with a gross plot size of 3.6m x 3m. Furrow irrigation method was used using 40cm furrow width. The four rows were irrigated by one furrow every 10-14 days irrigation interval. Ten centeral rows were harvested as a net plot area in which the data was converted in to a hectare. The experimenthad nine treatments as indicated in Table 1. Except Urea, all fertilizer sources were applied at planting using basal application. While, Urea fertilizer was applied in three equal splits (planting, tilering and butting) stages of the crop. Seed and fertilizer rates were calculated only for net planted plots without considering furrow spaces. However, furrow space was considered as part of netharvestable area.

Table 1. Treatment setup

No	Treatment	Description	Nutrient application rates ($Kgha^{-1}$)					
			N	P_2O_5	K_2O	S	Zn	B
1	NPSZnBK	All	138	92	30	10	5	2
2	NPSZnK-B	B-omitted	138	92	30	10	5	-
3	NPSBK-Zn	Zn-omitted	138	92	30	10	-	2
4	NPBZnK-S	S-omitted	138	92	30	-	5	2
5	NPSZnB-K	K-omitted	138	92	-	10	5	2
6	NSZnBK-P	P-omitted	138	-	30	10	5	2
7	PSZnBK-N	N-omitted	-	92	30	10	5	2
8	NP	NP alone	138	92	-	10	-	-
9	Control	-	-	-	-	-	-	-

Soil Sampling, Preparation and Analysis: From each experimental site, one composite soil sample before planting was taken from five points following X- pattern sampling technique at the depth of 0-20 cm. The sampled soils were air dried and sieved by (≤2 mm) sieve for analysis. Soil pH, Soil Organic carbon (SOC), Cation Exchange Capacity (CEC), Available Phosphorus (AP), Total Nitrogen (TN) and soil texture were analysed at Adet Agricultural Research Center's Soil Laboratory. Soil pH was determined using 1:2.5 soil-water suspensions ratios according to (Taye *et al.,* 2002). Olsen (1954) was used for AP analysis while Kjeldahl method (Bremner and Mulvaney, 1982) was used for TN analysed. Wet oxidation and ammonium acetate methods were used to determine SOC and CEC respectively.

As indicated in Table 2, Soil pH values of the experimental sites was found from strongly to moderately acidic ranges based on (Tekalign, 1991) which is optimum **(5-6)** for wheat growth and development (Sims, 1996). AP values ranged from low (5-9) to medium (10-18) $mgKg^{-1}$ based on (Cottenie A., 1980) nutrient rating scale. While, based on Tekalign (1991) SOC (1.5-3%) and TN (0.12-0.25%) values found at moderate levels. All CEC readings also found at high rating level (25-40) $Cmol_{(+)}Kg^{-1}$ according to Hazelton P. and Murphy (2007). Based on textural triangle, all experimental fields had clay dominated texture.

Table 2. Experimental sites' selected soil properties (taken before planting)

Parameters	Mecha		Ayehu Shekudad	
	Site 1	Site 2	Site 1	Site 2
pH(H_2O)	5.45	5.24	5.37	5.21
SOC (%)	1.572	1.778	1.856	2.048
CEC	33.24	32.14	33.38	33.20
AP (P-Olsen)	17.11	12.98	17.51	5.27
TN (%)	0.112	0.176	0.196	0.211
Clay (%)	66	66	50	44
Silt (%)	26	26	30	34
Sand (%)	8	8	20	22
Textural class	Clay	Clay	Clay	Clay

Data Collection and Analysis: Agronomic data like plant height, spike length, harvest index (HI) and all biological yields (grain + above ground biomass) were collected. The grain yield was adjusted to 12.5% of moisture content. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). Least significant difference (LSD) was used for mean separation at 5% probability.

Results and Discussion

Plant Height and Spike Length: Plant height showed significant difference among treatment means except at one experimental site (Table 3). Most of the significant differences generated from N omitted, P omitted and control treatment as compared to the other treatments. Except Nitrogen and Phosphorus, plant height of the testing crop didn't show clear responses. Addition or omitted of other nutrients other than N and P did not show any difference in plant height. As shown in Table 3 the minimum plant height values recorded in one or all of the three treatments (control, N-omitted or P-omitted). But the maximum values observed in any one of the treatments which received Nitrogen and Phosphorus nutrients together. This showed, the potential of Nitrogen and Phosphorus nutrients to determine yield and yield components of bread wheat. All the trends showed on plant height were reflected on spike length of bread wheat two of the testing sites.

Table3. Plant height and spike length values in the study sites

	Plant height (cm)				Spike length (cm)			
	Mecha		Ayehu Shekudad		Mecha		Ayehu Shekudad	
Treatments	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
NPSZnBK	81.5	79.5	69.6	70.5	8.3	8.3	7.3	7.6
NPSZnK-B	81.9	77.9	66.5	72.5	8.1	7.6	6.8	7.1
NPSBK-Zn	78.6	75.2	72.1	69.0	7.9	8.5	7.4	7.1
NPBZnK-S	81.1	75.4	68.1	68.7	8.2	7.3	7.2	7.3
NPSZnB-K	79.5	77.7	65.7	67.6	8.3	7.5	6.7	7.3
NSZnBK-P	79.9	74.1	68.3	54.5	7.7	7.4	7.3	6.0
PSZnBK-N	69.3	70.1	60.9	66.8	6.9	7.1	6.3	7.1
R-NP	78.7	75.9	68.6	68.7	7.8	7.5	7.3	6.9
Control	68.5	68.6	63.1	57.0	6.8	6.8	6.7	6.0
Pro.Sig	*	NS	*	**	**	NS	NS	*
LSD	8.7	-	6.5	7.8	0.8	-	-	1.0
CV	6.6	9.7	5.7	6.9	5.7	9.1	9.6	8.3

*Note: ** = Highly significant, * = Significant, NS = Non significant*

Grain and Biomass Yields: Except at one site in Mecha district, both grain and biomass yield of bread wheat showed significant difference among treatment means (Table 4). Similar to plant height and spike length, significant difference among treatment means for grain and biomass yields also generated from the N and P omitted as well as control treatments when compared with other treatments. Except at site 2 in Ayehu Shekudad district, the minimum grain yield values recorded were in control treatment followed by Nitrogen omitted treatment. However, the maximum values were observed in any one of the treatments which received Nitrogen and Phosphorus nutrients together.

A clear negative response on both grain and biomass yield of bread wheat was observed when either of the two or both major nutrients (N and P) are omitted. Similar to the rainy season, these two nutrients affected bread wheat productivity and showed their potentials on limiting of biological yields (grain and biomass) under irrigation system in any of the studied west Amhara arable lands which is in line with the finding of (Tadele *et al.*, 2018). Tadele and his colleagues stated that; sulphur, Zinc, Boron and Potassium were not yield-limiting nutrients in Ethiopian soils at this time. Except Nitrogen and Phosphorus nutrients, there was no a significant change on both grain and biomass yields of wheat either due to adding or omitting of Sulphur, Zinc, Boron and Potassium nutrients. Therefore, still it is possible to maximize wheat productivity with feasible economical profits by using optimum rate Nitrogen and Phosphorus source fertilizers. For this evidence, look at how much biological yields of wheat declined at Ayehu Shekudad district in site 2 due to low available Phosphorus reading (Table 2 and Table 4). This might be indicated that it is important to add more Phosphorus amounts on sites having low available Phosphorus values rather than adding Sulphur, Zinc, Boron and Potassium nutrients.

Table 4. Grain and biomass yield of bread wheat values in the study districts

	Grain yield ($Kgha^{-1}$)				Biomass yield ($Kgha^{-1}$)			
	Mecha		Ayehu Shekudad		Mecha		Ayehu Shekudad	
Treatments	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
NPSZnBK	3416.7	2324.8	2635.7	2932.8	7500.0	5208.3	5255.2	5863.9
NPSZnK-B	3529.4	1895.7	2610.3	2669.7	7638.9	4166.7	5345.5	5675.0
NPSBK-Zn	3714.7	2338.9	2501.2	2919.3	7916.7	5208.3	5284.7	5744.4
NPBZnK-S	3533.6	1869.5	2634.4	2656.5	8194.4	4375.0	5487.8	5325.0
NPSZnB-K	3524.9	1922.1	2644.4	2817.7	6597.2	4652.8	5467.0	5641.7
NSZnBK-P	3431.8	1945.8	2486.8	1540.1	8333.3	4236.1	5024.3	3191.7
PSZnBK-N	2170.8	1458.8	1635.2	2423.3	4583.3	3229.2	3368.1	4897.2
R-NP	3381.8	1995.4	2437.6	2911.2	7187.5	4375.0	5269.1	6055.6
Control	1883.9	1107.5	1546.6	1572.6	3958.3	2430.6	3175.3	3236.1
Pro.Sig	*	NS	**	**	*	NS	**	**
LSD	1086.3	-	550.8	577.8	2945.2	-	1140.9	1051.4
CV	19.9	32.5	13.7	13.5	25.0	28.3	13.7	12.1

*Note: ** = Highly significant, * = Significant, NS = Non significant*

Similar to the individual experimental sites, all the biological yields and yield components showed significant difference among treatment means (Table 5). As discussed for the individual parameters, in the combined analysis, the significant differences were observed in control and N omitted treatments as compared with other treatments. Except the control and N omitted treatments other treatments didn't show any significant difference with each other in yields and yield components. In other words, yield without Nitrogen is nearly equal sometimes below the yield attends on the control treatment even if all other nutrients existed in optimal levels. As shown from individual and combined analysis results, Nitrogen is still the leading yield limiting nutrients in Ethiopian soils followed by Phosphorus which is line with (Tadele *et al.,* 2022). He and his colleagues explained that the yield-limiting nutrients to produce maize in major maize-growing areas in Amhara region were Nitrogen and Phosphorus in the respective order.

Table 5. Combined analysis data of biological yields and yield components of the study sites

Treatments	Plant height (cm)	Spike length (cm)	Grain yield (Kgha^{-1})	Biomass yield (Kgha^{-1})
NPSZnBK	76.9	8.0	2792.4	5987.8
NPSZnK-B	75.4	7.5	2678.5	5717.0
NPSBK-Zn	75.3	7.9	2851.6	6136.6
NPBZnK-S	74.9	7.6	2679.1	6019.1
NPSZnB-K	74.3	7.5	2697.2	5572.3
NSZnBK-P	74.1	7.5	2621.4	5864.6
PSZnBK-N	66.8	6.8	1754.9	3726.9
R-NP	74.4	7.5	2604.9	5610.5
Control	66.7	6.8	1512.6	3188.1
Pro.Sig	*	**	**	**
LSD	6.6	0.6	710.9	1590.3
CV	9.6	9.2	30.7	31.8

*Note: ** = Highly significant, * = Significant*

Conclusion

In most of the experimental sites, both biological yields and yield component did show significant and negative responses for Nitrogen followed by Phosphorus. Either adding or omitting of sulphur, Zinc, Boron and Potassium nutrients didn't show any significant changes on all biological yields. In our study, Nitrogen is the leading yield limiting nutrient followed by Phosphorus nutrient which is similar to with the rainy season production. Yield without Nitrogen is nearly equal sometimes below the yield attends on the control treatment even if all other nutrients existed in optimal levels. Therefore, it is still possible to enhance wheat productivity under irrigation using sole Nitrogen and Phosphorus fertilizers sources with integrating other improved wheat production technologies. However, frequent revision of soil fertility status is too important for updating nutrient type requirements for enhancing wheat productivity and production in Amhara region.

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4. Effect of Nitrogen Rate and Irrigation Regime on Tomato (*Solanum lycopersicum* L.) Yield in Efratanagidim District, North Shoa, Amhara Region, Ethiopia

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Abstract

Application of optimum water and fertilizer is an important factor in improving crop productivity. A field experiment was conducted in Eferatagidim district, North Shoa, Amhara, Ethiopia, during the irrigation season of 2019 and 2020 with the objective of determining N rate and irrigation depth for optimum tomato yield. The experiment consisted of factorial combinations of three-irrigation depths (75% ETc, 100% ETc and 125% ETc) and four N rates (0, 46, 92 and 138 Kgha^{-1}N). The treatments were laid out in a split plot design with four replications. The main plot was arranged for the irrigation regime while the sub plot was for the Nitrogen rates. Data on growth, yield, and yield-related traits of tomatoes include; plant height, number of fruit clusters per plant, fruit length, fruit diameter, number of marketable fruit, number of un-marketable fruit, the total number of fruit, marketable fruit yield, un-Marketable fruit yield, total yield were collected. Data were subjected to analysis of variance using R studio. The results indicated that the experimental site had low total Nitrogen content and application of N fertilizer significantly improved tomato yield. Increasing irrigation depth also significantly increased tomato yield. The result indicated that the highest mean marketable fruit yield (35903 Kgha^{-1}) was obtained from the combined application of 125% ETc with 92 Kgha^{-1} N while the lowest (13655 Kgha^{-1}) marketable fruit yield was obtained from 75% ETc with 92 Kg a^{-1} N. The partial budget analysis also indicated that the highest net benefit (266272.1 ETB) as well as acceptable marginal rate of return (1240) for the invested capital were recorded from the combined application of 125% ETc with 92 Kgha^{-1} N. Therefore, application of 125% ETc with 92 Kgha^{-1} N resulted in highest net benefit.

Keyword: ETc, Irrigation regime, N rate, Tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is the most widely grown vegetable in the world. The crop is a reach source of vitamin, mineral and antioxidant, which are important for human diets. The crop also contains lycopene, which is responsible for reducing different cancers and neurodegenerative diseases (Srinivasan, 2010). The crop is one of the most profitable crop providing a higher income for farmers. According to FAO (2016), the production of Tomato is estimated to be 55,000 tons in 2013 but showed a decreasing trend compared with the production recorded in 2011 (81,738 tons). The possible reason attributed to disease and pest (such as tutaabsoluta and late blight), poor agronomic practice, shortage of improved varieties, poor quality seed and post-harvesthandling practice.

Nutrient especially Nitrogen and Phosphorus can be the major limiting factor for plant growth and development next to sunlight and water. Nitrogen is essential for building up of protoplasm and protein which is responsible for cell division and initial meristematic activity (Singh and Kumer, 1996). It also promotes flower and fruit setting of tomato. Thus, Nitrogen has a positive effect on tomato growth and development in soil with limited N supplies (Hokam *et al.*, 2011). Next to Nitrogen fertilizer, Phosphorus containing fertilizers is the second most important input for increasing crop production. High level of Phosphorus throughout root zone is essential for rapid root development and for good utilization of water and other nutrient by the plant. Tomatoes have the greatest demand for Phosphorus at the early stages of development (Csizinszky, 2005).

In Ethiopia, fertilizer rates especially N and P were determined for tomato in some parts of Ethiopia. But the rate, for instance the fertilizer recommendation for N ranged between 56-230 Kgha^{-1} and for P ranged from 48-137 Kgha^{-1} (Balemi, 2008; Etissa *et al.*, 2013; Kebede and Woldewahid, 2014; Wubengeda *et al.*, 2016) (. The probable reason for this attributed to soil and agro-ecological variability. Moreover, these recommendations were too general to use for specific areas.

Likewise, water is the most limiting factor for crop production especially in areas where the amount and distribution of rainfall is not sufficient to sustain crop growth and development (Gulen and Eris, 2004) . In Ethiopia, where tomato is growing rainfall could not meet crop water needs and application of irrigation water is mandatory

Recently, our research center with the support of AGP project conducted production constraint assessment on AGP supported district Efratanagidm. The result of the assessment indicated that; Onion and tomato were the most important vegetable crops and there was no fertilizer recommendation for these crops. Thus, the present study was proposed with the objectives of determining N rate and irrigation regime for optimum tomato yield in Efratanagidm districts.

Materials and Methods

The experiment was conducted in Eferatagidm district, North Shewa Zone of the Amhara Regional State during irrigation season of 2019 and 2020. The district is 139 kilometers away from the zonal capital, DebreBirhan town and 273 km from Addis Ababa along Dessie road. Efratanagidm district lies between 10°5’N-100 32’N and 39° 50’E- 390 0’ E latitude and longitude (Figure). The topography of the district is generally rugged and broken, with many hills and ridges, making most part of the area unsuitable for agriculture, even though cultivated. The major land use pattern of the district includes croplands 47%, forest and bush 23%, and grazing 10%. The district is well known by its underground and surface water like rivers and streams. Nazero, Jewuha and Jara are the three big rivers known in the Woreda (EGDOA, 2019). The dominant crops cultivated in the district are Sorghum (*Sorghum bicolor)*, Tef ([*Eragrostis tef (Zucc.) Trotter*], Maize (*Zea mays*), Mungbean (*Vigna radiate*), Haricot bean (*Phaseolus vulgaris)*, Onion (*Allium cepa)* and tomato (*Solanum lycopersicum)*. Disease and pest, lack of access on improved technologies, shortage of post-harvesthandling techniques of onion and tomato, and lack of fertilizer recommendations are some of the challenges for crop production in the district (Chanyalew *et al.*, 2018). The long-term rain fall, maximum and minimum temperature of the district were presented in Table .

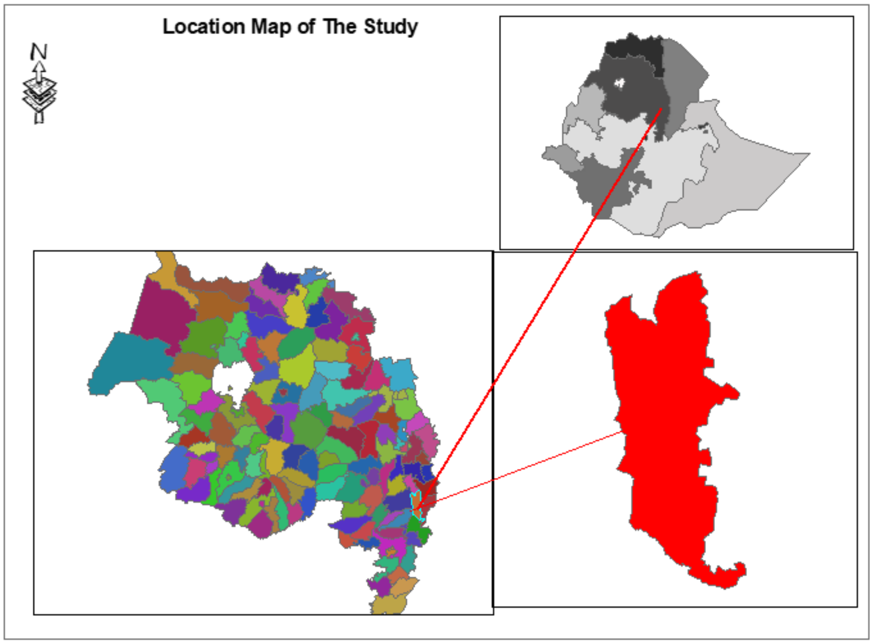

Figure 1. Location map of the study

The treatments were consisted of factorial combination of four levels of Nitrogen (0, 46, 92 and 138 Kgha^{-1}N) and three levels of irrigation depth expressed as a percentage of potential Evapotranspiration (ETc) i.e. IRR1 (75% ETc), IRR2 (100% ETc) and IRR3 (125% ETc). The experiment was laid out in split plot design with four replications. The main plot was assigned to irrigation depth and frequency while the sub plot was to-Nitrogen rate. The experimental field was prepared following the conventional tillage practice before planting. The space between blocks and plots were 1.5 and 1m respectively. Ridge was constructed between block and plot to control movement of water and fertilizer from one plot to the other. The gross plot size for the main plot was 56.4 m^2 and for the sub plot was 9.6 m^2 which is 4 rows and 8 plants per row. The harvestable plot size was 4.8 m^2.

Tomato variety *Kochero* and *Weyno* were used as a test crop for the first and second year of the experiment. The reason for varietal difference was attributed to the fact that un-availability of the seed of Kochero variety from the market. Seedlings were grown on seedbed for one month. The seedlings were supplied with N nutrient from urea. Uniform seedlings with their growth were transplanted to the prepared ridges in spacing of 30 cm and 100 cm for plants and rows respectively. Irrigation depth and frequency was applied based on the recommendation of DBARC (Debra birhan

Agricultural Research Center) (Table). The required amount of depth of irrigation water in each growth stage were determined using FAO CROPWAT 8.1 model (Table). Then the required amount of irrigation water applied for each treatment were calculated by multiplying the depth of irrigation water with the area of the plots. The water was applied with cane method. The depth of effective rainfall during the growth period were deducted from the depth of irrigation water with the respective growth period (Table). Disease and pest were regularly monitored and treatment were applied based on the recommendations of research.

Table 1. Depth of Irrigation water during the growth period

		Depth of irrigation water (mm)		
Month	Growth Period	75% ETC	100% ETC	125% ETC
January	Initial	22.3	29.7	37.1
January	Initial	22.3	29.7	37.1
January	Initial	22.3	29.7	37.1
January	Initial	22.3	29.7	37.1
January/February	Developmental	22.3	29.7	37.1
February	Developmental	40.1	53.4	66.8
February	Developmental	40.1	53.4	66.8
March	Mid	62.3	83.1	103.9
March	Mid	62.3	83.1	103.9
April	Late	62.3	83.1	103.9
April	Late	62.3	83.1	103.9
Total irrigation depth (mm)		440.8	587.7	734.6
Total irrigation water (m^3ha^{-1})		4407.9	5877.2	7346.4

Equal amount of P (40 $Kgha^{-1}$) was applied to all plots at planting from TSP. N was applied in splithalf at planting and the resthalf after 45 days after transplanting the seedlings from urea.

Rain gauge was installed in the experimental field to collect rainfall data. The rainfall (effective rainfall) were deducted from the amount of irrigation water applied when it occurs in the irrigation interval. A total of 11 days in 2019 and 9 in 2020 were recorded with days having effective rainfall (Table). The long-term metrological data of the station also indicated that the experimental area received 177.5 mm rain during these years (Table 3).

Table 2. Effective rainfall recorded during the growth period

Year	Date	Growth stage	Effective rainfall (mm)	Year	Date	Growth stage	Effective rainfall (mm)
1	April 3, 2019	Late	5	2	April 6, 2020	Late	18
1	April 4, 2019	Late	10	2	April 10, 202	Late	12
1	April 5, 2019	Late	30	2	April 11, 2020	Late	9
1	April 8, 2019	Late	14	2	April 15, 2020	Late	24
1	April 14, 2019	Late	2	2	April 18, 2020	Late	14
1	April 15, 2019	Late	5	2	April 21, 2020	Late	8
1	April 16, 2019	Late	14	2	April 22, 2020	Late	31
1	April 17, 2019	Late	35	2	April 27, 2020	Late	18
1	April 21, 2019	Late	7	2	April 29, 2020	Late	8
1	April 17, 2019	Late	3				
1	April 30, 2019	Late	18				

Table 3. Long-term metrological data of the experimental field

Month	Mean Rain fall (mm)*	Mean Max temperature (ºC)**	Mean Min temperature (ºC)**
January	32.1	27.4	10.4
February	45.1	28.5	11.0
March	83.0	29.8	12.9
April	177.5	30.2	13.9
May	51.3	32.2	14.0
June	70.7	33.6	14.8
July	203.6	31.2	15.4
August	357.3	29.4	15.0
September	461.5	30.1	14.1
October	35.2	29.8	11.2
November	61.2	29.0	9.5
December	23.3	28.0	9.0

** = Average of 40 years, ** = Average of 31 years*

Composite surface soil samples (0-20 cm depth) were collected before planting for the determination of soil physico-chemical properties. The samples were air dried, ground and passed through a 2 mm sieve for most parameters except for OC and TN which passed through 0.5 mm sieve. Soil texture was determined by hydrometer method (Bouyoucos, 1951). Soil pH was measured with digital pH meter potentiometerically in supernatant suspension of 1:2.5 soil to distilled water ratio (Van Reeuwijk, 1992). Cation exchange capacity (CEC) was determined by 1M ammonium acetate method at pH 7 (Chapman, 1965) whereas organic carbon (OC) was determined by the dichromate oxidation method (Walkley and Black, 1934). Total N in the soil was measured by the micro kjeldhal method (Jackson, 1958.). Available P was analyzed by Olsen method (Olsen, 1954) colorimetrically by the ascorbic acid- molybdate blue method (Watanabe and Olsen, 1965).

Data Collection: The following data were collected at different growth stages of tomato.

Plant Height (cm): Ten plants were selected randomly from each experimental plot to measure plant height by a steel tape from the ground to the main apex during 50% flowering. The average values were considered for analysis.

Number of Fruit Clusters: the number of fruit clusters per plant was counted at physiological maturity from randomly selected five plants. The average values were considered for analysis.

Fruit Length and Diameter (cm): Ten fruits of different size (very large, large, medium, small and very small) were collected from each selected plant and the length and diameter of each fruit was measured by using a digital caliper. The mean diameter of a fruit was obtained by adding the diameter of all the selected fruits and then dividing the sum by the number of selected fruits. The average values were considered for the analysis.

Total Number of Fruit (ha^{-1}): The sum total number of fruits of successive harvests of pink to full-ripe stage where dropped fruits were not considered at all.

Marketable Fruit Yield (Kg): fruits whose diameter was > 3cm and which were free of damage from the net plot area were considered marketable at each harvest using a sensitive balance. The total marketable fruit yield is the sum of successive harvests.

Unmarketable Fruit Yield (Kg): fruits whose diameter were ≤ 3cm and which were damaged by insect, diseases, sun burn, etc. from the net plot area were considered as unmarketable yield. The total unmarketable fruit yield is the sum of successive harvests.

Total Fruit Yield (Kg): This was obtained by adding average marketable and un marketable fruit yield of successive harvests.

Statistical Analysis: The collected data were subjected to two factors analyses of variance (ANOVA) to evaluate the main and interaction effect of the factors (irrigation regime and N rate) on the selected parameters using R studio. Where ever the treatment effects were significant, mean separation was made using the Duncan's multiple range test at 5% level of significance. Correlation coefficients was calculated to study the associative relations among the measurement traits according to Gomez and Gomez (1984). Correlation between parameters were computed when applicable according to Gomez and Gomez (1984).

Partial Budget Analysis: Based on the procedures described by CIMMYT (1988), the economic analysis was done using partial budget analysis. For partial budget analysis, the variable cost of fertilizer and labor were taken at the time of planting and during other operations. Price of tomato fruit yield was also considered. The return was calculated as total gross return minus total variable cost. Net benefits and costs that vary between treatments were used to calculate the marginal rate of return to invested capital as we move from a less expensive to a more expensive treatment. To draw farmers' recommendations from marginal analysis in this study, 100% return to the investments was used as reasonable minimum acceptable rate of return.

Results and Discussion

Soil Physicochemical Properties (Before Planting): The laboratory analysis result of the soil-physicochemical properties of the experimental soil is presented in

Table Pre-sowing soil analysis result indicated that the textural class of the soil is clay. The mean pH of the soil was 7.12 which is in the neutral soil reaction (Hazelton and Murphy, 2016). This indicated that the pH of the soil is suitable for the production of most crops including tomatoes. The soil's potential CEC (29.3 cmolc/Kg) was in the high range (Landon, 2014). According to Tadesse *et al.,* (1991) the soil's organic carbon and total Nitrogen content was in the low range. Therefore, the application of N-containing fertilizer is mandatory for increasing tomato yield. The exchangeable K content of the soil is rated as very high (Berhanu, 1980). Similarly, Kassie *et al.*, (2019) also reported that high K content in the study area. According to the rating developed by Olsen (1954) for the irrigated area, the soil available P content of the experimental soil is high. The same author classified the soil Olsen available P content of irrigated soil as < 12 $mgKg^{-1}$ is low, 12-17 $mgKg^{-1}$ marginal, 18-25 $mgKg^{-1}$ is adequate and > 25 $mgKg^{-1}$ is high. Similarly, others authors also reported that yhe high available Phosphorus content of the study area with a mean value of (Tesfay *et al.,* 2020; Temeche *et al.*, 2021; Temeche *et al.*, 2022)

Table 4. Soil Physico-chemical properties of the experimental soil

Sample #	Textural class	*BD (gcm^3)	pH (1:2.5)	CEC (cmo(+) Kg^{-1})	EX.K (cmo(+) Kg^{-1})	AV.P (ppm)	OC (%)	OM (%)	T.N (%)
1	Clay (S=20%, C=44%, Si=36%)	1.36	7.14	29.3	1.45	29.33	1.38	2.37	0.147
2	Clay (S=20%, C=46%, Si=34%)	1.42	7.12		1.48	28.76	1.39	2.39	0.133
3	Clay (S=16, C=40, Si=36)	1.41	7.1		1.23	29.68	1.36	2.35	0.133
Mean	Clay	1.39	7.12	29.3	1.39	29.3	1.38	2.37	0.14

**BD = Bulk density; CEC = Cation exchange capacity; EX.K = Exchangeable Potassium; AV.P = Available Phosphorus; OM = Organic matter; T.N = Total Nitrogen; S = sand; C = clay; Si = silt*

Effect of Irrigation Regime on Mean Growth, Yield Component and Yield of Tomato: Many irrigation systems in Ethiopia for most crops including tomatoes are traditional and rely on farmer expertise (Beyene *et al.,* 2018). This will result in over or under-application of water. This is due to farmers not receiving enough expert information on when, how, and how much water to irrigate with (Yenesew and Tilahun, 2009). Therefore, application of optimum amount of irrigation water based on field trial is vital for increasing the yield of tomato. In our study, the irrigation water applied influenced most of the measured parameters including fruit length ($P \leq 0.01$), fruit diameter ($P \leq 0.05$), marketable fruit yield ($P \leq 0.01$), un-marketable fruit yield ($P \leq 0.01$) and total yield ($P \leq 0.05$) (Table 3). The highest marketable fruit yield was obtained from the application of 125% ETc. This treatment increased marketable fruit yield by 22.3% (5209 $Kgha^{-1}$) and 56.4% (10311.1 $Kgha^{-1}$) compared with application of 100% and 75% ETc, respectively. Others authors also reported that marketable yield of tomatoes was significantly affected by the amount of water applied and a maximum yield of 32 tha^{-1} was recorded with the application of 100% ETc irrigation compared to 85% ETc (25 tha^{-1}) and 70% ETc (23 tha^{-1}) (Kifle, 2018). The total and marketable yield of tomato was lowest in the most stressed treatment of 75% deficit level. The yield amounted to 45.1 tha^{-1} on average for 0% deficit irrigation treatments and 18.4 tha^{-1} for 75% deficit irrigation treatment for Melka Shola cultivar. These values were 45.2 tha^{-1} and 13.1 tha^{-1} for Melkassa Marglobe cultivar (Birhanu and Tilahun, 2010). Edossa *et al.,* (2014) also reported that the highest total yield of 82.14 tha^{-1} was recorded from full irrigation followed by 57.3 tha^{-1} from 80% ETc irrigation level. The lowest total yield of 49.3 tha^{-1} from 60% of full irrigation depth. Indicating that tomato crop should be irrigated at full water requirement to get maximum fruit yield. The higher marketable yield (31.504 tha^{-1}) and total yield (37.65 tha^{-1}) were obtained from 100% ETc and the lowest marketable yield (18.841 tha^{-1}) and total yield (25.02 tha^{-1}) was obtained from deficit level of 50%ETc in Arbaminch Zuria Woreda in SNNPR region (Habtewold and Gelu, 2019). Bekele (2017) also reported that treatment receiving 100 % ETc irrigation level has a 6.94 % and 15.19 % yield increment as compared to 75% and 50% ETc irrigation level, respectively. The same authors also reported that application of 100 % ETc level has a significant yield difference with 50% ETc level but it is at par with that of 75 % ETc level.

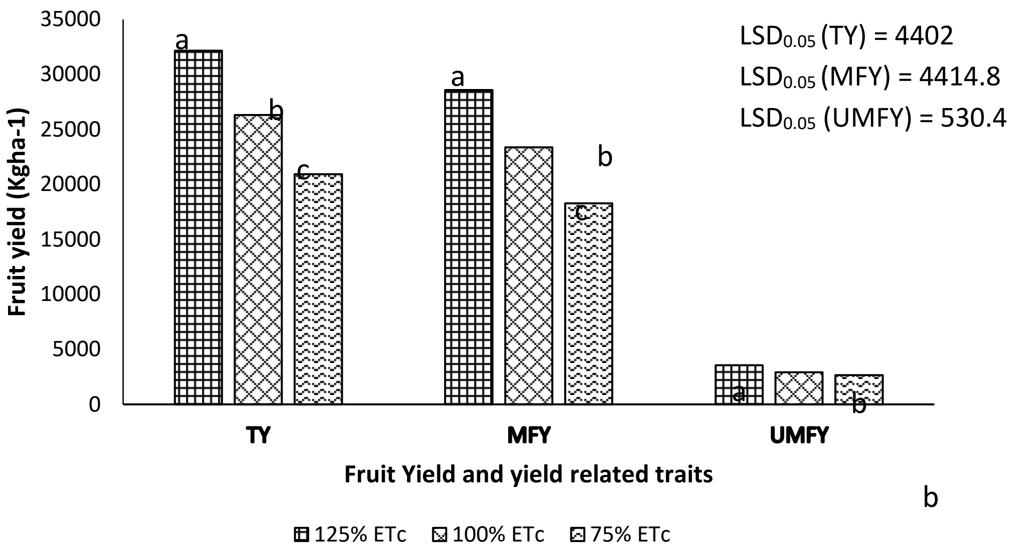

Figure 2. Fruit yield of tomato as influenced by different irrigation regime

Effect of Nitrogen Fertilizer on Mean Growth, Yield Component and Yield of Tomato

Nitrogen is one of the most limiting nutrients, affecting plant growth and yield worldwide (Du *et al.,* 2017; Li *et al.,* 2021). Nitrogen is a crucial nutrient for the physiological and metabolic process in a tomato; adequate N availability increases marketable yield (Akter *et al.,* 2015).

Tomato yield is constrained by poor soil fertility management and lack of site-specific fertilizers recommendation (Etissa *et al.,* 2013; Ortas, 2013; Biramo *et al.,* 2019; Alia *et al.,* 2020; Mohammed, 2020). Our result also confirmed that the soil of the experimental site is low in soil total N (Table 4). Therefore, application of N containing fertilizer is mandatory for the test crop.

The role of application of N nutrient in increasing tomato yield are well-documented (Weston and Zandstra, 1989; Aman and Rab, 2013; Etissa *et al.,* 2013; Kebede and Woldewahid, 2014; Bilalis *et al.,* 2018; Kaniszewski *et al.,* 2019; Abera *et al.,* 2020) and as the rate of N fertilizer increased, the yield of tomato also increased (Warner *et al.,* 2004).

The effect of different rate of Nitrogen fertilizer on fruit length, fruit diameter, number of marketable fruit, and total yield was non-significant. Nevertheless, it significantly affected plant height ($P \leq 0.05$), number of fruit cluster per plant ($P \leq 0.001$), number of un-marketable fruit $P \leq 0.01$), total number of marketable fruit ($P \leq 0.01$), marketable fruit yield ($P \leq 0.01$), and un-marketable fruit yield ($P \leq 0.01$). The result of the analysis indicated that, increasing N fertilizer rate resulted in a progressive increase nearly all the collected parameters (Table). The highest number of fruit cluster per plant (11.7), total number of fruit (849124), and marketable fruit yield (25516 $Kgha^{-1}$) were observed from application of 138 Kg N increased the respective parameters by 23.2% (2.2), 75.4% (364972), 29.8% (5856.8 $Kgha^{-1}$) compared with the lowest result recorded from N un-fertilized plot, respectively (Table). The highest value of number of unmarketable fruit yield (83444) was observed from application of 92 $Kgha^{-1}$ N. This treatment increased the respective parameters by 102.6% (40970) compared with the lowest yield observed from N un-fertilized plot (Table 5).

Table 5. Main effect Nitrogen fertilizer on growth, yield related and yield of tomato

N Rate	*PH	NFCPP	NUUMF	TNUF	MFY	UMFY
0	61.2^{ab}	9.5^{c}	39925^{b}	484152^{b}	19659.2^{b}	2394.8^{b}
46	58.7^{b}	10.4^{bc}	74166^{a}	576640^{ab}	23795.1^{a}	3101.4^{ab}
92	63.5^{a}	11.4^{ab}	83444^{a}	656057^{ab}	24689.3^{a}	3517.4^{a}
138	64.5^{a}	11.7^{a}	80895^{a}	849124^{a}	25516^{a}	3150.6^{ab}
LSD0.05	4.3	1.02	23795	350846.8	3220.9	841.7

**PH = Plant height; NFCPP = number of fruit cluster per plant; NUUMF = Number of un-marketable fruit; TNUF= Total number of fruit; MFY = Marketable fruit yield; UMFY = Un-Marketable fruit yield*

Interaction Effect of Irrigation Regime and Nitrogen Rate on Mean Growth, Yield Component and Yield of Tomat: In vegetable crop production, nutrient and water management are related and optimal management of one program necessitates good management of the other (Hochmuth and Hanlon, 2010). Du *et al.,* (2017) reported that there were significant interactions between the amount of irrigation water and applied N on tomato. Our result also confirmed that the interaction of irrigation amount and N rate was significant. Tomato plants are sensitive to water stress (Berihun, 2011). Suboptimal application of nutrients and low soil fertility status especially N and P also adversly affect tomato yield (Pandey *et al.*, 1996; Mehta *et al.*, 2000; Balemi, 2008). Combined over years, only number of unmarketable fruits, marketable fruit yield and unmarketable fruit yields were significantly influenced by the interaction of irrigation regime and Nitrogen rate (Tables 6 and 7 (Other parameters were not significantly influenced by the interaction of irrigation regime and N rate. The highest (118986) number of unmarketable fruit yield was obtained from the combined application of 75% ETc with 92 $Kgha^{-1}$ N, while the lowest (34791) was obtained from 75% ETc with 0 $Kgha^{-1}$ N (Table 6). In addition, the highest (4160 $Kgha^{-1}$) unmarketable fruit yield was recorded from the combined application of 125% ETc with 92 $Kgha^{-1}$ N and the lowest (2250 $Kgha^{-1}$) was recorded from the combined application of 75% ETc with 0 Kg N ha^{-1}. The highest (35903 $Kgha^{-1}$) and lowest (13655 $Kgha^{-1}$) marketable fruit yield observed with from combined application of 125% ETc with 92$Kgha^{-1}$ N and 75% ETc with 92$Kgha^{-1}$ N, respectively (Table 6). The result indicated that there was a consistent yield increment with increasing the irrigation in all levels of N rate. Nevertheless, the yield increment in all levels irrigation regime with application of N nutrient was not consistent. Indicating that yield of tomato mainly determined with application of irrigation water. Similarly, different scholars reported the effect of irrigation water and nutrient on tomato yield (Berihun, 2011; Edossa *et al.*, 2014; Xiukang and Yingying, 2016; Benti *et al.*, 2017; Wang and Xing, 2017; Wu *et al.*, 2021)

Table *6*. Interaction effect of irrigation depth and N on growth, yield related and yield of tomato

	*NUUMF			MFY (Kgha^{-1})			UMFY (Kgha^{-1})		
N Rate	75%ETc	100% ETc	125% ETc	75% ETc	100% ETc	125% ETc	75% ETc	100% ETc	125% ETc
0	34791^{e}	40340de	44643de	17127^{fg}	19299^{def}	22551^{cdef}	2250^{c}	2386^{c}	2548^{bc}
46	58898^{cde}	58553^{cde}	105048^{ab}	23942^{cde}	26277^{bc}	26329^{bc}	2493^{bc}	2929^{abc}	3882^{ab}
92	118986^{a}	69225^{bcde}	62122^{cde}	13655^{g}	24510^{bcd}	35903^{a}	2897^{abc}	3495^{abc}	4160^{a}
138	99073^{abc}	67440^{bcde}	76172^{bcd}	18385^{efg}	23429^{cde}	29571^{b}	2931^{abc}	2908^{abc}	3613^{abc}
LSD 0.05		41214.2			5578.8			1457.9	

**NUUMF = Number of un-marketable fruit; MFY = Marketable fruit yield; UMFY = Un-Marketable fruit yield*

Table 7. Mean square value of the collected parameters

Source of variation	Mean squares values with respective degrees of freedom in parenthesis									
	*PH	NFCPP	FL	FD	NUMF	NUUMF	TNUF	MFY	UMFY	TY
Year 1										
Rep (3)	778**	23,2*	1.7^{ns}	0.7^{ns}	6.2E+11^{ns}	7E+09^{ns}	7.4E+11^{ns}	7E+07^{ns}	4556870*	95636739^{ns}
IRR (2)	105^{ns}	3.3^{ns}	2.1^{ns}	2.2^{ns}	3.3E+11^{ns}	1.3E+09^{ns}	3E+11^{ns}	8E+08*	9927332**	967940020**
Ea (6)	43	2.5	4.2	2.8	2.9E+11	2.9E+09	2.8E+11	7E+07	822555	65659571
N (3)	160^{ns}	24.4***	0.6^{ns}	3^{ns}	4.8E+11^{ns}	9.8E+09**	5.8E+11^{ns}	2E+08**	5281912^{ns}	218834398**
IRR*N (6)	24^{ns}	4.8^{ns}	8.4*	2.1^{ns}	3E+11^{ns}	4.8E+09*	3.1E+11^{ns}	1E+08**	656831^{ns}	136686523**
Eb (27)	55	2.5	2.5	1.7	3.4E+11	1.7E+09	3.4E+11	3E+07	2184225	36020610
CV (a)	12.7	22.4	0	0	121.1	81.8	109.8	26.1	37.4	22.5
CV (b)	17.1	17,2	0	0	118.4	79.4	108.9	22.2	37.9	20.6
Year 2										
Rep (3)	497.4**	52.5**	3.4^{ns}	1.3^{ns}	1.06E+11*	6.6E+09*	1.6E+11*	1.9E+08^{ns}	3818861^{ns}	246606106^{ns}
IRR (2)	23.4^{ns}	1.1	4.2^{ns}	4.4^{ns}	1.22E+10^{ns}	1.8E+09^{ns}	2.2E+10^{ns}	1.2E+07^{ns}	947568^{ns}	13416668^{ns}
Ea (6)	35.7	27.0	8.3	5.6	1.66E+10	1.3E+09	2.5E+10	4.9E+07	919165	57370435
N (3)	141.3***	39.2***	1.3^{ns}	6^{ns}	7.19E+10**	9.6E+09***	1.3E+11***	1.4E+08***	3616510*	188747611***
IRR*N (6)	31.9^{ns}	3.8*	16.8*	4.2^{ns}	3.83E+09^{ns}	5.4E+09^{ns}	4.7E+09^{ns}	7.6E+06^{ns}	210979^{ns}	8114158^{ns}
Eb (27)	18.69	1.2	4.9	3.3	1.05E+10	5.1E+09	1.2E+10	1.9E+07	913197	23152964
CV (a)	8.8	15.2	5.8	6.3	28.8	48	30.5	38.8	47.5	37.9
CV (b)	6.3	10.3	4.4	4.9	22.9	29.8	21.4	24.3	47.4	24.1
Mean										
Rep (3)	389**	11.6^{ns}	4.3^{ns}	0.6^{ns}	3.1E+11^{ns}	3.5E+09^{ns}	3.5E09^{ns}	33863123^{ns}	3.4E+07^{ns}	2278435*
IRR (2)	41.1^{ns}	3.6^{ns}	61.3**	16.3*	1.7E+11^{ns}	1.5E+09^{ns}	1.5E09^{ns}	425290587**	4.3E+08**	3445620*
Ea (6)	17.7	3.6	15.0	2.1	2.1E+11	1.1E+09	1.1E09	26041947	2.6E+07	375941
N (3)	79.8*	12.2***	3.9^{ns}	4.4^{ns}	2.4E+11^{ns}	4.9E+09**	4.9E09**	81154645**	8.1E+07**	2640956^{ns}
IRR*N (6)	25.8^{ns}	2^{ns}	26.8^{ns}	1.5^{ns}	1.5E+11^{ns}	2.1E+09*	2.1E09^{ns}	77510565**	7.8E+07**	299269^{ns}
Eb (27)	26.5	1.5	92.6	2.1	1.7E+11	8.1E+08	8.1E08	14785487	1.5E+07	1009733
CV (a)	6.8	17.7	3.2	3.2	80.7	48.5	72.6	21.8	20.2	19.2
CV (b)	8.3	11.4	2.4	2.5	72.2	40.8	65.3	16.4	33	16

**PH = Plant height; NFCPP = number of fruit cluster per plant; FL = Fruit length; FD = fruit diameter; NUMF = Number of marketable fruits; NUUMF = Number of un-marketable fruit; TNUF = Total number of fruits; MFY = Marketable fruit yield; UMFY = Un-Marketable fruit yield; TY = Total yield; Ea = Error term for the main plot; Eb = Error term for the sub plot*

Partial Budget Analysis: According to the dominance analysis of the mean value; application of 75% ETc with 92 Kg N, 75% ETc with 138 Kg N, 100% ETc with 0 Kgha^{-1} N, 100% ETc with 138 Kg N, 125% ETc with 0 Kg N, 125% ETc with 46 Kg N and 125% with 138 Kg N were dominated by other treatments (1240) for the invested capital.

Table). Likewise, the combined application of 75% CWR with 46 Kg N, 100% CWR with 46 Kg N and 125% CWR with 92 Kg N Were fulfilled the reasonable minimum acceptable rate of return (MRR) (100%). The result indicated that the highest MRR was obtained from 75% CWR with 46 Kg N. Likewise, the combined application of 125% CWR with 92 Kg N also gave the minimum acceptable MRR. Hence, the highest net benefit (266272 ETB) and MRR (3890) were recorded from the combined application of 125% ETc with 92 Kgha^{-1} N and 75% ETc with 46 Kgha^{-1} N respectively (1240) for the invested capital.

Table). Therefore, application of 125% ETc with 92 Kgha^{-1} N resulted in highest net benefit as well as acceptable rate of return (1240) for the invested capital.

Table *8*. Partial budget analysis

Treatment	Mean (MFY)	*FGP	GB	CF	CL	TVC	NB	D	MB	MC	MRR
75ETc*0 N	17127	8.5	145580	0	21600	21600	123980	DM	0	0	
75% ETc *46 N	23942	8.5	203508	1450	21600	23050	180458		56477	1450	3890
75% ETc *92 N	13655	8.5	116067	2900	21600	24500	91567	DM			
75% ETc *138 N	18385	8.5	156272	4350	21600	25950	130322	DM			
100% ETc *0 N	19299	8.5	164049	0	28800	28800	135249	DM			
100% ETc *46 N	26277	8.5	223352	1450	28800	30250	193102		12644	7200	160
100%ETc*92 N	24510	8.5	208338	2900	28800	31700	176638		-16464	1450	-1140
100%ETc*138 N	23429	8.5	199148	4350	28800	33150	165998	DM			
125%ETc*0 N	22551	8.5	191679	0	36000	36000	155679	DM			
125%ETc*46 N	26329.2	8.5	223798	1450	36000	37450	186348	DM			
125%ETc*92 N	35903	8.5	305172	2900	36000	38900	266272		89634	7200	1240
125%ETc*138 N	29571	8.5	251354	4350	36000	40350	211004	DM			

**FGP=Farm gate Price of tomato; GB=Gross benefit; CF=Cost of fertilizer; CL= Cost of labour; TVC= Total variable cost; NB= Net benefit; D= Dominance; DM= Dominated treatment; MC= Marginal cost; MB= Marginal benefit; MRR= Marginal rate of return*

Conclusion and Recommendation

Tomato is Ethiopia's widely-grown vegetable crop but its production is affected by multiple biotic and abiotic factors and the average yield from farmer's fields is far below the crop potential. limited availability of improved cultivars that are suitable for different purposes, insect pest and disease, suboptimal application of nutrients and low soil fertility status especially N and P, water shortage are some of factor that infulence tomato production.

Irrigation regime and N nutrient application significantly affected most of the parameters under study. Significantly, the highest (35903 $Kgha^{-1}$) marketable tomato yield was observed with application of 125% ETc with 92 $Kgha^{-1}$ N. This treatment combination was also resulted in acceptable minimum rate of return for the invested capital. Therefore, application of 125% ETc with 92 $Kgha^{-1}$ N was recommended for tomato production in Eferatagidim district and similar areas.

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5. Yield-Limiting Plant Nutrients on Wheat Productivity under Irrigation in North Shoa Zone, Ethiopia

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Abstract

The consecutive two years over six locations field experiment was conducted during irrigation seasons of 2021 and 2022 on clay and clay loam soils to assess the yield limiting nutrients on growth, yield and yield components of wheat. The experiment consisted of 9 treatments, including application PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, and control (without nutrient input). Treatments were randomized and arranged in a randomized complete block design and replicated tree times at a site. The soil analysis result of the experimental locations indicated neutral to moderately alkaline soil reaction, low to moderate organic matter and total Nitrogen, medium to high available P, high to very high exchangeable K and low to medium ranges of available S. The grain and biomass yield result of the experiment revealed that Nitrogen is the most yield limiting nutrient and there was a reduction in wheat grain yield 29.13% 7.36% and 1.04% for the omission of N, S and P respectively. *Nutrients K, B and Zn omission resulted in no significant positive impact on yield, even there were cases that application of these nutrients showed yield penalty. There was high nutrient response variability across locations. All sites responded to N. While 67.0% of the study sites showed response to S application. Therefore, it can be concluded that not only N and but also, S important in the study site for the production of wheat under irrigation system.*

Keywords: Nutrients omission, Yield limiting nutrients, Wheat under irrigation, North-shoa

Introduction

Excessive degradation of soil fertility is the major consequence of low crop productivity (Paavola, 2008; Tena and Beyene, 2011; Shepherd *et al.*,2015). The lower productivity of crops in Ethiopia is mostly related to intensive cropping, imbalanced fertilization, inadequate application of organic manures, and soil erosion (Birhan *et al.,* 2016). Matching between applied nutrients, soil supplies and plant needs considerably improves the efficiencies of applied inputs, and productivity and profitability of crops (Akram *et al.*, 2022).

Wheat (*Triticum aestivum* L.) is an important crop which providing that supports about 35% of world population (Akram *et al.*, 2022)., Its global area coverage is about 220 million ha with a total of 750 million t production per year (Tadesse *et al.*, 2018). Its important is continuously increased over the years in Ethiopia and one of the most strategically important cereal crops prioritized by the government. The target of the government of Ethiopia is to increase the production of wheat both by increasing the productivity and increasing the area (including by irrigation). This target can be achieved by using efficient management of fertilizers, using improved seeds, management of pests, etc. Ethiopia is one of the major wheat producing countries in sub-Saharan African countries followed by South Africa, Sudan and Kenya (Tadesse *et al.*, 2018). The current productivity of wheat in the country is 3.88tha^{-1} (CSA, 2021) which is still lower compared to its attainable potential of greater than 5-tha-1 (Birhan *et al.,* 2016).

Nutrient management involves using crop nutrients as efficiently as possible to improve productivity while protecting the environment. When applied in proper quantities and at the right times, added nutrients help to achieve optimum crop yields; applying too little limit yield while applying too much does not make economic sense it rather can harm the environment (Khokhar, 2019).

For fertilizer use to be efficient and environment-friendly, balanced use is a prerequisite. Therefore, adequate mineral fertilization is considered to be one of the most important requirements for better yield and quality of crops (Parashar *et al.*, 2020). One nutrient could be more yield-limiting than the other in different soils and environmental conditions. Nutrient inadequacies can affect the crop's ability to utilize other nutrients supplied. This leads to the need for investigating yield-limiting factors in various regions of the country. Identification of the most yield-limiting nutrient is the most important in formulating nutrient management strategies to maximize the profitability of crop and forage production while protecting the environment.

In targeting the right fertilizers to the right places, the EthioSIS (2014) revealed that in addition to N and P, identified a number of essential plant nutrients that are deficient and critically required by the agricultural soils of the country. Accordingly, the country customized the use of a number of soil nutrients and that were identified deficient in the agricultural soils appeared on the fertilizer market before the validation studies.

Thus, the evaluation/validation of the soil fertility map developed by EthioSis can help to determine which nutrients are the most limiting to crop production and hence the nutrient omission technique the simplest and straight forward technique evaluates the nutritional requirements of crops and the most yield limiting nutrient (Laviola & Dias 2008; Miranda *et al.*, 2010). Therefore, this research was initiated to identify nutrient(s) that are major yield-limiting in Kewot and Efrata Gidim districts under irrigation for bread wheat production.

Materials and Methods

Description of the Study Areas: The experiment was conducted for two consecutive (2020-2021) irrigation seasons on six locations at Kewot (Chare, Wanza, Merye) and Efrata Gidim (Freedwoman, Yimilo1, and Yimilo2) districts. *Annual mean minimum and maximum temperatures were 10 and 25^{o}c, respectively.* The study locations have a uni-modal rainfall pattern and receiving an average annual rainfall range from 900-2000 mm at Kewot and 900-1200 mm at Efra tana Gidim. Vertisols are the dominant soil in the study area. Major crops grown under irrigation are onion, cabbage, tobacco and pepper, in decreasing orders of area coverage. Fig 1 represents the location map of the study areas.

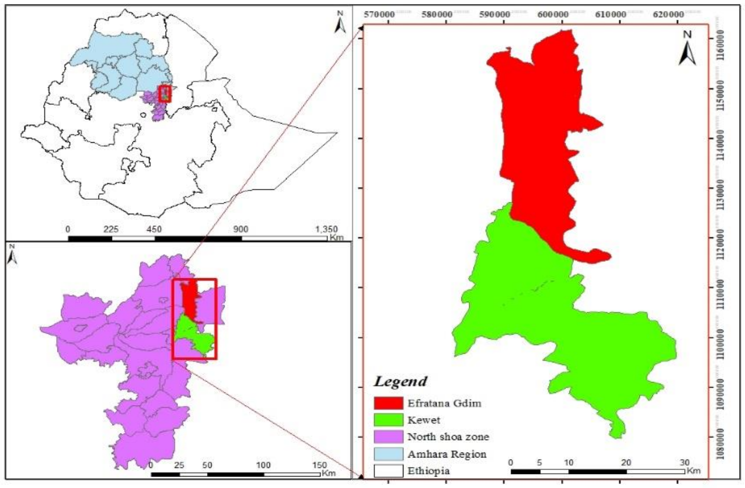

Figure 1. Location map of the study area

Treatments and Experimental Design: In an omission plot, adequate amounts of all nutrients are applied except for the omitted nutrient. The yield in such an omission plot is related to the soil supplying capacity of the omitted nutrient. The nutrient omission trials (NOTs) consisted of nine treatments i.e., PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, and control (with no nutrient input). The amount of each nutrient in the treatment (Kgha^{-1}) were N= 111, P_2O_5= 38, K_2O = 60, S= 10.5, Zn = 5, and B= 1. The experiment was laid out in randomized complete block design (RCBD) and replicated three times across each farmers' field.

Table1. Treatment details

No	Treatments	Treatment Details
1	- N (PKSZnB)	The N-limited yield is measured in a zero-N omission plot. The plot receives sufficient fertilizer P, K, S, Zn, and B to achieve high yield, but no fertilizer sources of N are applied.
2	-P (NKSZnB)	The P-limited yield is measured in a zero-P omission plot. The plot receives sufficient fertilizer N, K, S, Zn, and B to achieve high yield, but no fertilizer sources of P are applied.
3	-K (NPSZnB)	The K-limited yield is measured in a zero-K omission plot. The plot receives sufficient fertilizer N, P, S, Zn, and B to achieve high yield, but no fertilizer sources of K are applied.
4	-S (NPKZnB)	The S-limited yield is measured in a zero-S omission plot. The plot receives sufficient fertilizer N, P, K, Zn, and B to achieve high yield, but no fertilizer sources of S are applied.
5	-Zn (NPKSB)	The Zn-limited yield is measured in a zero-Zn omission plot. The plot receives sufficient fertilizer N, P, K, S, and B to achieve high yield, but no fertilizer sources of Zn are applied.
6	-B (NPKSZn)	The B-limited yield is measured in a zero-B omission plot. The plot receives sufficient fertilizer N, P, K, S, and Zn to achieve a high yield, but no fertilizer sources of B are applied.
7	NPKSZnB	Full fertilization of nutrients applied, Fertilizers N, P, K, S, Zn, and B are applied sufficiently to ensure that yield is not limited by an insufficient supply of the added nutrients. Grain yield in the plot with full fertilization and crop management can be used to estimate an attainable yield target
8	RNP	Only recommended amount of N and P is applied. The yield without N, P limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot
9	Control	The Nutrient-limited yield is measured in a no fertilizer that should not receive any fertilizer of N, P, K, S, Zn, and B.

Table 2. Each nutrient application rates ($Kgha^{-1}$)

No	Treatment	Nutrient ($Kgha^{-1}$)					
		N	$P_2 0_5$	$K_2 0$	S	Zn	B
1	- N (PKSZnB)	0	38	60	10.5	5	1
2	-P (NKSZnB)	111	0	60	10.5	5	1
3	-K (NPSZnB)	111	38	0	10.5	5	1
4	-S (NPKZnB)	111	38	60	0	5	1
5	-Zn (NPKSB)	111	38	60	10.5	0	1
6	-B (NPKSZn)	111	38	60	10.5	5	0
7	NPKSZnB	111	38	60	10.5	5	1
8	RNP	111	38	0	0	0	0
9	Control	0	0	0	0	0	0

Management of the Experimental Field: The NOTs study sites were randomly selected at 6 farmer lands each year. The experimental fields for all NOTs were prepared with an oxen-drawn moldboard plow before planting and human power at planting time. The plot sizes of each treatment was 7.2 m^2, and wheat variety Kekeba was used. Plant spacing of 20 cm between-rows was used and the space between plots and replications was 2m and 2.5m respectively. All nutrients were applied at planting while N was applied in two equal splits: half at planting, and the resthalf after 35 days of planting. Urea, triple superphosphate (TSP), Muriate of potash (MOP), Zinc EDTA, $MgS0_4$, and borax were used as fertilizer sources for N, P, K, Zn, S, and B, respectively. Weeds, diseases, and pests managements were uniform for all plots.

Data Collection: Parameters like growth and yield components (plant height, spike length, number of totals, and fertile tilers) and grain, and straw yield for each site were collected following the procedures stated below

Plant Height (cm): An average height of ten plants, in each experimental plot was measured from ground to the tip of the spike excluding awns.

Number of Total Tillers: number of total tillers was counted in each plot at different location of plot and values averaged for a single reading.

Number of Fertile Tillers Plant^{-1}: number of fertile tillers per plant was counted in each plot at different location of plot and values averaged for a single reading.

Spikes Length was measured from10 randomly selected spikes atharvest from each plot through measuring tape and average to represent the spike length in centimeters (cm).

Grain Yield (Kgha^{-1}): grain yield in Kg/plot and the moisture content was simultaneously measured for each treatment and finally adjusted to 12.5% moisture content.

Straw Yield (Kgha^{-1}): It was the difference between the total biomass yield and the grain yield.

Soil Sample Collection and Analyses: After selecting the experimental sites, pre-planting soil samples were collected from each site for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0-20 cm using an auger randomly from 10 spots by walking in a zigzag pattern. After thoroughly mixing, 1 Kg of the composite samples was taken and air dried and grounded to pass a 2 mm mesh-sized sieve.

The soil texture was anlysed following Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using the pH-water method by making a soil-to-water suspension of a 1: 2.5 ratio and was measured using a pH meter. The soil OC content was determined by the wet digestion method (Walkley and Black, 1934). Total Nitrogen (TN) was determined by using the modified micro Kjeldahl method (Coterie, 1980), and available P (ava. P) was analyzed using Olsen's calorimetric method as described by Olsen *et al.,* (1954).

Statistical Analysis: The collected data were subjected for the analysis of variance (ANOVA) using R software program using R version 4.2.1 (R Core Team, 2022). Normality and homogeneity of variance tests were checked and combined analysis for the 6 sites and the 2 years was done. The Least Significant Difference (LSD) at 5% level was used to separate the treatment means for those parameters that were statistically significant.

Results and Discussion

Soil Physicochemical Properties: The initial physicochemical characteristics of the experimental soil were determined using standard laboratory procedures as mentioned earlier. The soils of the experimental locations were belonging to clay to clay loam textural class. The soil pH of the study sites ranges from 6.7 to 8.16. The average the soil pH of the six sites is 7.52 with slightly alkaline soil reaction (Murphy, 1968), it is near to the ideal soil pH value of crop needs, therefore it needs closely monitored. Based on the analysis result the TC ranged low to moderate and he average was found in low TC soil chemical categories (Berhanu, 1980). TN was ranged from 0.067% to 0.165% with average value of 0.12 which was under low categories according to soil chemical characteristics (Tekalign,1991). The test crop was also significantly responded to the application N in the testing location. The available of soil P for the study sites ranged from 9.75 $mgKg^{-1}$ to 18.92 $mgKg^{-1}$. Based on the result the average available soil P content was under high range (Olsen *et al.*, 1954), the available P of the study sites was above the critical P content which is sufficient for crop production. Sufficient soil P is important for achieving optimal crop production, but excessive soil P levels may create a risk of P losses and eutrophication of surface waters. The test crop was not significantly responded to the application of P. There could be maintenance Phosphorus application is important. The soil analysis result showed low to medium ranges of available S (Hariram and Dwivedi, 1994). Based on this the soil analysis result indicated the average value of available soil S content is 5.21 ppm which was found to be below the critical value for crop production. The average exchangeable K is 1.65 ($cmolKg^{-1}$) it is very high exchangeable (FAO, 2006) and found to be surplus soil inherent K, it is above the critical level of soil K properties. The test crop was not responded to the application of K fertilizer.

Table 3. Soil Physical and Chemical properties

Location	pH (1:2.5)	Ex. K ($coolKg^{-1}$)	Av. P (ppm)	TN (%)	Av. S (ppm)	TC (%)	C/N ratio	Textural Class
Yimilo1	6.81	1.30	18.92	0.097	1.39	0.59	9.83	Clay loam
Yimilo2	6.70	1.98	17.91	0.067	7.12	0.92	13.71	Clay
Aregawy	8.16	1.60	9.75	0.101		1.04	10.26	Clay
Merye	7.96	2.30	11.55	0.165	*2.10*	1.23	10.40	Clay
Wanza	8.15	1.82	16.22	0.117	*1.42*	1.36	11.56	Clay
Feredewuha	7.36	0.92	18.87	0.171	14.01	2.03	8.70	Clay

Effects of Nutrient Omission on Yield Components of Wheat: Plant height, spike length, total and fertile tillers of wheat significantly varied due to nutrient omission treatments at 2 sites. The data from Table4 revealed that, the yield components of wheat didn't respond significantly to nutrient omission treatments, at Freedwoman, Areaway, Mere and Wanza sites but significantly responded at Yimilo 1 and 2 sites. While, the combined summarized data from. The data showed that the maximum plant height (77.67 cm) and spike length (8.cm) were obtained from the omitted Zn at Yimilo 1. While at Yimilo 2, application of all nutrients gave the highest plant height while the maximum spike length observed Zn omitted treatment. The mean number of productive tillers ranged from 6.73 to 8.0 at Yimilo 1 and 6.93 to 8.92 at Yimilo 2. The statistically lower plant height, spike length and productive tillers compared to other treatments were observed from the control and N omitted treatments.

Table 4. Effects of nutrient omission on plant height and spike length at each location

Treatment	Plant Height (cm)						Spike Length (cm)					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)	60.6c	71.20c	93.60	86.27	87.33	88.07	6.73b	7.26bc	8.52	8.83	8.00	8.80
-P (NKSZnB)	69.8bc	81.63ab	96.20	90.03	90.97	89.10	7.75a	8.55a	9.40	8.93	8.23	9.57
-S (NPKZnB)	73.67b	80.37ab	96.77	89.69	89.43	87.47	7.94a	8.92a	9.58	8.68	8.15	9.22
-K (NPSZnB)	72.23b	84.77a	95.17	90.55	89.97	87.00	7.85a	8.81a	9.04	8.53	8.13	9.18
-Zn (NPKSB)	77.67ab	84.93a	95.57	87.03	91.60	88.33	8.00a	8.46a	9.22	8.40	8.40	9.13
-B (NPKSZn)	71.13b	79.73ab	95.20	88.80	90.73	87.53	7.72a	8.64a	9.71	8.90	8.55	9.15
NPKSZnB	76.53ab	86.17a	95.37	88.03	90.87	88.43	7.75a	8.68a	9.47	9.13	8.37	8.87
RNP	76.83ab	82.00a	95.00	89.80	91.53	88.43	7.67a	8.60a	8.87	8.77	8.62	9.60
Control	59.47c	74.43bc	93.00	87.27	84.23	88.63	6.77b	6.93c	8.65	8.30	7.90	8.78
LSD (<0.05)	10.51	6.51	ns	ns	ns	ns	0.65	0.55	ns	ns	ns	ns
CV (%)	8.47	4.71	2.82	2.92	3.18	2.22	4.99	3.87	5.51	4.96	7.15	2.80

Effects of Nutrients Omission on Yield and Harvest Index: The analysis of variance showed that grain and straw yield responded significantly to nutrient omission treatments (Table 5 and 6). The mean combined data of grain and straw yield of wheat significantly influenced by nutrients omission. All sites responded to Nitrogen omissions strongly while, 67.0% to Sulphur. Omission of P, K, S, Zn and B had no statistical difference.

Table 5. Effect of nutrient omissions on the grain yield (Kgha^{-1})

Treatment	Sites					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)	1076.81b	2071.67b	2663.48c	5129.67c	4618.06c	5454.01
-P (NKSZnB)	3236.02a	4175.66a	4502.22a	6409.67a	5893.52ab	5088.00
-K (NPSZnB)	3241.01a	4408.65a	4352.68ab	6175.67ab	6208.33ab	5745.33
-S (NPKZnB)	2913.68a	4048.66a	4513.12a	5325.00bc	4560.65c	6072.02
-Zn (NPKSB)	3062.12a	4408.33a	4696.66a	6273.00ab	6458.33a	5296.33
-B (NPKSZn)	3211.81a	4729.33a	4565.65a	6361.00a	6048.61ab	5596.11
NPKSZnB	3230.30a	4133.33a	4288.33ab	6208.33ab	6118.06ab	5634.01
RNP	3216.33a	4278.00a	4491.57a	5588.00abc	5636.58b	6004.67
Control	1003.30b	2460.00b	2870.28c	4801.00c	3798.61d	5202.34
LSD (<0.05)	472.32	787.4	602.95	1030.6	717.19	ns
CV (%)	10.13	11.76	8.27	6.01	7.48	10.48

The combined data in Table5 and Figure 2 showed the highest grain yield (5085.30 Kgha^{-1}) was recorded from B omitted treatments followed by Zn and K omitted treatments (5035.5 and 5022.00 Kgha^{-1}) respectively. The lowest grain yield (3497.70 Kgha^{-1}) was obtained from the control (no nutrient applied) followed by N omitted (3539.20 Kgha^{-1}). Similarly, the lowest straw yield was observed from treatment that was not received any nutrient followed by N omission. The maximum straw yield was obtained from K omission. Nitrogen omission significantly reduced the grain and straw yield compared. In other treatments grain yield was observed significantly at par in comparison to treatment where all the nutrients were supplied except the control. The largest reduction in the grain yield was observed with the omission of Nitrogen followed by Sulphur and Phosphorus. The study showed that the grain and straw yield reduction was more noticeable with N omission. The yield reduction was also observed from S omission. The addition of K, Zn, and B caused grain yield penalty numerically compared to omission of those nutrients (Table).

The summarized data from Table and Figure showed that the reduction of grain yield due to omission of different nutrients from treatment that received all nutrients and relative importance of each nutrient in comparing with treatment that received all nutrients. Compared to the results of N omissions, the highest grain yield reduction (29.13%) followed by S (7.36%) and P (1.04%). Large reductions in the grain yield were observed with the omission of N and S compared to other nutrients. This implies that N is the most critical nutrient that affect grain yield considerably followed by S. Lower yield for N and S omission indicated that the N and S application cannot be supplied from the soil. This means the inherent N and S supplying capacity of the soil is not sufficient to for optimum production of wheat. It was in line with the soil analysis report from the study locations revealed that there was low total N content and low to medium available S (Table). Therefore, the present research finding revealed that N is the most yield limiting plant nutrient. Sulphur is becoming deficient and became a yield limiting nutrient in some sites of the study areas. The finding of this research is in line with the findings of Wondwosen and Sheleme, (2011), Ahmed *et al.,* (2014), Qureshi, (2016), and Ekka *et al.,*, (2020), stated that N is the most plant yield limiting nutrients and S is becoming deficient and identified as a yield-limiting nutrient. Assefa (2016) and Assefa (2022) studied the response of wheat to S on *vertisols* and *Nitisols* and his result indicated that that wheat significantly responded to S application. Soils that responded to S were having S below critical level S. In contrast to this study, reported by Abebe *et al.,* (2021), there was no a significance yield differences observed with application of all nutrients in the form of blended fertilizer compared to recommended NP.

Table 6. Effects of nutrients omission on straw yield of wheat (Kgha^{-1})

Treatment	Sites					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)	1457.87^{b}	2942.13^{c}	7766.20^{b}	7791.67^{bc}	5851.85^{c}	8990.67^{ab}
-P (NKSZnB)	3923.61^{a}	4842.59^{ab}	8971.76^{a}	9085.33^{abc}	7863.42^{ab}	10884.00^{ab}
-K (NPSZnB)	4073.61^{a}	5290.51^{a}	8617.59^{ab}	9745.67^{a}	7590.28^{b}	10956.00^{a}
-S (NPKZnB)	3854.63^{a}	6081.02^{a}	8261.10^{ab}	7772.33^{bc}	7389.58^{b}	9166.67^{ab}
-Zn (NPKSB)	4189.82^{a}	5526.85^{a}	8245.37^{ab}	9259.33^{ab}	8016.20^{ab}	10662.00^{ab}
-B (NPKSZn)	3852.78^{a}	5741.90^{a}	8580.09^{ab}	8597.33^{abc}	7821.76^{ab}	10217.00^{ab}
NPKSZnB	3957.41^{a}	5221.30^{a}	8896.76^{a}	9229.33^{ab}	7810.18^{ab}	9851.33^{ab}
RNP	3909.26^{a}	5541.67^{a}	9265.28^{a}	8206.00^{abc}	7097.22^{b}	9651.00^{ab}
Control	1552.41^{b}	3435.19^{bc}	5289.35^{c}	7356.67^{c}	5583.33^{c}	8531.67^{b}
LSD (<0.05)	1863.22	1163.13	1379.45	1029.39	1442.18	1127.12
CV (%)	7.36	9.18	8.06	17.39	16.80	7.93

Table 7. The effects of nutrient omission on mean grain yield, straw yield and harvest index over locations and years

Treatment	Grain Yield (Kgha^{-1})	Straw Yield (Kgha^{-1})	Harvest Index (%)
-N (PKSZnB)*	3497.70c	5800.10d	38.35
-P (NKSZnB)	4884.20a	7595.20ab	40.22
-K (NPSZnB)	5022.00a	7712.20a	40.33
-S (NPKZnB)	4572.10b	7087.50c	39.61
-Zn (NPKSB)	5032.50a	7649.90ab	40.37
-B (NPKSZn)	5085.30a	7468.40abc	41.17
NPKSZnB	4935.40a	7494.40abc	40.41
RNP	4776.50a	7278.40bc	40.85
Control	3439.20c	5291.40e	40.48
LSD (P<0.05)	201.21	458.39	ns
CV (%)	8.85	9.74	13.8

**NPKSZnB=All, RNP=recommended N and P, All-N=PKSZnB (N omitted), All-P= NKSZnB (P omitted), All-K = NPSZnB (K omitted), All-S= NPKZnB (S omitted), All-B= NPSKZn (B omitted), All-Zn= NPSKB (ZN omitted), control=no fertilizer (no nutrient) applied.*

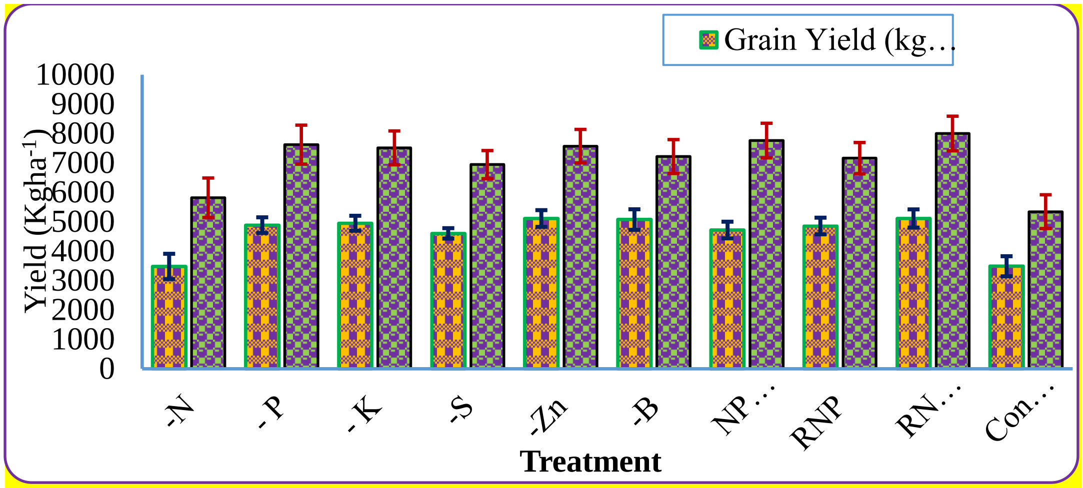

Figure 2. Effects of nutrient omission on grain and Straw Yield of Wheat under irrigation

Table 8. Grain yield reduction for each nutrient omission compared to all the nutrients added

Treatment	Grain Yield ($Kgha^{-1}$)	Grain yield reduction ($Kgha^{-1}$)	% Reduction
-N (PKSZnB)	3597.70	-1437.73	-29.13
-P (NKSZnB)	4884.20	-51.20	-1.04
-K (NPSZnB)	5022.00	86.60	1.75
-S (NPKZnB)	4572.10	-363.30	-7.36
-Zn (NPKSB)	5032.50	97.100	1.97
-B (NPKSZn)	5085.30	149.90	3.04
NPKSZnB	4935.40		
RNP	4776.52		
Control	3539.22		

Table 9. Straw yield reduction for each nutrient omitted compared to all the nutrients added

Treatment	Straw yield ($Kgha^{-1}$)	Straw yield reduction ($Kgha^{-1}$)	% Reduction
-N (PKSZnB)	5800.11	-1694.3	-22.61
-P (NKSZnB)	7595.21	100.80	1.35
-K (NPSZnB)	7712.20	217.81	2.91
-S (NPKZnB)	7087.52	-406.92	-5.43
-Zn (NPKSB)	7649.90	155.50	2.07
-B (NPKSZn)	7468.41	-26.00	-0.35
NPKSZnB	7494.42	-2203.01	-29.40
RNP	7278.40		
Control	5291.43	-	-

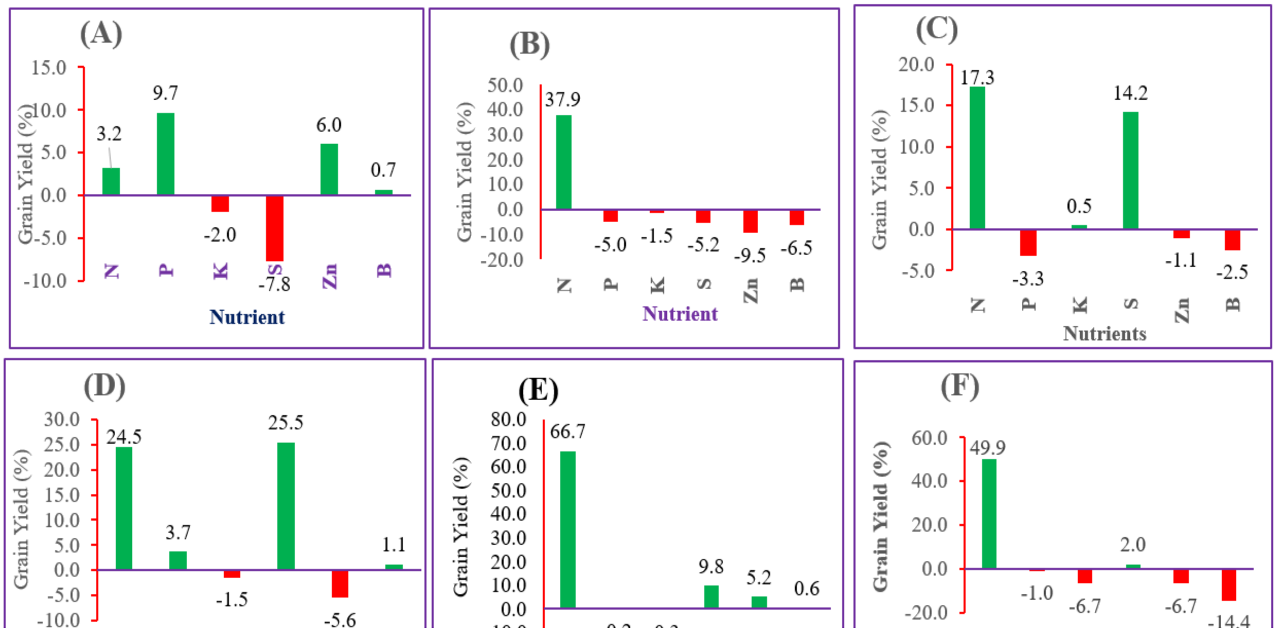

Figure 3. Relative importance of nutrients at (A) Aregawy, (B) Feredewuha, (C) Merye, (D) Wanza, (E) Yimilo-1, and (F) Yimilo-2 on grain yield of wheat

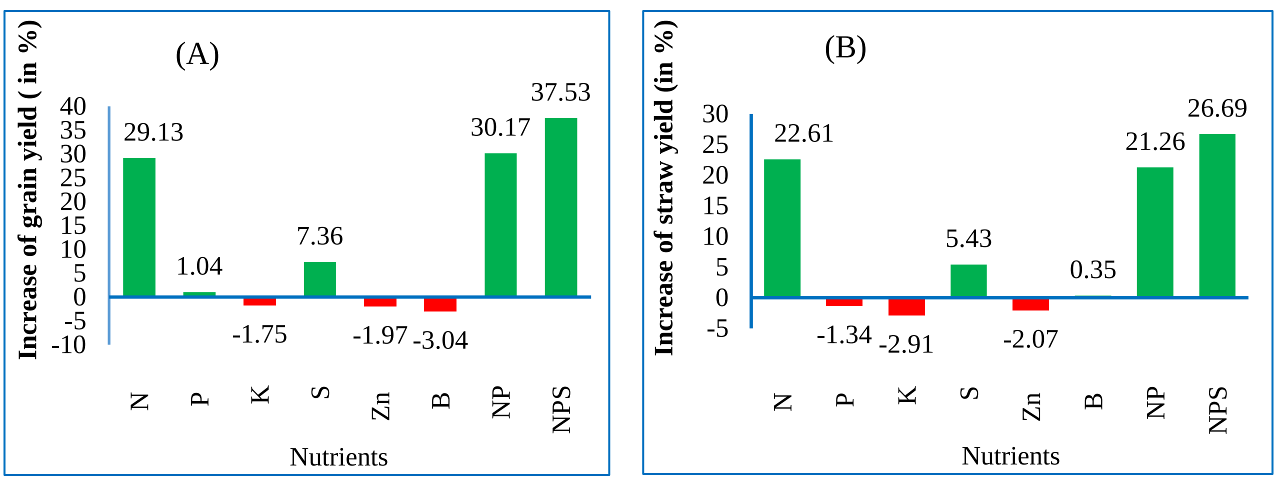

Figure 4. Mean relative importance of nutrients on the grain (A) and straw (B) yields

Conclusion and Recommendation

This study revealed that considerable soil nutrient variabilities exist within the study sites. The soil analysis result of the study sites showed that total N and S was in low to medium ranges. The highest grain yield (5085.30 Kgha^{-1}) was attained with B omitted followed by, Zn and K omitted (5035.5 and 5022.00 Kgha^{-1}) respectively. The lowest grain yield (3497.70 Kgha^{-1}) was obtained without any fertilizer input followed by N omitted (3539.20 Kgha^{-1}). There was no significance difference between RNP and application of all nutrients on grain yield. While, significantly lower grain yield was obtained from treatment received S omitted compared to RNP and All nutrients added. N, S, and P omission resulted in a grain yield penalty by 29.13, 7.36, and 1.04 % respectively. To attain the maximum wheat yield production under irrigation N is the most yield limiting nutrient. K, B, Zn nutrients did not show a positive yield increment. Therefore, only N, P and S were the yield limiting nutrients for the production of wheat under irrigation for the study sites.

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6. Yield-Limiting Plant Nutrients on Onion Productivity under Irrigation in North Shoa Zone, Ethiopia

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Abstract

The field experiment was conducted during irrigation season in 2022 to study the yield limiting nutrients on yield and yield components of onion. The experiment consisted of 10 treatments, involving application PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, recommended NP+30Kgha^{-1} S and control (without nutrient input). Treatments were randomized and arranged in a randomized complete block design and replicated three times at a site. The soil analysis result of the experimental locations indicated neutral to moderately alkaline soil reaction, low to moderate organic matter and total Nitrogen, medium to high available P, high to very high exchangeable K and low to medium ranges of available S. The Marketable onion yield result of the experiment revealed that Nitrogen is the most yield limiting nutrient and there was a reduction in marketable onion yield 10.6% for the omission of N. respectively. P, K, Zn and B nutrients omission resulted in no significant difference in marketable onion yield. Compared to the total nutrient's application. Therefore, N is yield limiting nutrient for the production of onion under irrigation for the study sites. Besides, maintenance Phosphorus application is important. Recommended NP alone gave better yield than S omitted. Application of RNP with 30 Kgha^{-1} S gave 19.05% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result also supported that, the study sites had low soil N and S chemical properties, the soil N and S content is below the critical value for crop production.

Keywords: Nutrients omission, Yield limiting nutrients, Onion under Irrigation, North-shoa

Introduction

Onion *(Allium cepa* L.*) is an important vegetable crop grown worldwide next to tomato.* Vegetables production grew faster between grown-up 65 percent (446 million to 1128 million tons) in 2019 compared to its status in 2000. Of the five vegetables that account about 42–45 % of the vegetables, the share of onion is about 9 % (FAO, 2020). The productivity of onion in Ethiopia is 8.89tha^{-1} and it is far below the world average (19.13tha^{-1}) according to FAO (2020). *T*he soil fertility is one of the major constraints for low onion productivity in Ethiopia *(*Kumilachew *et al.,* 2014; Alemayehu and Jemberie, 2018).

Fertilizer application to onion is required to attain maximum bulb yield as onion plants have shallow, sparsely branched root system (*Khalid, 2019*) that could not extract nutrients in the lower surfaces. Among the various factors a*ff*ecting the yield of crops, adequate mineral nutrient management plays a major role to optimize the quality and quantity of harvested plant products (Lakshmi & Sekhar, 2018). Nutrient management involves using crop nutrients as efficiently as possible to improve productivity while protecting the environment. When applied in proper quantities and at the right times, added nutrients help to achieve optimum crop yields; applying too little limit yield, while applying too much does not make economic sense it rather harms the environment (Khokhar, 2019).

Crop nutrient requirement varies with cultivars, yield potential, season, and locations. The steady depletion of native soil fertility and the occurrence of multiple nutrient deficiencies in farmers' fields, identified nutrient management as a key factor limiting sustainable onion production (Thangasamy, 2016). Nutrient inadequacies can affect the crop's ability to utilize other nutrients supplied. This leads to the need for investigating yield-limiting factors in various regions of the country. Identification of the most yield-limiting nutrient is the most important in formulating nutrient management strategies to maximize the profitability of crop and forage production while protecting the environment.

The productivity of vegetable crops significantly improves by application of nutrients. Onions are the most susceptible crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence they require and often respond well to addition of fertilizers (Brewster, 1994; Rizk *et al.,* 2012). In the target of the right fertilizers to the right places, EthioSIS (2014) revealed that in addition to N and P, identified a number of essential plant nutrients that are deficient and critically required by the agricultural soils of the country. Accordingly, the country customized the use of a number of soil nutrients and that were identified deficient in the agricultural soils appeared on the fertilizer market before the well-coordinated validation.

Thus, the evaluation/validation of the soil fertility map developed by EthioSiS can help to determine which nutrients are the most limiting to crop production and hence the nutrient omission nutrienttechnique is the simplest and straight forward technique that evaluates the nutritional requirements of crops and the most limiting nutrient (Laviola & Dias 2008; Miranda *et al.,* 2010). Therefore, this research was initiated nutrient(s) that are major yield-limiting in Kewot under irrigation conditions for onion production.

Materials and Methods

Description of the Study Area: The field experiment was conducted during in the irrigation season in Kewot district of North Shewa Zone at Aregay, and Merye sites. The trial was conducted on farmers' fields. Annual mean minimum and maximum temperatures were 10 and 25^{o}c, respectively. The study locations have a uni-modal rainfall pattern and receiving an average annual rainfall range from 900-2000 mm at Kewot. Major crops grown under irrigation are onion, cabbage, tobacco and pepper, in decreasing orders of area coverage. Fig 1 represents the location map of the study areas.

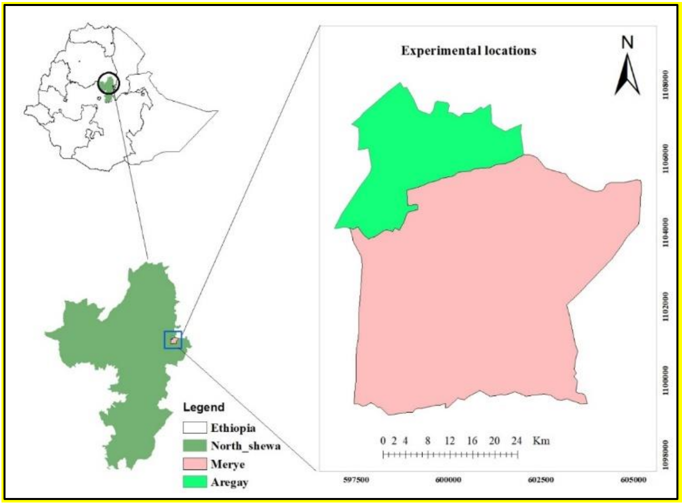

Table 1. Location map of the study area

Treatments and Experimental Design: The trials consisted of ten (10) treatments: Control (with no nutrient input), All-N, All-P, All-K, All-S1, All-B, All-Zn, RNP, RNP+S2 and All (NPKSZnB). The amount of each nutrient in the treatment (Kgha^{-1}) were N= 107, P_2O_5= 76, K_2O = 60, S1= 10.5, S2=30, Zn = 5, and B= 1. The experiment was laid out in randomized complete block design (RCBD) replicated three times across each individual farmers' fields.

Table 1. Treatment details

No	Treatments	Treatment Details
1	-N (PKSZnB)	The N-limited yield is measured in a zero-N omission plot. The plot receives sufficient fertilizer P, K, S, Zn, and B to achieve high yield, but no fertilizer sources of N are applied.
2	-P (NKSZnB)	The P-limited yield is measured in a zero-P omission plot. The plot receives sufficient fertilizer N, K, S, Zn, and B to achieve high yield, but no fertilizer sources of P are applied.
3	-K (NPSZnB)	The K-limited yield is measured in a zero-K omission plot. The plot receives sufficient fertilizer N, P, S, Zn, and B to achieve high yield, but no fertilizer sources of K are applied.
4	-S (NPKZnB)	The S-limited yield is measured in a zero-S omission plot. The plot receives sufficient fertilizer N, P, K, Zn, and B to achieve high yield, but no fertilizer sources of S are applied.
5	-Zn (NPKSB)	The Zn-limited yield is measured in a zero-Zn omission plot. The plot receives sufficient fertilizer N, P, K, S, and B to achieve high yield, but no fertilizer sources of Zn are applied.
6	-B (NPKSZn)	The B-limited yield is measured in a zero-B omission plot. The plot receives sufficient fertilizer N, P, K, S, and Zn to achieve a high yield, but no fertilizer sources of B are applied.
7	NPKSZnB	Full fertilization of nutrients applied, Fertilizers N, P, K, S, Zn, and B are applied sufficiently to ensure that yield is not limited by an insufficient supply of the added nutrients. Grain yield in the plot with full fertilization and crop management can be used to estimate an attainable yield target
8	RNP	Only recommended amount of N and P is applied. The yield without N, P limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot
9	RNP+S2	Recommended amount of N and P plus S2 is applied. The yield without N, P, and S2 limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot and the same S2 rate used in the –S2 plot
10	Control	The Nutrient-limited yield is measured in a no fertilizer that should not receive any fertilizer of N, P, K, S, Zn, and B.

Table 2. Each nutrient application rate (Kgha^{-1})

No	Treatment	Nutrients (Kgha^{-1})					
		N	P_2O_5	K_2O	S	Zn	B
1	- N (PKSZnB)	0	76	60	10.5	5	1
2	-P (NKSZnB)	107	0	60	10.5	5	1
3	-K (NPSZnB)	107	76	0	10.5	5	1
4	-S (NPKZnB)	107	76	60	0	5	1
5	-Zn (NPKSB)	107	76	60	10.5	0	1
6	-B (NPKSZn)	107	76	60	10.5	5	0
7	NPKSZnB	107	76	60	10.5	5	1
8	RNP	107	76	0	0	0	0
9	RNP+S2	107	76		30	0	0
10	Control	0	0	0	0	0	0

Management of the Experiment: All experimental fields were prepared with an oxen-drawn plough before planting and human power at planting time. The plot sizes of each treatment was 3m by 2.4 m (7.2 m^2). Bombay Red variety was used. The spacing of 5, 20 and 40 cm was between plants, row and ridge respectively while 2m between plots and 1,5m between replications used.

All nutrients were applied at planting while, N was applied in two equal splits: half at planting, and the resthalf after 45 days of planting. Urea, triple superphosphate (TSP), Muriate of potash (MOP), Zinc EDTA, $MgSO_4$, and borax were used as fertilizer sources for N, P, K, Zn, S, and B, respectively. Weeds, diseases, and pests managements were uniform for all plots.

Data Collection: Parameters like growth, yield and yield components (Plant height, bulb size, bulb weight, leaf number, marketable yield, unmarketable yield, total bulb yield for each site was collected with the procedures stated below.

Bulb Length (cm): The vertical average length of the matured bulb measured with a caliper.

Bulb Diameter (cm): The horizontal cross-sectional length of the matured bulbs of sampled plants measured with caliper at the widest point in the middle portion of bulbs

Mean Bulb Weight (gplant^{-1}): The average weight of matured bulbs, measured with balance atharvest.

Soil Sample Collection: After selecting the experimental sites, pre-planting soil samples were collected from each site for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0-20 cm using an auger randomly from 10 spots by walking in a zigzag pattern. After thoroughly mixing, 1 Kg of the composite samples was taken and air dried and grounded to pass a 2 mm mesh-sized sieve.

The soil texture was analysed following Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using the pH-water method by making a soil-to-water suspension of a 1: 2.5 ratio and was measured using a pH meter. The soil OC content was determined by the wet digestion method (Walkley and Black, 1934). Total Nitrogen (TN) was determined by using the modified micro Kjeldahl method (Coterie, 1980), and available P (ava. P) was analyzed using Olsen's calorimetric method as described by Olsen *et al.,* (1954).

Statistical Analysis: The collected data were subjected for the analysis of variance (ANOVA) using R software program using R version 4.2.1 (R Core Team, 2022). Normality and homogeneity of variance tests were checked and combined analysis for the 6 sites and the 2 years was done. The Least Significant Difference (LSD) at 5% level was used to separate the treatment means for those parameters that were statistically significant.

Results and Discussion

Soil Physicochemical Properties

The initial physicochemical characteristics of the experimental soil were determined (Table) using standard laboratory procedures as mentioned earlier. The soils of the experimental locations were belonging to clay textural class the average the soil pH of the two sites is 8.22 with moderately alkaline soil reaction (Murphy, 1968), it is above the ideal soil pH value of crop needs, therefore it needs closely monitored to amend with gypsum. Based on the analysis result the average TC and TN is 1.34 and 0.12 % respectively which is low categories according to soil chemical characteristics (Tekalign, 1991), the test crop was significantly responded to N application in the testing location. Medium range available P (Olsen *et al.,* 1954), the available P of the study sites was within the critical P content which is optimal for crop production. The average exchangeable K is 1.7 ($cmolKg^{-1}$) it is very high exchangeable (FAO, 2006) and found to be above the critical level of soil chemical properties. The test crop was not responded to the application of K fertilizer, this implies there was sufficient inherent soil K content. The soil analysis result showed low to medium ranges of available S (Hariram and Dwivedi, 1994). Based on this the soil analysis result indicated the average value of available soil S content is 8.86 ppm which was found to be below the critical value for crop production.

Table 3. Soil Physical and chemical properties

Location	PH (1:2.5)	Ex. K ($cmolKg^{-1}$)	OC (%)	AV. P (ppm)	T.N (%)	AV. S (ppm)	Texture (%)			Textural class
							Sand	Clay	Silt	
Merye	8.24	2.67	1.24	12.56	0.119	4.12	22	52	26	Clay
Aregay	8.2	0.72	1.43	13.20	0.114	13.60	10	60	30	Clay

Effects of Nutrient Omission on Yield and Yield Components of Onion: The yield components of onion showed no significantly response to nutrients omitted at all sites. However, it significantly ($p<0.01$) affected the marketable and total bulb yields (Table 4)

Table 4. ANOVA table for each parameter

Effects	PH	LL	LN	BL	BD	MBY	TBY
Rep	ns	ns	ns	ns	ns	ns	ns
Location	ns	ns	ns	ns	ns	*	*
Treatment	ns	ns	ns	ns	ns	**	**
Treatment*Location	ns	ns	ns	ns	ns	ns	ns
CV (%)	6.27	7.59	5.94	7.16	7.56	14.03	13.16

PH=plant height, Leaf Length, Leaf Number, Bulb Length, Bulb Diameter, Marketable Bulb Yield, Total Bulb Yield

Effects on Bulb Yeld: There was a significantly ($p<0.01$) effect of treatments on the marketable and total bulb yields at Merye site but non-significant at Aregay (Figure A and B). At Merye the highest marketable bulb yield (33.03 tha^{-1}) was recorded from the application of recommended NP fertilizer combined with 30 $Kgha^{-1}$ S followed by K omitted (28.10 tha^{-1}) treatments. The lowest marketable bulb yield (18.01 tha^{-1}) was obtained from control treatment followed by N omitted (20 tha^{-1}). A similar trend was observed on total bulb yield the highest total bulb (33.55 tha^{-1})

being from recommended NP combined with 30 $Kgha^{-1}$ S. In both marketable and total bulb yields omission of K and B resulted in a non-significant difference with treatments that resulted in the highest yield.

The result presented on Figure showed the mean marketable and total bulb yield. The result showed that, omitting some of the nutrients significantly influenced both marketable and total bulb yield of onion. The highest marketable bulb yield (25.5 tha^{-1}) was recorded with RNP+30 $Kgha^{-1}$ S followed by RNP (22.05 tha^{-1}). The lowest marketable bulb yield (15tha^{-1}) was obtained from control treatment followed by N omitted (16.83 tha^{-1}). The highest total bulb yield (26 tha^{-1}) yield was obtained from RNP+30 $Kgha^{-1}$ S. Nitrogen is the most yield limiting plant nutrient from the current study. The summarized data from Fig 3 showed that the relative importance of nutrients on marketable yield of onion due to omission of different nutrients from treatment that received all nutrients. In comparing the yield penalty of by omitting each nutrient, N resulted in the highest marketable bulb yield reduction (10.6%) followed by S (7. 6%). While application omitting of nutrients including P, K, Zn and B did not significantly affect marketable bulb yield. In short, K, P, Zn and B nutrients are not yield limiting nutrients for the onion production of the study area. This implies that N is the most critical nutrient that affect bulb yield of onion in the study area under current soil situation. Lower bulb yield from omission of N indicated the soil N is very low to support the production of onion for the attainable yield with the applied Nitrogen fertilizer. This means the inherent N supplying capacity of the soil is not enough to supply for the optimum production onion. The soil analysis result of N was the lower ranges. Hence, N is the most onion yield limiting nutrient for the study areas.

The result clearly showed that RNP alone gave better yield than S omitted, this might be the antagonistic interaction effect exist between nutrients. The previous study report stated, antagonistic effect of P and S nutrient effect on the uptake and utilization of each other nutrient and changes in N: S ratio affected by S and P application (Aulakh and Pasricha, 1977). In addition, other study revealed that, the interaction of soil nutrients affects their availability to crops as on overabundance one may result in deficiency of another nutrients (Karimizarchi *et al.*, 2014). Application of RNP alone gave 55.6%, 24.8% and 20.8% marketable bulb yield advantage than control, N omitted and S omitted respectively. Application of RNP with 30 $Kgha^{-1}$ S gave 19.05.0% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result supported that, the study sites had low to medium ranges, the one site soil S content is below the critical value for crop production (Hariram and Dwivedi, 1994). The K, P, B and Zn omission did not show bulb yield penalty, rather a slight yield increase was observed by omitting these nutrients. In Ethiopia, different Studies conducted on nutrient omission trials and on S showed different results leading to different conclusions. For instance, by Beamlaku *et al.*, 2023), revealed K, S, Zn and B were not yield limiting nutrients for tef production in Adet area. Similar result was also reported by Tadele *et al.*, 2022, stated that the most yield limiting plant nutrients for the production of maize for the majority of maize growing areas of Gojam was N followed by P while, K, S, Zn and B were not yield limiting. On the contrary, Kiros and Singh (2009) found that S application significantly increased grain yield, N-use efficiency and S uptake. Wondwosen and Sheleme (2011) also stated that S was identified as crop yield limiting nutrient in the Alfisols of southern Ethiopia. Based on Assefa's (2016) finding, S application on the *vertisols* and *nitisols* significantly affected the grain yield of bread wheat. He reported that soils of responding sites had S content below critical level S for optimum production of crop. Recently, research report by Assefa (2022) revealed, Nitrogen was the most yield limiting nutrient followed by S.

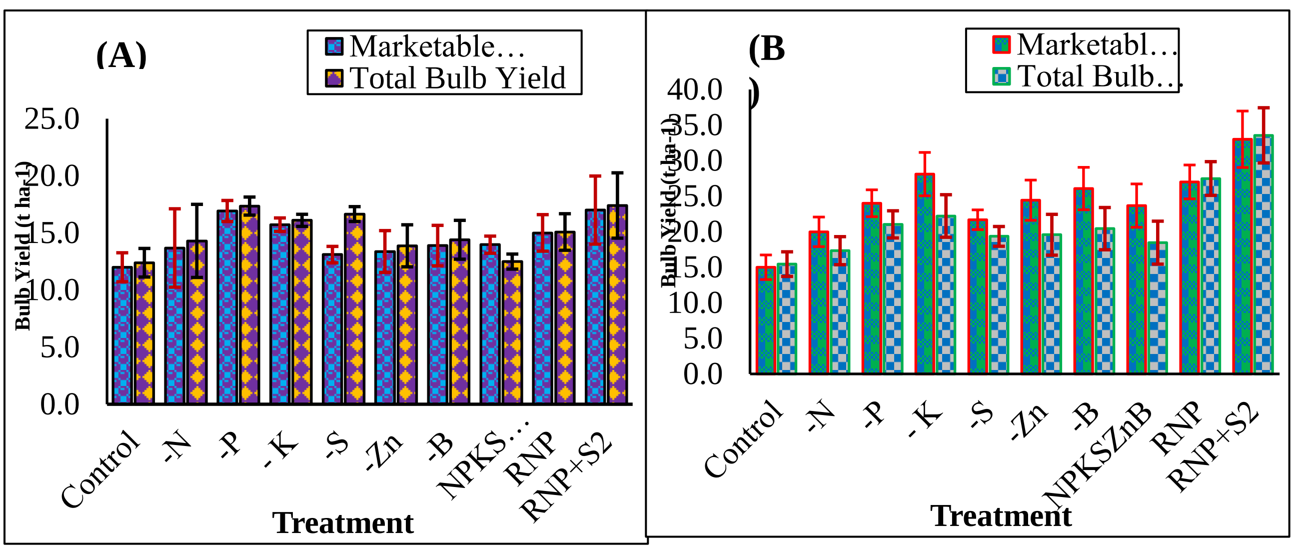

Figure 2. Effect of nutrient omission on Marketable and Total Bulb Yield at Aregay (A) and Merye (B)

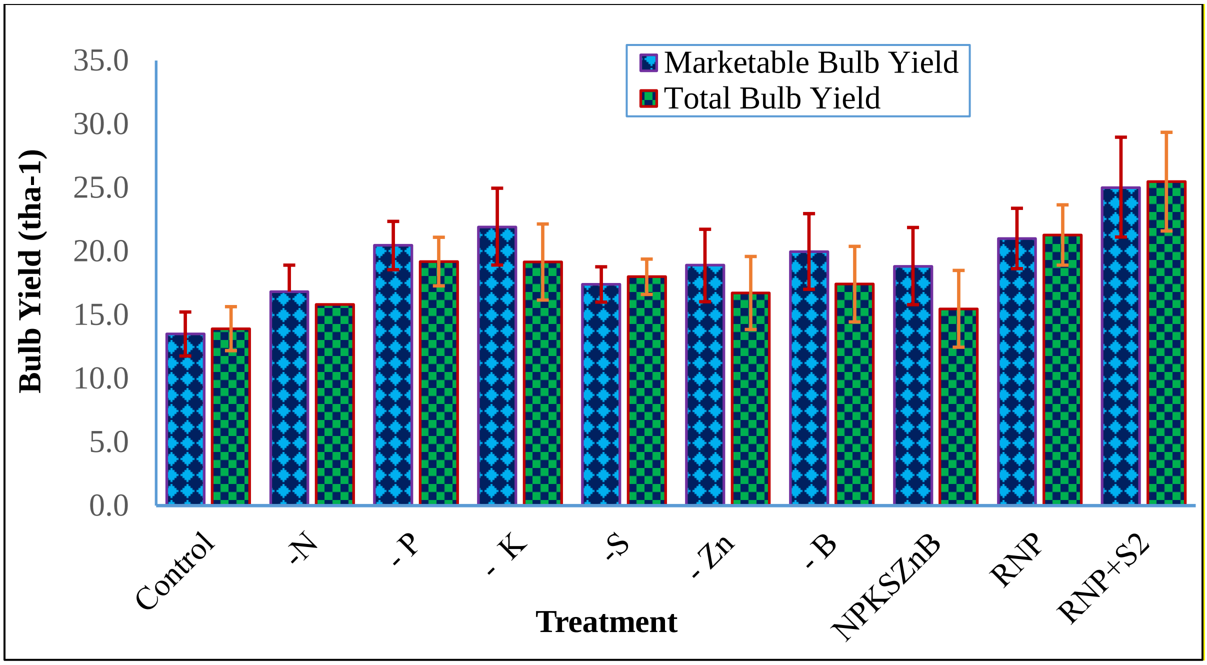

Figure 3. Effect of omitting of nutrients on mean marketable bulb yield and total bulb yield

Table 5. Marketable bulb yield reduction due to omission of nutrients to all nutrients added at Merye site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	19.98	-3.69	-20.71
-P	24.00	0.33	1.85
-K	28.10	4.43	24.86
-S	21.68	-1.99	-11.17
-Zn	24.43	0.76	4.26
-B	26.07	2.40	13.47
NPKSZnB	23.67		

Table 6. Marketable bulb advantage due to comparison of RNP from each treatment at Merye Site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb increment (tha^{-1})	% increment
Control	15.0	12.0	80.0
-N	19.98	7.0	35.1
-P	24	3.0	12.5
-K	28.1	-1.1	-3.9
-S	21.68	5.3	24.5
-Zn	24.43	2.6	10.5
-B	26.07	0.9	3.6
NPKSZnB	23.67	3.3	14.1
RNP+S2	33.0	-6.0	-18.2
RNP	27.0		

Table 7. Marketable bulb yield reduction due to omission of nutrients compared to all nutrients added at Aregay site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	13.67	0.30	1.68
-P	16.91	-2.94	-16.50
-K	15.65	-1.68	-9.43
-S1	13.10	0.87	6.22
-Zn	13.34	0.63	3.54
-B	13.88	0.09	0.51
NPKSZnB	13.97		

Table 8. Marketable bulb yield comparison of RNP from each treatment at Aregawy site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable yield increment (tha^{-1})	% increment
Control	12.0	3.0	25.1
-N	13.68	1.3	9.6
-P	16.92	-1.9	-11.3
- K	15.72	-0.7	-4.6
-S	13.1	1.9	14.5
-Zn	13.37	1.6	12.2
-B	13.89	1.1	8.0
NPKSZnB	13.97	1.0	7.4
RNP+S2	17.0	-2.0	-11.8
RNP	15.0		

Table 9. Overall mean marketable bulb yield reduction due to omission of nutrients compared to all nutrients added

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	16.83	-1.99	-10.60
-P	20.46	1.64	8.71
-K	21.91	3.09	16.25
-S	17.39	-1.43	-7.61
-Zn	18.9	0.16	0.85
- B	19.98	1.16	6.16
NPKSZnB	18.82		

Table 10. Overall mean marketable bulb yield comparison of RNP from each treatment

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable yield increment (tha^{-1})	% increment
Control	13.5	7.5	55.6
-N	16.8	4.2	24.8
-P	20.5	0.5	2.6
- K	21.9	-0.9	-4.2
-S	17.4	3.6	20.8
-Zn	18.9	2.1	11.1
-B	20.0	1.0	5.1
NPKSZnB	18.8	2.2	11.6
RNP+S2	25.0	-4.0	-16.0
RNP	21.0		

Conclusion and Recommendation

Based on the results over two testing locations it was revealed that the supplying capacity of the soils to N was low, medium available P, high to very high exchangeable K, low to medium soil S. The highest marketable bulb yield (25.5 tha^{-1}) was recorded with RNP+30 $Kgha^{-1}$ S followed by K omitted (28.10 tha^{-1}). While the lowest marketable bulb yield (18.01 tha^{-1}) was obtained from control treatment followed by N omitted (20tha^{-1}). The omission of N caused by 10.9% marketable bulb yield of onion. For that reason, the use of N nutrients increases onion productivity under irrigation condition. The effect of N, omission caused the highest bulb yield. N is the most considerably nutrient in the study area. Nutrients P, K, B, Zn omission have not significant impact on yield onion in contrary application of those nutrients have also yield penalty. In summary, based on the result, there was N nutrient response variability across locations and there needs rate determination on N with P nutrients. Application of RNP with 30 $Kgha^{-1}$ S gave 19.05% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result supported that, the study sites had low to medium ranges, the one site soil S content is below the critical value for crop production. Based on this there need more investigation to claim the soil of the study district deficient in S in addition to N and P.

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7. Effect of Inorganic Fertilizers and Green Manuring on the Yield of Subsequent crops of Irrigated and Rain fed System in the Lowland Areas of North Shewa

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Abstract

The experiment was carried out in the low land areas of north Shewa of Kewet district, Yelene farmers' training center (FTC) irrigation scheme in the 2017/18-2018/19 main and irrigation cropping seasons to evaluate the effect of green manuring and inorganic fertilization on yield and yield components of subsequent crops. This research was designed using Split Plot Design. The main plot used green manures which consisted of three levels, i.e: without green manure, incorporation of Crotalaria juncea and Tepherosia vogelii as green manure. The subplot was inorganic Nitrogen and Phosphorus (NP) fertilizer rate consisted of three levels: without NP fertilizer (control), 50% recommended fertilizer (RF) dose of NP and 100%RF dose of NP for onion and mung bean. The results showed that fertilization of inorganic NP and application of crotalaria green manure increase the yield of onion. Application of 50% recommended NP with Crotalaria juncea green manure gave 33.7 tha^{-1} onion yield compared to the same dose of NP without green manure (20.3 tha^{-1}). Based on this study, 50% recommended NP fertilizer with crotalaria juncea green manure is recommended for the production of onion in the study area. Therefore, promotion and expansion of the finding to sustainable production of the crop is critically important.

Keywords: *Crotalaria, green manure, onion, sorghum, tephrosia*

Introduction

Agricultural production is dependent on the soil and its level of fertility status and the supply of adequate nutrients. Inadequate nutrient supply and poor soil structure in most cases are some of the major constraints in our agricultural system as it seriously affects the resource poor farmers that practice low- input agriculture (Jaja *et al.,* 2015). The application of green manures to soil is considered a good management practice in any agricultural production system because it can increase cropping system sustainability by reducing soil erosion and ameliorating soil physical properties, increasing soil organic matter and othe plant nutrients, increasing nutrient retention, and reducing global warming potential (Tejada *et al.*, 2008).

Decline in soil fertility is one of the primary constraints to agricultural production in sub-Saharan Africa (Sanchez and Jama, 2002). In Ethiopia, farmers typically apply insufficient inputs to the soil, usually below the recommended rates of nutrients and organic fertilizers as a result soils of Ethiopia are in decline trends of their fertility status (IFPRI, 2010). Therefore, maintenance of soil fertility is a pre-requisite for long term sustainable crop production and soil health. The maintenance of soil organic matter is desirable for satisfactory crop production (Debnath, *et al.,* 2014). According to the report of soil fertility map of Amhara region by ATA (2016), cultivated soils of the region were on lower range of organic matter. Even old research reports indicated that the nutrient status Ethiopian soils is low (Hailu, 1988; Asnakew, 1994). The situation could be improved through various mechanisms including by the addition of different sources of organic manure to the soil, such as, farm yard manure, compost, crop residues, and organic wastes as well. Green manure is the cheapest source of organic manure that supplies Nitrogen, and other nutrients for crop production. The combined application of green manure and inorganic fertilizers increases the yield of crops and improve availability of nutrients in the soil as well as increase the nutrient recovery (Abedin and Mukhopadhaya, 1990). Moreover, green manuring along with inorganic fertilizer helps to release nutrient elements slowly during the period of crop growth (Singh *et al.,* 1990). Reports of different findings on integration of green manure and chemical fertilizers indicate significantly higher yield increase in wheat than that of sole application of chemical fertilizer (Akter *et al.,* 1993). Similarly research findings of green manuring on the *nitosols of Ethiopia was reported by Birhanu et al., (2012).*

Generally, green manuring has recently been under practice in different parts of the world.

Estimates suggest that a 40-50 days old green manure crop can supply up to 80-100 $Kgha^{-1}$ N. Some of the potential green manuring legumes are, *crotalaria juncea*, *cowpea*, and *mung bean*, etc.. *Crotalaria juncea*, and mung bean grown as green manure crops have been reported to contribute 8-21 tons of green matter and 42-95 $Kgha^{-1}$ N (Mishra and Naik, 2004). Crotalaria juncea has higher rate of biomass production and can produce dry matter to the extent of 16 to 19 tha^{-1} within a short period of 45-60 days and on an average about 5tha^{-1} dry matter can easily be produced, which is sufficient for meeting out nutritional demand of a crop during growing season (Lokesh *et al.,,.2015).* Fertilizer with doses of 135 Kg N ha^{-1} + 66 Kg P_2O_5 ha^{-1} and application of Crotalaria juncea green manure yield of maize obtained as many as 7.234 tha^{-1}, (Subaedah *et al.,* 2015). Crotalaria juncea is a strong Nitrogen fixer, resistant to root knot nematodes, and can be incorporated into the soil after little more than a month of growth. It can be used in rotation between primary crop plantings in both irrigated and dry land fields (Rutherford, 2009). Although it is well known that green manure plants are used worldwide as a source of organic fertilizer (green manure), they have not been fully utilized by farmers, particularly resource-poor farmers. Therefore, this study was conducted to evaluate the effect of green manuring and inorganic fertilization on yield and yield components of subsequent crops

Materials and Methods

Description of Experimental Site: The experiment was carried out at low land areas of north Shewa of Kewet district, Yelene farmers' training center (FTC) irrigation scheme in the 2017/18-2018/19 main and irrigation cropping seasons. The study site, Kewet, is located about 225 km from Addis Abeba in the north east direction, at an altitude of 1252 m.a.s.l and at 09^0 9' to 10^0 03'N latitude and 40^0 02' to 38^0 9'E longitude. The average annual rainfall is 760.2 mm and the mean maximum and minimum temperatures are 31.5 and 14.5°C, respectively. The rainfall distribution across months and main crop growing seasons during the two experimental years was indicated below in Figure 1.

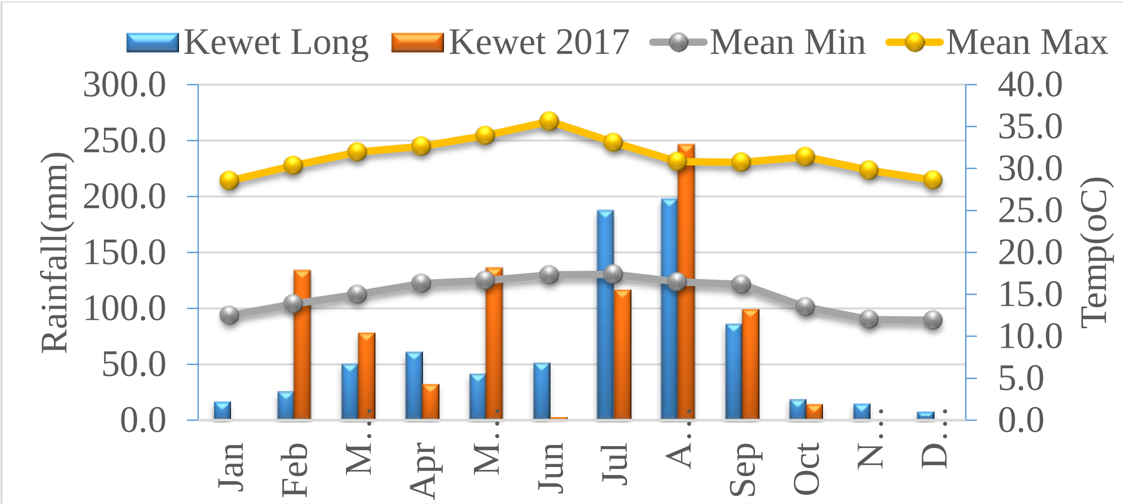

Figure 1. Rainfall distribution across months in the three experimental seasons

Experimental Design and Procedures: The experiment was conducted with two factors of split plot with three replications. It consisted of two green manure species and control as main plot and three rates of NP (0, 50% and 100% recommended dose). Plant species used for green manure were Crotalaria juncea and Tophrosia vogelli. The land was divided in to three blocks. Each block also was divided in to three main plots, and then each of the main plots were further divided in to 3 subplots with a size of 2.6m by 3m. The size of each main plot was 11m by 3m. The distance between the main plots and subplots were 1.5m and 1m respectively. Seed of green manure was drilled to a depth of 1cm between rows of sorghum in the rainy season as an inter crop at flowering plants were chopped and incorporated into the soil. On fresh and dry weight basis 5.93 and 1.48 tha^{-1} of crotalaria juncea green manure was incorporated but biomass of Tophrosia green manure was low to estimate its amount due to poor performance (Table 2). After harvesting of main season sorghum at December 1, 2017 the land was prepared and onion seedlings were transplanted on January 4, 2017. Recommended fertilizer 242 and 100 $Kgha^{-1}$ NPS and urea was applied. Then, before 20 days of harvesting of first irrigation crop green manure crops were drilled for second time as cover crops with irrigation (short fallow between 1st and 2nd irrigation-for about 8 weeks period) and was incorporated before the second irrigation). In the beginning of April 2018 yield data of onion such as marketable and unmarketable were collected. The general performance of both green manure species were not well established as compared to the first (main) season incorporated but already existed biomass was chopped and incorporated and irrigated.

After one month at the beginning of May 2018 the land was prepared and mung bean was sown at the rate of 40 Kgha^{-1} of seed rate with 121 Kg of NPS fertilizer as full recommendation of NP (100%), half of the recommended NP (50%) and 0% (no fertilizer). During the growing season of mung bean there was excess rainfall that determined the dry matter production of mung bean especially the development of pods that contribute for yield production. Harvesting of mung bean with data of plant height and straw yield was done on first July of 2018. Land was prepared on October 2018 and onion seedlings was transplanted on November first and harvested on mid-January of 2019 for last time.

To measure soil pH, Av. P, OC, TN, Av. K, and texture, soil samples were taken before to the experiment's commencement and following harvesting from each experimental treatment. Following Van Reeuwijk's (1992) instructions, the pH of the soil was measured in H_2O (pH-H_2O) using a pH meter and a 1:2.5 soil to solution ratio. the organic content of the soil, which was examined using Walkley and Black's methodology (1934). Jackson (1958) introduced the modified Kjeldahl approach that was used to determine the total Nitrogen (TN) content of soils. The Olsen extraction method was used to extract the available Phosphorus from soil samples (Olsen *et al.*, 1954). Using a spectrophotometer, the extract's P content was determined in accordance with Murphy's (1968) method.

Data Analysis: Collected data of onion and mung bean were analyzed using LSD at 0.05% of probability.

Partial Budget Analysis: A partial budget analysis using marginal rate of return and dominance was performed (CIMMYT, 1988). The average market price for onions and mung beans over the course of two consecutive years was used to calculate the output's economic worth. The labor force and average input cost applied to the inorganic and green manure fertilizers are utilized to determine the economic advantage of integrated fertilizer use.

Results and Discussion

Soil Chemical Properties: The proportions of sand, clay and silt were 68, 20 and 12 and its textural class was clay (Table 1). The pH value of the soils of the study site was alkaline. Percent soil organic carbon content was below critical level and available Potassium was medium to very high level (Table 1). Organic carbon content of the soil after green manure incorporation was found well improved. Ghoous *et al.*, (2018) reported that soil organic carbon increased proportionaly to the added organic matter.

There were statistically significant variations in the available Phosphorus content when the effects of green manure species were examined using analysis of variance. The findings are displayed in Table 1, with the mean available Phosphorus concentration for each treatment of green manure. Tephrosia had the greatest mean accessible Phosphorus value of 20.76 ppm, whereas crotolaria had the lowest mean available Phosphorus content of 17.89 ppm. By comparison, the lowest mean accessible Phosphorus level of 16.19 ppm was obtained with the treatment of none green manure. Numerous variables, including as soil fertility, nutrient availability, and the application of green manure, affect Tephrosia's growth rate and biomass output. Leguminous plants like tephrosia are frequently grown as green manure crops to increase soil fertility and fix Nitrogen. However, in comparison to other green manure crops like crotalaria, its growth rate and biomass output can be lower. The availability of Phosphorus in the soil has been found to be one factor influencing Tephrosia's low and slow development rate (Vanlauwe *et al.*, 2014).

Table 1. Selected physical and chemical properties of the experimental soil before planting and after harvesting

Before planting	pH (1:2.5)	OC (%)	TN (%)	Av. P (ppm)	Exch. K ($cmolKg^{-1}$)	Clay	Silt	Sand	Textural Class
	7.74	1.44	0.11	13.01	2.35	68	20	12	Clay
After harvesting									
Crotalaria juncea	7.75	1.57	0.129	17.89					
Tephrosia	7.70	1.53	0.124	20.76					
Sole	7.79	1.50	0.123	16.19					

Effects of Intercropping Green Manure on the Growth and Yield Components of Sorghum

The grain yield of sorghum was not significantly affected by intercropping and averaged 6002 $Kgha^{-1}$ in crotalaria, 6802 $Kgha^{-1}$ in tephrosia, and 5424 $Kgha^{-1}$ in sole was obtained. Plant height and thousands kernel weight of sorghum was also not significantly affected by intercropping, and averaged plant height and thousands kernel weight of sorghum were 250.7 cm and 25.4 g in crotalaria juncea, 254.5 cm and 26.2 g in tephrosia vogeli and 260.8 cm and 26.3 gm in sole green manuring intercropping respectively (Table 2)

Table 2. Mean response of Sorghum growth and yield parameters for intercropping of green manure at Kewet District, 2017/18

Treatment	Fresh/Dry biomass green manure (tha^{-1})	PH (cm)	Grain Yield ($Kgha^{-1}$)	TKW (g)
1.Crotalaria juncea	5.93 (1.48)	250.67	6002.2	25.43
2.Tephrosia	-	254.50	6802.2	26.18
3.Sole	-	260.77	5424.2	26.28
CV (%)		4.30	13.45	11.65
LSD (0.05)		ns	ns	ns

The results showed that, at first irrigation 2017/18 after incorporation of green manure marketable yield of onion was affected significantly ($p<0.05$) by different fertilizer dose of fertilizer and green manure application. As the dose of recommended fertilizer increases the marketable yield of onion was also increased and the highest marketable yield (42.2 tha^{-1}) was obtained by the application of full recommended dose of fertilizer and crotalaria green manure incorporation followed by full dose of fertilizer application with sole green manure incorporation (39.4 tha^{-1}). This result is consistent with the results of research conducted by Sukartono *et al.,* (2011) who report the increase in the levels of organic carbon and Nitrogen with organic fertilizer application.

Table 3. Mean response of onion and mug bean growth and yield component for application of green manure and inorganic fertilization on different Irrigation season at Kewet district, 2018

Green Manure	2017/18 Marketable onion (tha^{-1})			2018 Mung bean ($Kgha^{-1}$)			2018/19 Marketable onion yield (tha^{-1})		
	0%RF	50%RF	100%RF	0%RF	50%RF	100%RF	0%RF	50%RF	100%RF
Crotalaria	25.0^{bc}	36.0^{ab}	42.2^{aa}	586.3^{ab}	380.5^{cd}	302.6^{d}	15.6^{c}	31.3^{a}	30.7^{a}
Tephrosia	19.3^{c}	26.1^{bc}	35.0^{ab}	472.5^{bcd}	508.7^{bc}	509.2^{bc}	18.3^{bc}	26.5^{ab}	34.2^{a}
Control	20.9^{c}	33.2^{aba}	39.4^{a}	551.6^{abc}	724.3^{a}	571.0^{abc}	15.8^{c}	29.2^{a}	30.4^{a}
CV (%)	20.9			21.7			19.4		
LSD (5%)	11.15			220.6			8.51		

Table 4. Mean response of onion marketable yield for application of green manure and inorganic fertilization on irrigation season at Kewet district, 2018

GreenManure	Marketable onion		
	0%RF	50%RF	100%RF
Crotalaria	20.3^{cd}	33.7^{a}	36.4^{a}
Tephrosia	18.8^{d}	26.3^{bc}	34.6^{a}
Sole	18.3^{d}	31.2^{ab}	34.9^{a}
CV (%)	20.4		
LSD (5%)	6.7		

Economic Analysis: The partial budget analysis data of the various treatments is presented in Table 5. The highest net benefit (70,761 ETB) with marginal rate of return (MM) of 912.4% was obtained from only half dose of recommended inorganic fertilizer utilization, while the next higher net benefit (70,493 ETB) with MMR of 340% was obtained from dose of recommended inorganic fertilizer utilization treatment only. But as integrated soil fertility management perspective using green manure in the farming system is incomparable with sole utilization of inorganic fertilizer but using integration of both nutrients sources is indispensable. From this study 50% recommended fertilizer with crotalaria juncea as green manure material is advantageous with the benefit of sustainable production system.

Table 5 Partial budget analysis

Treatment	TVC	GR	NB	MRR%
Tephrosia + 0%	1200	46554	45354	D
Crotalaria + 0%	3000	51024	48024	148.3
Sole + 50%	5492	76253	70761	912.4
Tephrosia + 50%	6692	62884	56192	D
Crotalaria + 50%	8492	76134	67642	636.2
Sole + 100%	10984	81477	70493	114.4
Tephrosia + 100%	12184	80221	68037	D
Crotalaria + 100%	13984	80473	66489	D
Sole + 0%	-	46520	46520	D

Conclusion and Recommendation

Based on these findings, intercropping of Crotalaria juncea had no significant influence on main season sorghum production while providing a benefit of soil improvement for later crops such as onion yield enhancement when compared to non-fertilized plots with green manure. Crotalaria juncea might be intercropped throughout the main season to increase biomass output of green manure, which benefits from a favorable environment and growing conditions. Application of 50% recommended fertilizer with the addition of crotalaria green manure as organic fertilizer is a preferable option for resource-constrained farmers, reducing the price the of inorganic fertilizer expenditure by 50% in the research locations.

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8. Identification of yield-limiting nutrient for Onion (*Allium cepa*) and Tomato (*Solanum lycopersicum*) in Raya Kobo district under irrigation

Samuel Adissie, Kassa Sisay, Habtemriam Teshome, and Tigabu Fenta

Abstract

Knowing the most yield-limiting soil nutrient is crucial process for feeling yield gap in all crop production systems. The proper supply of nutrients in balanced amounts is essential for the maximum production of onion and tomato. The study was conducted to know the response of onion and tomato to the omission of different nutrients to their growth and yield under open field conditions at Raya kobo District during 2020/21 under irrigation. The experiment was laid out in the Randomized Complete Block Design (RCBD) with three replications. The soil samples were taken using an auger before planting for the analysis of the physicochemical properties. Analysis of variance was computed using R software. The analysis result showed that statistically the lowest marketable yield of onion was recorded from the omission of nitrogen and from the control treatment. In contrast, the highest total unmarketable yield of onion was recorded from the control treatments. Similarly, the combined analysis showed that the highest marketable yield was recorded from Boron omitted plots with significant difference from N omitted and the control and at par with the others. In contrast, the lowest total marketable yield was recorded from the control and N-omitted treatments. There was also a substantial and positive correlation between marketable yield and the number of clusters per plant and no fruit/cluster at (P <0.01). The analysis of variance indicates that N was the most yield-limiting nutrient for both onion and tomatoes production than any other nutrient. This study was conducted to know which nutrient was yield limiting and did not address what amount was needed. Therefore, optimum fertilizer rate determination on the yield-limiting nutrient should be conducted

Keyword: Fertilizer, Nitrogen, Omission,

Introduction

Soil fertility heterogeneity in smallholder farming systems is a major factor that affects productivity and the suitability of crop and nutrient management recommendations for different locations. The optimum productivity of any cropping system depends on an adequate supply of plant nutrients. Even if all other factors of crop production are optimal, the fertility of the soil largely determines the ultimate yield. It describes the available nutrient status of the soil and its ability to provide nutrients for optimum plant growth (Dev., 1997). Fertilizer is one of the most important sources to meet this requirement. However, indiscriminate use of fertilizers may cause adverse effects on soils and crops, both in terms of nutrient toxicity and deficiency, either through overuse or inadequate use (Ray *et al.,* 2000).

Diagnostic techniques (omission of nutrients), including identification of deficiency symptoms, soil and plant analysis, are helpful in determining specific nutrient stresses and the quantity of nutrients needed to optimize the yield (Havlin *et al.,* 2007). The optimal amount of nutrients is the main issue, particularly in Ethiopia, for the development of vegetables (Melkamu *et al.,* 2022). Soil fertility evaluation, thus, is the key to adequate and balanced fertilizer application in crop production.

Ethiopia has enormous potential to cultivate vegetable crops on a small as well as large commercial scale. The country has a high potential to benefit from onion production, and the demand for onions is increasing over time due to their high bulb yields, seed, and flower production potential (Lemma and Shimelis, 2003).

Among the common irrigated vegetables, onion accounts for the largest area coverage and local consumption in Ethiopia. In particular, onion it is a popular vegetable grown under irrigation in most of the traditional and recent modern irrigation schemes in the Amhara region.

Tomatoes are also of high economic importance vegetables in Ethiopia. The reward of tomato cultivation is a high yield, usually achieved by following the proper fertilizer recommendation. Fertilization of the tomato plant significantly impacts crop yield. In Ethiopia, farmers experience decreasing yields primarily due to pests, diseases, and inadequate fertilization (Yemane *et al*., 2016). According to Kassa (2018), limited use of agricultural inputs, particularly improved seeds and fertilizers, contributes to low tomato production and productivity.

Tomatoes have proven advantageous to societies in terms of sustenance, trade, and well-being. However, Ethiopia's tomato output falls considerably short of the average production levels seen in some other nations, and the fruits are of poor quality (Yebirzaf *et al*., 2016). Tomato production in Ethiopia is constrained by several factors, with sub-optimal fertilizer application and the selection of high-yielding varieties being the most important. Nutrient deficiencies limit agricultural yields worldwide, and the availability of these vital elements not only satisfies the nutritional needs of the tomato crop but also boosts its growth and productivity. The use of balanced fertilizers and appropriate variety recommendations are important agronomic practices used to increase the growth and quality of tomatoes (Tsedu *et al.*, 2021).

Onions and tomatoes are also of the most widely produced and highly commercialized vegetable crops in Kobo district, North Wollo Zone of the Amhara Region. The crop is grown in the area under irrigation. Among the different varieties of onion, Bombay Red has been the most widely cultivated commercial vegetable crop using pressurized (drip and sprinkler) and gravitational irrigation since the establishment of the Kobo Girana Valley Development Program Office (KGVDP) in 1999. However, the productivity of the crop in the district is 9.46 tons per hectare (KGVDP, 2013), which is far less than the regional average (12.3 tons per hectare) and the world average bulb yields (19.31 tons per hectare), respectively (CSA, 2020/21). There are a number of constraints that contribute to the low productivity of onions and tometoes in Ethiopia. The low yield of onions and tometoes in the country is reported to be due to low soil fertility, inappropriate fertilizer rates, lack of improved varieties, and poor management practices (Lemma and Shimelis, 2003). As a result, this study was conducted to determine the most yield-limiting nutrients for onion and tomato production.

Materials and Methods

Description of the Study Area

The experiment was conducted at Raya kobo District in 2020/21 under irrigation.

The district is located at 571 km North of Addis Ababa, the capital city of Ethiopia, 360 km far from Bahir Dar (the capital city of Amhara region) and 50 km North of Woldia town. Geographically the experimental site is located at 12°09‘N latitude and 39°38‘E longitude with an elevation of 1468 meters above sea level (figure 1)

Based on the data from Kobo meteorological station the rainfall pattern is characterized by seasonal, poor distribution and erratic with a mean annual rainfall of 559.3 mm that ranges from 294-679 mm. The study district has a mean annual minimum and maximum temperature of 12.12 °C and 32.69 °C, respectively. The district receives high rainfall in July and August.

The district is characterized by mixed farming (that is crop and livestock production). The most commonly produced crops are sorghum (*Sorghum bicolor* (L.) Moench), teff (*Eragrostis tef* Zucc.Trotter), and pulse crops like chickpea (*Cicer arietinum* L.), mung bean (*Vigna radiata*) and lentil (*Lens culinaris*). Currently, farmers are tring producing additional vegetable crops such as onion *(Allium cepa),* tomato *(Solanum lycopersicum)* and other horticultural crops for sale.

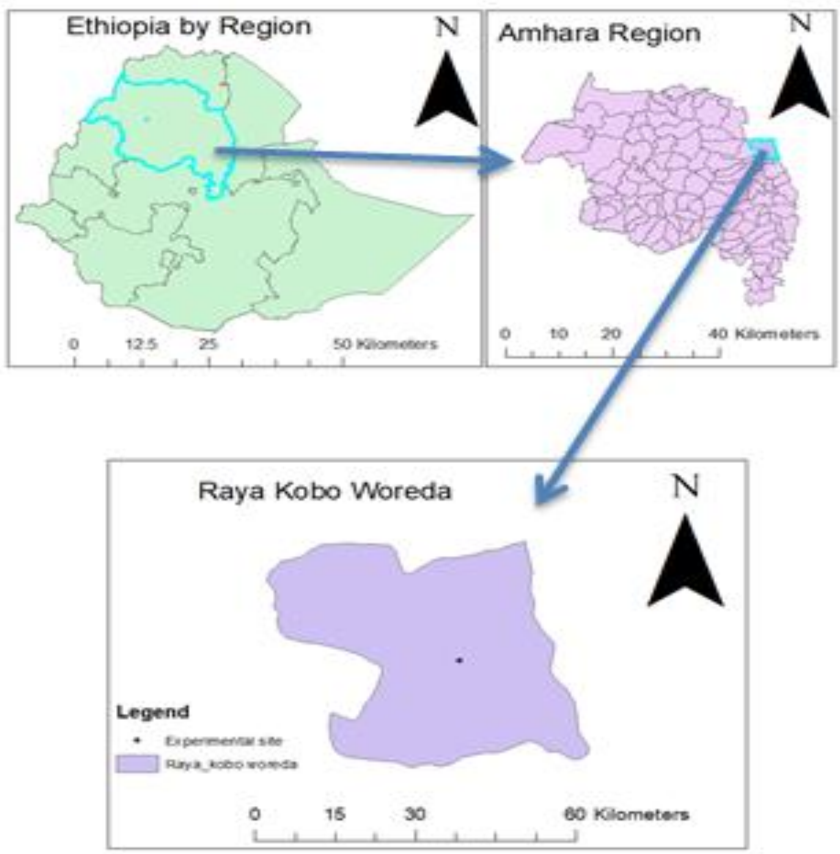

Figure 1. Location of the study area

Treatments and Experimental Design

The treatments were laid out in Randomized Complete Block Design (RCBD) replicated three times. The experiment consisted of nine treatments with the following arrangements.

1. NPKSZnB (all)
2. NPKSZn (-B)
3. NPKSB (-Zn)
4. NPKZnB (-S)
5. NPSZnB (-K)
6. NKSZnB (-P)
7. PKSZnB (-N)
8. RNP
9. No fertilizer

The full doses of all fertilizers with respective treatments except the nutrients to omit were applied as basal dose and remaining half rate of nitrogen was applied at knee height stage. Urea, Triple Super Phosphate (TSP), Murate of Potash (MOP), Calcium Sulfate ($CaSO_4.2H_2O$), Zinc Sulfate ($ZnSO_4.7H_2O$) and Borax ($Na_2B_4O_7.5H_2O$) were used as sources of fertilizer for supplying N, P, K, S, Zn and B, respectively. The detailed description of fertilizers and their amount is described in Table 1:

Table 1. Detail description of fertilizer rate

Treatments	Nutrient rates (Kgha^{-1})					
	N	P	K	S	Zn	B
NPKSZnB	92	92	30	10	5	2
NPKSZn	92	92	30	10	5	0
NPKSB	92	92	30	10	0	2
NPKZnB	92	92	30	0	5	2
NPSZnB	92	92	0	10	5	2
NKSZnB	92	0	30	10	5	2
PKSZnB	0	92	30	10	5	2
RNP	92	92	0	0	0	0
control	0	0	0	0	0	0

RNP = Recommended nitrogen and Phosphorus

Experimental Procedure for Onion: Bombay Red onion variety was used as an experimental material. It was released by Melkasa Agricultural Research Center during 1980. The variety has a characteristic of medium-red bulb color, erect leaf arrangement and flat globe bulb shape. It is an early maturing variety taking less than 120 days to reach maturity (MoANRS 2011).

A nursery bed of 10 m long and 1 m wide was marked out and cleared. The land was ploughed thoroughly and made into a fine tilth. The onion seeds were drilled at 10 cm distance between rows lightly covered with the soil. The pots were irrigated daily using watering can. Weeds were frequently removed as they emerge in the nursery by hand pulling. Vigorous, healthy, good-looking seedlings and nursery beds were selected for transplanting and the seedlings were irrigated one day before removing to facilitate uprooting. After 55 days, the seedlings were transplanted late in the afternoon to reduce the risk of desiccation and poor establishments.

The experimental field was ploughed two times using oxen. Large sized clods were broken-down to make the land to fine tilth, and the field was then marked out into blocks and plots. The spacing between blocks and plots were 1.5 and 1 m respectively. Experimental plots with a size of 2.4 m × 3 m (7.2 m^2) were prepared and ridges were made with a spacing of 40 cm × 20 cm × 10 cm. The intra and inter-row spacing were 10 and 20cm respectively. There were six rows per plot each row having 20 plants with a total number of 120 plants with a net experimental area of 6.6 m^2. The experiment was conducted under furrow irrigation method and the source was river water. The irrigation interval after transplanting was two times in a week for the first 4 weeks for better establishment and then extended to five days' interval until 14 days remained to harvest. All other agronomic practices were applied uniformly for all plots

Experimental Procedure for Tomato: Seedlings were raised in nursery beds at Kobo sub center; the beds of 1×10 m size were well prepared and were raised 5 cm from the soil surface to provide good drainage for the removal of surplus irrigation water. The seeds were sown in rows spaced 15 cm apart and covered lightly with fine soil and then with two-three cm thick grass mulch before irrigation. The beds were irrigated every day until the seeds germinated fully and twice a week afterwards. Transplanting of seedlings on experimental field was done at 3-5 true leaf stage when seedlings attained the height of about 15-25cm. Recommended agronomic practices such as weeding, cultivation, irrigation, fertilizer application, staking and disease management were carried out uniformly during the growing season for all plots. The experimental sites were prepared using standard cultivation practices before planting. Trial fields were plowed using oxen-drawn implements by farmer as usual.

Seedlings were carefully transplanted after 7 weeks to the experimental plots (3×4m dimensions) which were prepared to accommodate 40 plants per plot (four rows) at a recommended spacing of 100 cm between rows and 30 cm between plants (Lemma, 2002). The spacing between two plots in each replication and between adjacent blocks was 1m and 1.5 m, respectively. The total amount of fertilizers was applied during transplanting while urea was applied in two equal splits. The first half of urea was applied at the time of planting while the remaining half was applied 21 days after transplanting of seedlings. Watering was done using furrow irrigation at three days interval. Experimental plots were irrigated every day for the first two weeks to secure uniform establishment and then at weekly interval. Experimental plots were kept free from weeds manually and other cultural practices such as disease and insect pest control were performed as per the recommendation for tomato production. Disease was managed by application of recommended fungicides (Ridomil) at a rate of 3.5 $Kgha^{-1}$ in seven days' intervals.

Data Collection

Onion Yield and Yield-Related Data

Plants in the central four rows were used for data collection, leaving aside plants in the border rows and those at the end of each row.

Plant Height: it was measured from the ground to the shoot tip of the main plant from randomly selected 10 plants at maturity.

Bulb diameter (polar and equatorial diameter): Bulb diameter of five sample bulbs was measured both vertically and horizontally using caliper.

Marketable Bulb Yields: it is the weight of healthy and marketable bulbs (20 g to 160 g in weight). Bulbs below 20 g in weight are considered too small to be marketed whereas those above 160 g were considered oversized according to Lemma and Shimeles (2003).

Unmarketable Bulb Yield: The total weight of unmarketable bulbs that are under-sized (< 20 g) and oversized (160 g)

Total Bulb Yield ($Mgha^{-1}$): The total bulb yield was measured from the total harvest of net plot as a sum weight of marketable and unmarketable yields in Kg per plot and finally converted into tha^{-1}.

Tomato Yield and Yield Related Data

Plant Height (cm): Heights of five randomly selected plants from the ground level to the apex grown in net plot area using meter were measured at maturity stage and the mean values were used for further analysis.

Number of Clusters Per Plant: The number of clusters in five randomly selected plants in the plot was counted at 50% flowering and the mean values were used for further analysis.

Number of Fruits Per Cluster: The number of fruits in lower, middle and upper clusters of five randomly selected tomato plants was counted and the mean values were computed and used for further analysis.

Fruit Length (cm): The fruit length of five randomly selected marketable fruits from each plot was measured using caliper meter from the neck of the fruit to bottom and their average was calculated in centimeter (cm).

Fruit Diameter (Width) (cm): The diameter of five randomly selected marketable fruits at the middle portion of fruits from each plot was measured using caliper and the mean values were taken for analysis.

Marketable and Unmarketable Yield (tha^{-1}): Diseased, insect pest, physiologically, and mechanically damaged fruits were considered as unmarketable (Lemma, 2000), while fruits free from any visible damages were considered as marketable. Both marketable and unmarketable fruits obtained from each net plot area were separately weighed with analytical balance in Kg and converted into hectare basis.

Total Fruit Yield (tha^{-1}): It was obtained by adding marketable and unmarketable fruit yields.

Soil Sampling and Analysis: Soil samples were collected from each of the selected farmers' fields. Soil samples from each site were randomly collected from the 0 to 20 cm deep plough layer using an auger. The collected soil samples were air dried at room temperature and were ground to pass through a 2 mm sieve for most parameters and through 0.5 mm sieve to determine total nitrogen and organic carbon. Soil pH was determined by a pH meter after extraction from a soil: water ratio of 1:2. Organic matter was determined using the Walkley and Black dichromate method (Nelson and Sommers, 1982) and total N using Kjeldhal's method (Bremner and Mulvaney, 1982) For available P determination, Olsen's (Olsen *et al*., 1954) method; exchangeable K was estimated by 1M ammonium acetate extraction followed by flame photometric determination.

Statistical Data Analysis: All the measured parameters were subjected to analysis of variance (ANOVA) appropriate to completely randomized block design using R software and the interpretations were made following the procedure described by Gomez and Gomez (1984). Treatment means that were significantly different were compared using Duncan's Multiple Range Test (DMRT) at 5% level.

Results and Discussion

Physicochemical Properties of the Soils on Onion Site

Results of pre-sowing soil analysis showed that soils of the experimental sites were clay loam in texture (Table 2). The total nitrogen was 0.14%, and this range is low level (Tekaligne *et al*., 1991). This implies that in the study area, nitrogen is deficient and onion yield is to be increase with the increasing of nitrogen up to certain range. The soil organic matter was found to be medium level according to Berhanu (1980). The soil reaction (pH) of the trial site was 6.4 and it is conducive for any agriculture. Available phosphorus is high according to (Olsen *et al.*, 1954). According to Jones (2003) all K, B and Zn are adequate in the study area.

Table 2. Physico-chemical property of the trial site

P^H	OM	T.N (%)	Avail P(ppm)	K (ppm)	Zn (mg Kg^{-1} Soil)	B (mg Kg^{-1} Soil)	%clay	%silt	%sand
							32.5	32.5	35
6.4	1.85	0.14	17.3	210	1.2	3.1	Clay loam		

Effect of Omission of Nutrients on Yield and Yield-Related Parameters of Onion

Application of micronutrients and macronutrients for onion did not contribute for plant height and equatorial diameter as it is indicated in table (3). We find also application of all nutrients is not significantly affected polar diameter as compared to application of nitrogen and phosphorus. It was slightly affected when all nutrients are omitted. From table 3.3 it is clearly indicated that, only nitrogen and phosphorus may be required to improve yield related parameters of onion. Our result is contradicted with the result of ((Kiros *et al.*, 2018); MANNA *et al*., 2014) which stated application of boron and zinc significantly improve vegetative growth, plant height, bulb diameters. (Awatef *et al*., 2015) also contradicted with our result who showed that application of potassium increased plant height and diameters of onion.

The marketable yield of onion is influenced by the omission of nitrogen. Omission of nitrogen is statistically similar with the control treatment. Application of all nutrients in the study area is not statistically different from the recommended rates of nitrogen and phosphorus nutrients. Omission of phosphors was not found also to be yield-limiting nutrient as there was not yield reduction when it was omitted. This implies that to boost the yield of onion in the study area, only the nitrogen fertilizer is required with a maintenance application of P.

In agreement with the current finding, sole application of nitrogen can influence bulb yield of onion (Gateri *et al.,* 2018; Tekalign *et al*., 2012; Abdissa *et al*., 2011; Biesiada and Kołota, 2009). This may be attributed that the nitrogen content in the study area is low as it is indicated in critical nutrient range table (Table 2). But in contradicted to the finding of (Tilahun *et al.,* 2021), who stated the interaction of nitrogen and sulfur increases onion yield there was not interaction of any nutrients to increase bulb yield of onion as it was only influenced with nitrogen.

Our finding also differ from the findings of (Mandal *et al.,* 2020) who stated that addition of sulfur increases yield of onion. From the result, it is observed that application of macronutrients other than nitrogen did not impose significant marketable onion yield difference over the control. This may be attributed to the lowlands of Eastern Amhara which is rich with phosphorus, potassium and sulfur either depositing from highlands or it is naturally rich with those mineral nutrients

Micronutrients did not impose significant marketable bulb yield to onion in our study. This result contradicted with the findings of (Prusty *et al.,* 2020) who stated application of micro nutrients (Zn and B) brought significant yield difference over the control. Non responsiveness on the application of micronutrients in the lowlands of eastern Amhara on marketable onion yield, may be attributed to the natural richness of micronutrients on the study area as it is indicated in critical range table (Table 2).

Table 3. Effects of nutrient omission on plant height, polar diameter and equatorial diameter

Treatments	PH(cm)*	Polar diameter(cm)	Equatorial diameter(cm)
NPKSZnB (all)	45.2	4.6ab	4.7
NKSZnB (-P)	45.0	4.6ab	5.0
NPKSZn (-B)	43.8	4.5ab	4.9
RNP	43.9	4.7a	4.8
NPKSB (-Zn)	44.3	4.4ab	4.9
NPKZnB (-S)	45.1	4.8a	5.1
NPSZnB (-K)	44.4	4.5ab	4.9
PKSZnB (-N)	41.5	4.6ab	4.9
Control	41.5	4.3b	4.8
CV	5.6	4.6	5.1
Sig. Levele (5%)	ns	*	ns

**PH= Plant height, means with the same letters are not significantly different*

Table 4. Effect of nutrient omission on total yield, marketable and unmarketable yield of onion (ton/ha)

Treatments	Un marketable yield (ton/ha)	Marketable yield (ton/ha)
NPKSZnB (all)	0.5ab	17.5 a
NKSZnB (-P)	0.4ab	17.0 a
NPKSZn (-B)	0.3 b	14.7 ab
RNP	0.5 ab	15.7 ab
NPKSB (-Zn)	0.4 ab	17.5 a
NPKZnB (-S)	0.4 ab	15.6 ab
NPSZnB (-K)	0.4 ab	14.3ab
PKSZnB (-N)	0.4 ab	12.5 b
Control	0.6 a	12.4 b
CV	28	13.5
Sig. Levele (5%)	*	*

Means with the same letters are not significantly different

Physico-Chemical Properties of the Soil on Tomato Sites: The experimental site analysis results indicated that soil particle size distribution of the experimental sites was in proportions of 35% of sand, 32.5% of silt, and 32.5% of clay with the textural class of clay loam (Table 5). The analysis result shows that the available P content was 17.3 mg Kg-1 (Table 5) which is rated as medium according to (Cottenie, 1980). The total nitrogen content was 0.11% which is ranged at low level according to Tekalign's (1991) classification. Similarly, organic carbon content was 1.85% which is ranged at a low level according to Tekalign's (1991) classification.

Table 5. Physico-chemical properties of the soil before planting

Ph*	OM	T.N (%)	Avail.P (mg Kg^{-1})	%clay	%silt	%sand
				32.5	32.5	35
6.4	1.85	0.11	17.3	Clay loam		

*: *pH = Power of Hydrogen, OM=organic matter, T. N=Total Nitrogen, Avail. P=Available phosphorous*

Effect of Omission of Nutrients on Yield and Yield-Related Parameters of Onion

Effects of Omission of Nutrients on Number of Clusters per Plant: The Number of clusters produced per plant deferred among the tested treatments. Among the treatments NPKSB produced the highest number of clusters per plant (20.1) followed by NPSZnB, NPKSZnB and NPKSZn treated plots (Table 6). On the other hand, smallest number of cluster per plant (9.6) was obtained from the control plot (no fertilizer plot). The observed difference in the production of clusters is probably due to the application of nitrogen fertilizer. The maximum number of clusters per plant might be due to the effects of fertilizers in promoting flower bud formation. In line with this Nishat *et al*., (2021) noted that the number of cluster $plant^{-1}$ in tomato increased as the rates of NPSBZn fertilizer increased and the plants in plots which did not receive fertilizer showed minimum number of cluster $plant^{-1}$.

Effects of Omission of Nutrients on Number of Fruits per Cluster: Omission of nutrient showed variations in the number of fruits per cluster. The highest number of fruits per cluster (67.7) was recorded from potassium omission plots, while control treatment produced the lowest fruit number per cluster (23.3) (Table 6). The results are in agreement with the findings of Islam *et al*., (2018) minimum no of fruit per cluster was found in control treatment. Additionally, Yemane *et al*., (2018) reported that statistically least number of fruits per plant was observed at the zero rate of urea.

Effects of Omission of Nutrients on Plant Height: There was a significant effect ($P < 0.05$) of fertilizers on tomato plant height via application of mineral fertilizers as compared to each treatment. Significantly, the longest plant height (102.7cm) was obtained from plots treated with NPSZnB as compared to other treatments, while the shortest plant height (81.9cm) was recorded from non-fertilized plot (Table 6). This might be due to the application of nitrogen mainly related to the production of new shoots and improvement of vegetative growth, which is directly related to the increase in plant height. The results of this study coincide with the findings of Aman and Rab, (2013) who reported that the longest plant height was observed with the application of N while lowest plant height was observed with control. The findings were in line with Nishat *et al*., (2021) who reported that with increase of nitrogen level up to 300 Kg/ha, the plant height increased while Phosphorus had no significant influence on plant height. The findings of the present investigation are in conformity with the reports of Manoj *et al.*, (2013) who reported that plants under the lowest level of fertilizer remained significantly dwarf when compared with the rest of the treatments and also the height of tomato plants increased significantly with the increased levels of nitrogen.

Effects of Omission of Nutrients on Number of Branches per Plant: The number of branches per plant is an important parameter which indicates the yielding capacity of tomato variety (Shushay *et al*., 2013). The highest number of branches per plant (7.5) in this study was counted in NPSZnB treated plots which is significantly different from the control but not with other treatments (Table 6). The result of this experiment is in conformity with the findings of Manoj *et al.,* (2013) who reported that the branching was increased due to the application of inorganic fertilizers and Tsedu *et al.,* (2021) stated that non-fertilized plots produce the lowest number of branches.

Table 6. Effects of omission of nutrients on plant height, number of cluster plant^{-1}, number of fruit cluster^{-1} and number of branch plant^{-1} combined over sites

Treatments	Plant Height	Polar diameter	Equatorial diameter	No of cluster/plant	no fruit/cluster	no branch/ plant
NPKSZnB (all)	97.3^{ab}	9.4	5.2	18.7^{a}	50.8^{ab}	7.3^{a}
NKSZnB (-P)	90.7^{abc}	8.9	5.5	16.4^{ab}	49.2^{ab}	6.2^{ab}
NPKSZn (-B)	99.4^{a}	9.3	5.4	16.9^{a}	48.7^{ab}	6.6^{ab}
RNP	93.9^{abc}	8.9	5.4	15.9^{ab}	47.8^{ab}	5.8^{ab}
NPKSB (-Zn)	97.2^{ab}	9.1	5.6	20.1^{a}	60.3^{a}	7.4^{a}
NPKZnB (-S)	85.2^{bc}	8.9	5.4	15.5^{ab}	50.0^{ab}	6.6^{ab}
NPSZnB (-K)	102.7^{a}	8.9	5.4	19.5 ^{a}	67.7^{a}	7.5^{a}
PKSZnB (-N)	92.1^{abc}	8.7	5.4	11.2^{bc}	34.1^{bc}	5.5^{ab}
Control	81.9^{c}	8.7	5.2	9.6 ^{c}	23.3^{c}	4.7^{b}
CV (%)	7.2	4.2	3.8	18.8	24.5	21.1

Effects of Omission of Nutrients on Marketable, Unmarketable and Total Yield of Tomato: In the present study the analysis of variance revealed that the highest marketable fruit yield was recorded by application of NPKSZnB which were statistically different when compared with omission of N and non-fertilized plots but not with others (Table 7) in both sites. The lowest fruit yield was recorded from non-fertilized plots followed by omission of nitrogen (Table 7). This experiment indicates that fertilizer application is one of the most important factors for obtaining economical yield of tomato. The result of this experiment is in conformity with the findings of Nemomsa Beyene and Tilahun Mulu 2019 and Nishat *et al*., (2021) who reported that the lowest fruit yield was found in no fertilized plots or nil nitrogen fertilizer. Fertilizer N application affected, total and marketable fruit yields of tomato (Edossa *et al*., 2013). Acedo and Benitez (2021) stated that with inorganic NPK fertilizer marketable yields increased with increasing rates of application by more than two to three folds.

Accordingly, the highest unmarketable fruit yield was recorded in non-fertilized plots (Table 7) while the lowest marketable yield was noted by application of all nutrients (NPKSZnB) in farm one but, for farm two there were not statically significant different in terms of un marketable yield. The results are generally in agreement with Melkamu *et al.*, (2022) who reported that the more unmarketable yield was recorded at the unfertilized or controlled treatments.

Among all the treatments, the highest total marketable yield (34.8 tha^{-1}) was obtained from application of recommended NP fertilizers but not statically significant from omission of K, ZN, B, S and fully fertilized plots however, both treatments gave values significantly higher than the control. Similarly, the lowest total marketable yield (18.9 &19.9 t ha^{-1}) was found from nitrogen missing plots and non-fertilized plots respectively in farm one. On the other hand, in farm two highest total marketable yield (33.1t ha^{-1}) were obtained from the application of NPKSZn (B omitted) fertilizer which is significantly different from omission of N and control treatments but not with others (Table 7). Like farm one significantly lowest total marketable yield was recorded from control treatment followed by N omitted plot. Based on the combined analysis, the highest marketable yield was recorded from B omitted plots with significantly differ from N omitted and control treatments. Similarly, the combined analysis of total marketable yield shows that omission of N and control gives lower total yield compared to other treatments (Table 8). As illustrated in Table 8 below even if the highest total yield were obtained from omission of B it was not significantly differ from omission of P, K, S, Zn, recommended NP and application of NPKSBZn. This study indicates that the yield of tomato crop was affected by fertilization especially by nitrogen this might be the presence of low quantity of nitrogen in the soil of study site. The lowest yield in the unfertilized plot indicates that the indigenous soil is unable to supply sufficient amount of nutrients while the lower yield of N omitted plots indicates that N application cannot substitute by any other nutrient and has highest contribution to tomato yield.

The result of the present investigation agrees with the findings of Melkamu (2022) who reported that the maximum total fruit yields of tomatoes were obtained from the combined nitrogen and phosphorous application. In line with the present study Bilalis *et al*., (2018) noted that the highest fruit yield was obtained under inorganic fertilization. Ilupeju *et al*., (2015) also stated that application of fertilizer (organic or inorganic) improved the growth and fruit yield of tomato.

Table 7. Effects of omission of nutrients on marketable, unmarketable and total yield of tomato

Treatments	Marketable yield (t ha^{-1})		unmarketable yield (t ha^{-1})		total yield (t ha^{-1})	
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2
NPKSZnB (all)	24.3^{a}	30.5^{a}	5.4^{b}	5.6	29.6^{ab}	36.2^{a}
NKSZnB (-P)	16.9^{ab}	24.7^{ab}	6.8^{ab}	4.4	23.7^{bc}	29.1^{abc}
NPKSZn (-B)	24.2^{a}	27.9^{a}	7.8^{ab}	5.2	31.9^{ab}	33.1^{a}
RNP	26.2^{a}	23.8^{abc}	8.7^{a}	3.5	34.8^{a}	27.4^{abc}
NPKSB (-Zn)	23.3^{a}	23.6^{abc}	9.2^{a}	4.8	32.5^{ab}	28.5^{abc}
NPKZnB (-S)	23.9^{a}	26.0^{ab}	8.3^{ab}	4.9	32.2^{ab}	30.9^{ab}
NPSZnB (-K)	16.9^{ab}	25.2^{ab}	8.4^{a}	5.8	25.4^{abc}	31.0^{ab}
PKSZnB (-N)	11.5^{b}	17.4^{bc}	7.5^{ab}	5.3	18.9^{c}	22.7^{bc}
Control	10.5^{b}	15.5^{c}	9.4^{a}	4.1	19.9^{c}	19.5^{c}
CV (%)	24.5	21.7	19.8	30.4	18	20.33

Table 8. Effects of omission of nutrients on marketable, unmarketable and total yield of tomato combined over sites

Treatments	Marketable yield (t ha^{-1})	unmarketable yield (t ha^{-1})	total yield (t ha^{-1})
NPKSZnB (all)	28.1^{ab}	7.1^{ab}	29.6^{ab}
NKSZnB (-P)	24.7^{abc}	4.4^{bc}	23.7^{bc}
NPKSZn (-B)	32.2^{a}	8.1^{a}	31.9^{ab}
RNP	23.8^{abc}	3.5^{c}	34.8^{a}
NPKSB (-Zn)	23.6^{abc}	4.8^{abc}	32.5^{ab}
NPKZnB (-S)	26.0^{abc}	4.9^{abc}	32.2^{ab}
NPSZnB (-K)	25.2^{abc}	5.8^{abc}	25.4^{abc}
PKSZnB (-N)	17.4^{c}	5.2^{abc}	18.9^{c}
Control	$20.4b^{c}$	6.3^{abc}	19.9^{c}
CV (%)	21.3	31.4	18.0

Correlation among Growth, Yield and Yield Components of Tomato: Crop yield is the result of the cumulative interactions between all of the experimentally determined dependent and independent factors (characters). According to the available data, most tomato yield and yield components had a significant positive and linear association (Table 9). As a result, there was a substantial and positive correlation between marketable yield and the number of clusters per plant and no fruit/cluster (r = 0.60 and 0.51, respectively) at (P <0.01). On the other hand, marketable yield showed significant (P <0.05) correlations with plant height (r = 0.40*), number of branches per plant (r = 0.46*), and polar diameter (r = 0.46*). The presence of significant and positive correlation among yield and yield components indicates that increased growth parameters and yield components might contribute to tomato yield increment.

Table 9. Pearson Correlation Coefficients between growth and yield component of Tomato

parameters		NCP	NFC	NBP	Ph	Pd	Ed	My	Umy	Ty
NCP	Pearson Correlation									
	Sig. (2-tailed)									
NFC	Pearson Correlation	.909**								
	Sig. (2-tailed)	.000								
NBP	Pearson Correlation	.742**	.810**							
	Sig. (2-tailed)	.000	.000							
Ph	Pearson Correlation	.679**	.720**	.642**						
	Sig. (2-tailed)	.000	.000	.000						
Pd	Pearson Correlation	.511**	.386*	.191	.388*					
	Sig. (2-tailed)	.006	.047	.341	.046					
Ed	Pearson Correlation	.408*	.388*	.015	.294	.305				
	Sig. (2-tailed)	.034	.046	.940	.137	.122				
My	Pearson Correlation	.603**	.509**	.464*	.403*	.465*	.326			
	Sig. (2-tailed)	.001	.007	.015	.037	.015	.098			
Umy	Pearson Correlation	-.107	-.036	-.226	-.019	-.009	.378	.132		
	Sig. (2-tailed)	.596	.858	.257	.923	.963	.052	.511		
Ty	Pearson Correlation	.544**	.471*	.385*	.376	.436*	.394*	.973**	.356	
	Sig. (2-tailed)	.003	.013	.047	.053	.023	.042	.000	.069	

*** = significant at P < 0.01, *= significant at P < 0.05. Ph = Plant Height, NCP = No of cluster/plant, NFC = no fruit/cluster, NBP = no branch/ plant, Pd = Polar diameter Ed = Equatorial diameter, my = marketable Yield, Umy = unmarketable yield.*

Conclusion and Recommendation

Conducting of omission trial is indispensable to identify most yield limiting nutrients in specific area. From the result marketable yields of onion is influenced by only the omission of nitrogen in the study area. The lowest marketable yield of onion is recorded in omission of nitrogen and from the control treatment. However, yield of onion did not increase due to application of secondary (K&S) and micronutrients (B & Zn) than Recommended Nitrogen and Phosphorous fertilizer alone. From the application of phosphorus, yield and yield related parameters of onion did not also significantly differ compared to the control.

Higher mean total yield and marketable yields of tomato were also recorded with the application of nitrogen contain fertilizers whereas the lowest was recorded from the control and N-omitted treatments indicating that N was the most yield limiting nutrient for tomato production than any other nutrient in the study areas. However, yield of tomato did not increase due to application of secondary (K&S) and micronutrients (B & Zn) than Recommended Nitrogen and Phosphorous fertilizer alone. This indicated that the most yield-limiting nutrient in the study area is nitrogen for onion and tomato production. Overall, the results revealed that omitting N leads to significant yield penalty and application of nitrogen and phosphorous (for soil nutrient maintenance) should be adopted for achieving higher yield and profitability of onion. This study was conducted to know which nutrient was yield limiting and did not address what amount was needed. Therefore, optimum fertilizer rate determination on the yield limiting nutrient should be conducted.

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9. Determination of Irrigation Water Requirements and Frequency for Tomato in Efratanagidm District, North Shewa

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Abstract

Information on crop water requirements and the frequency of crops is vital for irrigation water planning. Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. It is an essential daily management practice for farmers growing irrigated crops. However, irrigation practice in terms of the amount of water to be used and frequency of application has lacked proper knowledge. The purpose of this study is therefore to deliver preliminary information on the seasonal water requirement of tomatoes based on the widely used FAO cropwat model. The experiment was conducted at the north Shewa Amhara region Efratanagidim District yimilo irrigation site. The experiment was conducted in a randomly completed block design with three replication and 15 treatments. The type of soil in the experimental site is clay textural class soil. The highest yield was 54.49 tha^{-1}while the lowest was 37.89 tha^{-1}. Statically 48.5 tha^{-1} yield in the amount of irrigation water 376.71 mm depth with the water use efficiency 10.79 Kgm^{-3} and safe 3127.33m^{-3} water from one hectare and get 0.59 ha additional irrigation land. The application of water in each stage was initial 33.64 mm with 5 days interval, development-one 60.54 mm with 9 days interval, development-two 94.18 mm with 14 days interval, mid 94.18 mm with 14 days interval and late 94.18 mm with 14 days interval water application used. Therefore, the total depth of the water during the growth period of tomato at Ataye and the same agroecology was 4431.94m^{3}ha^{-1} to get 48.95 tha^{-1} tomato yield gave an additional irrigation land without high yield penalty.

Keywords: Efratanagidiem district, tomato, water amount, water use efficiency

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably leads to an increase in food demand. Food security is a major concern in many parts of the world including East Africa, Rift valley of Ethiopia where rainfall is unpredictable and unreliable (Tesfaye, 2008). To maintain self-sufficiency in the food supply, one viable option is to raise the unit yield. A favorable method for raising yield per unit area is through irrigation.

Reported showed that the crop water requirement of crops correlated with the temperature and irrigation water demand (Kijne, 2010; Surendran *et al*., 2014). Developments in irrigation are often instrumental in achieving high rates of agricultural goals but proper water management must be given due weightage to effectively manage water resources. The proper management of existing irrigated areas is important for fulfilling food security to the increasing population (Hari *et al*., 1996).

Irrigation water management is a crucial component of any irrigation project. Wise use of water resources is becoming an important element in agriculture as the demand for the resource is dramatically increasing because of population pressure and hence feeding the world is a priority issue. Knowledge of crop water requirements is therefore quite helpful for planning a sound irrigation scheduling where water can be used efficiently and effectively.

Operational applications of ET estimate yet heavily rely on the FAO-56 model because of the minimum requirement of phonological and standard meteorological inputs (Evett *et al*., 1995; Eitzinger *et al*., 2002). In the FAO-56 approach, actual ET is calculated by combining reference evapotranspiration (ETo) and Kc. The Food and Agriculture of the United Nations has been extensively working on models that are capable of estimating crop water requirements and exercising irrigation scheduling of crops for any irrigation project for the last thirty years. The models have been widely used in the research, academia, and developments sectors.

Understanding crop water needs is essential for irrigation scheduling and water-efficient use in an arid region (Parry *et al*., 2005). Further, with increasing scarcity and growing competition for water, judicious use of water in the agricultural sector will be necessary (Ali*Figure* , 2010). Predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. In our study area, consistent information on irrigation water use is still lacking. CROPWA is an FAO model for irrigation management designed by Smith (1991) which integrates data on climate, crop, and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc), and irrigation water requirements

The CROPWAT model a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for the determination of crop evapotranspiration (FAO, 1998) and yield responses to water (Doorenbos and Kassam, 1979).

In Ethiopia, the major portion of irrigation water management is traditional where farmers are irrigating as long as the water is available, without considering whether it is above or below the optimum of the crop water requirement. For large dams, the information of crop water requirement of the proposed crops is usually used for design purposes and it is not exercised on the real duty of irrigation operation, however. Moreover, in areas where farmers are cultivating on small scale, the same information is critically limiting and more water is believed to be wasted (Roth G., 2014).

Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. It is an essential daily management practice for a farm manager growing irrigated crops. Proper timing of irrigation water applications is a crucial decision for a farm manager to 1) meet the water needs of the crop to prevent yield loss due to water stress; 2) maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources, and 3) minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater.

Irrigation criteria, in terms of frequency of irrigation and amount of application per irrigation, seasonal net irrigation requirement, and gross irrigation requirement for most of the lowland crops that are grown in the Middle Awash region of Ethiopia have been quantified by Melka Werer Research Centre. However, there was little effort undertaken in the many parts of Ethiopia especially in the Amhara region. Crop water use studies that were conducted in some other areas are not adopted because it was highly location-specific.

In North Shewa as such, there is no attempt to determine crop water requirements of irrigated crops except a study conducted at Shewarobit for onion and pepper and at Bakelo for wheat and potato to estimate crop water requirements. The aim of this research was therefore to estimate the net irrigation requirement of tomatoes (Lycopersicon*esculentum) and* estimate the irrigation frequency for tomatoes using the CROPWAT computer model in Ataye.

Materials and Methods

Description of the Study Area: The experiment was conducted at the Amhara region north Shewa Efratanagidim District yimilo irrigation site (Fig. 1). The site is located 154 km from Debreberehan town and 9 km from Ataye town. The geographic location of the experimental site is 39^0 54’ 27’’ E and 10°17’ 28’’N with an altitude of 1514 m.a.s.l. The area has two major seasons; the rainy and dry seasons. The rainy season lasts from the beginning of June to the end of September with a mean annual rainfall of 822 mm, while the dry season lasts mainly from October to the end of May. The hottest months, February, April, and May with a mean monthly maximum temperature of 27.7°C, while the coldest months are November and December with a mean minimum temperature of 11.5°C.

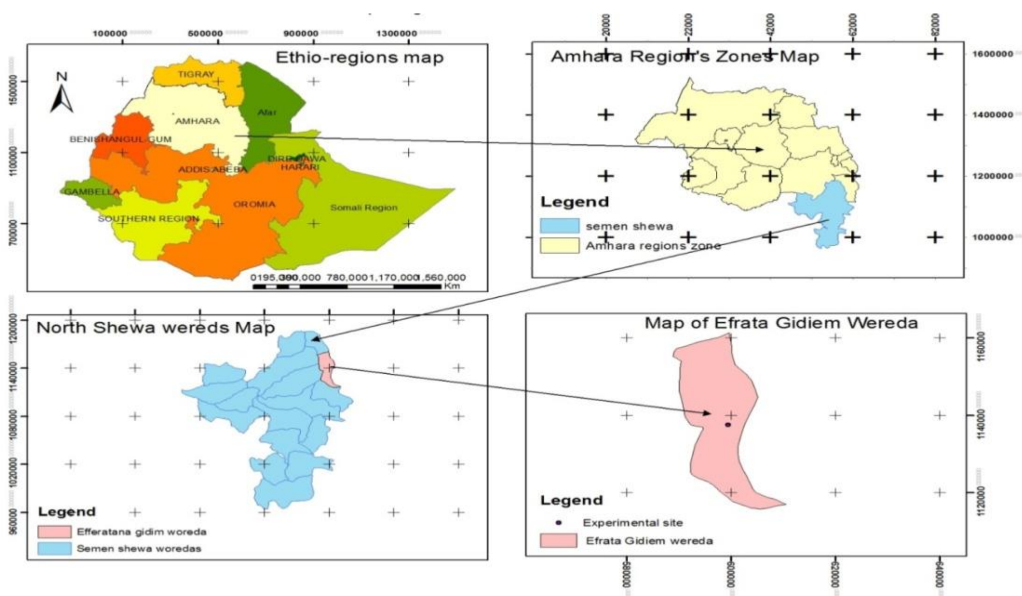

Figure 1. Location map of the experimental area

Field Layout and Experimental Design: The experiment was conducted in a randomized complete block design with three replication and 15 treatments set up. The unit plot size was 8.4m^2. Treatments were assigned to each experimental plot by using SAS Software to randomize within a replication. The space between plant, row, plot, and replication was 30cm, 75cm, 1m, and 2m respectively. The treatment set up shows in (Table 1).

Table 1. Treatments and applied water levels

Treatments	Applied water level
T1	50% ETC
T2	75% ETC
T3	100% ETC
T4	125% ETC
T5	150% ETC
T6	50% ETC before 3-day interval
T7	75% ETC before 3-day interval
T8	100% ETC before 3-day interval
T9	125% ETC before 3-day interval
T10	150% ETC before 3-day interval
T11	50% ETC after 3-day interval
T12	75% ETC after 3-day interval
T13	100% ETC after 3-day interval
T14	125% ETC after 3-day interval
T15	150% ETC after 3-day interval

The Reference evapor-transpiration value (ETo) for the site was calculated from the long-term meteorological variables (Monthly Minimum and Maximum temperature, wind speed, sunshine hours, and relative humidity) using the crop was version 8.0, based on the Penman-Moeinth formula. The Kc values have been adopted from the FAO cropwat computer model. FAO's (2009) cropwat computer model has finally been employed to obtain the crop water requirements of the crop and exercising irrigation scheduling for the site.

Experimental Field Management: Before planting the experimental field was first prepared by oxen power tiller according to farmers' conventional plowing practice (plowing was done twice before sowing the test tomato crop traditional plow called *Maresha*, drawn by a pair of oxen). Stubbles, weeds, etc. were removed from the field. The experimental field was divided into three main blocks (Replicates) and each block was divided into fifteen plots that received different treatment combinations. All agronomic practices were applied equally for each treatment according to the recommendation of the area (starting from sowing to harvesting recommended package of practices were followed). Disease, insect pests, weeding management, and fertilizer application were carried out as required.

Soil Sampling and Analysis: The composite soil samples were taken from the experimental field at 0-20cm depth using an auger before sowing. The soil samples were prepared with air-drying at room temperature, ground using a pestle and a mortar, and allow passing through a 2mm sieve. Working samples were obtained from bulk sample and was analyzed to determine the soil Physico-chemical properties like soil texture, organic carbon, organic matter, and soil pH, and electrical conductivity (EC) and bulk density (Table).

Table 2. Method to determine chemical and physical properties of soil

Table 2. Method to determine chemical and physical properties of soil	Properties of the soil		method
	Chemical	Physical	
pH	✓		P^H –meter or electrometer
EC	✓		EC-meter or electrometer
OC	✓		Walkley and black,1934
OM	✓		1.724*OC, Broadbent, 1953
Soil texture		✓	Hydrometer, Bouyoucous, 1962
Bulk density		✓	Volumetric meter

Field Operations and Yield Harvesting: The tomato (Woino variety) was raised on a plot of land adjacent to the experiment plot for thirty days under the recommendation of Anonymous, (1976) before being transplanted. The recommendation rate of Phosphorus and Nitrogen as a source of NPS and Urea fertilizer was applied at the rate of 240 $Kgha^{-1}$ and $100Kgha^{-1}$ respectively to the field.

Tomatoes harvested were estimated into marketable and non-marketable yields. Marketable yields were those crops harvested and transported to the market with the market prevailing price. Non-marketable yields were those crops obtained from the experimental site as damaged tomatoes and/or those that could not be sold.

Water-use Efficiency: According to Rasul, & Thapa, (2004) water use efficiency can be determined as the ratio of the amount of marketing yield crop yield to the amount of water required for growing the crops. It can be calculated as; $Eu = \frac{Y}{WR}$

Where; Eu = field water use efficiency (t/ha-mm)

Y = crop yield (t/ha)

WR = Water requirement of the crop (ha-mm)

Data Collected: The meteorological data were collected from the kombolcha branch meteorology agency. The crop data taken from the experimental site for analysis were growth parameters (plant height, fruit diameter, and the number of fruit), yield parameters (fruit yield) both marketable and unmarketable yield, and amount of water and frequency (interval) during the application period.

Data analysis: The collected data were subjected to analysis of variance (ANOVA) using SAS 9.0. Where ever the treatment effect was significant, mean separation was made using the least significance difference (LSD) test at a 5% level of probability. Correlation analyses of selected parameters were also performed using Pearson correlation.

Results and Discussion

Physico-chemical Properties of Soil before Planting: Some of the physio-chemical properties of soils of the study sites before planting are summarized in (*Table*). Accordingly, the location of soils belongs to the clay textural class based on the soil textural class determination triangle of the International Soil Science Society (ISSS) system (Rowell, 1994).

Table 3 Soil physical and chemical properties at Ataye

parameter	Value	parameter	Value
Sand (%)	28	*OC (%)	1.8
Clay (%)	38	OM (%)	3.04
Silt (%)	34	BD (g/cm^3)	1.37
pH	7.8	FC (%)	23.4
EC (ds/mm)	0.23	PWP (%)	6.95

**OC = organic carbon, OM = organic matter, BD = bulk density, PWP = permanent wilting point, FC = field capacity EC = electric conductivity*

Reference Evapotranspiration of the Experimental Site: The simulated result of the metrological data for reference evaporation of the study site is summarized concerning each month and the average ETO shows in (Table 4).

Table 4. Reference evapotranspiration (ETO) values at Ataye

Month	Min Temp	Max Temp	Humidity	Wind	Radiation	ETo
	°C	°C	%	km/day	MJ/m²/day	mm/day
January	12.1	25.7	60	156	18.2	3.9
February	12.8	27	60	173	21.1	4.59
March	13.6	26.7	59	173	18.5	4.4
April	13.6	27.7	69	156	19.9	4.45
May	14	27.2	62	173	21.2	4.75
June	13.8	26.1	76	104	18.1	3.73
July	11.8	21.1	88	104	15	2.82
August	12	20.8	90	104	14.9	2.77
September	12.8	22.5	83	112	16.9	3.24
October	12.6	24.6	64	190	19.8	4.23
November	11.3	25	62	190	21.1	4.3
December	11.5	25.2	60	173	18.9	3.97
Average	12.7	25	69	150	18.6	3.93

However, using 10 years' metrological data the reference evaporation generates by the CROPWAT model. As mentioned in Table 4, the highest monthly ETO for the site was observed in May (4.74 mm/day), while the lowest was observed in August 2.65 mm/day. This result indicated that ETO was higher during the dry season and lower in the rainy season. The study in line with FAO (1998) reported that the only factor affecting ETO is climate parameters which are the ETO increase with increasing of temperature in the dry season. The probable irrigation season for Ataye may start as early as November where the evapotranspiration rates are relatively low until the crops will have full maturity and hence planting during those periods will have two advantages; using the soil moisture reserve that could have been stored from that recedes in late September or early October. Secondly, planting crops at times of low evapotranspiration is implicated that the demand for the crops for water is also low. Therefore, irrigation water saving is more practical for early planning. To determine the amount of water needed and when to apply it, calculate the ETc (crop water use) between irrigations with the following equation, where Kc is the crop coefficient and ETo is the reference crop vapotranspiration: ETc = Kc * ETo**.** Doorenbos and Pruitt (1977) divided the kc curve into four stages: initial, crop development, mid and late-season stages. The Initial growth stage occurs from sowing to about 10% ground cover, the crop development stage from about 10% to70% ground cover. The Mid-season stage includes flowering and yield formation, while the Late-season includes ripening and harvesting.

Crops have different water requirements depending upon the place, climate, soil type, cultivation method, etc., and the total water required for crop growth is not equally distributed over its whole life span (Some, *et al*., 2006). The trend of average crop evapotranspiration (ETc) and reference evapotranspiration (ETo) for tomatoes was illustrated for the whole growing season in Figure . The ETc values were less than ETo in the early developmental stages, but the ETc increased with time due to canopy growth until it exceeded ETo near the end of the crop season. Low ETc rate occurred during the first Days or the month of Jan when only a few leaves contributed to the evapotranspiration and most ETc was evaporation from the soil. Water consumption increased from Feb to Mar, mainly due to water use by the plants during the vegetative stage. Maximum water requirements occurred during the flowering stage or the month of April (mid-stage) and water use decreased from the last day of April (fruit set stage). Daily ET crop varied from <2.41 mm/day at crop establishment to 2.92 mm/day at early vegetative growth and 4.33 mm/day at late vegetative growth and achieved a peak of 5.05 mm/day at flowering. ET crop then declined to a value of 4.35 mm/day during the ripening stage (late-stage). The performance of the various depth of water applied was based on tomato yield. These result agreements with FAO (1986) reported that the maximum water demand for tomato crop growth is the flowering stage.

Table 5. Crop water requirement for tomato

Month	Decade	Stage	Kc coeff	ETcrop mm/day	ETcrop mm/dec	Ir. Req. mm/day	Ir. Req. mm/dec
Jan	2	Init	0.6	2.34	11.7	2.34	11.7
Jan	3	Init	0.6	2.48	27.3	2.48	27.3
Feb	1	In/De	0.61	2.65	26.5	2.65	26.5
Feb	2	Dev.t	0.69	3.18	31.8	3.18	31.8
Feb	3	Dev.t	0.84	3.78	30.2	3.78	30.2
Mar	1	Dev.t	0.98	4.36	43.6	4.36	43.6
Mar	2	De/Mi	1.1	4.85	48.5	4.85	48.5
Mar	3	Mid	1.15	5.08	55.8	5.08	55.8
Apr	1	Mid	1.15	5.1	51	5.1	51
Apr	2	Mi/Lt	1.11	4.96	49.6	4.96	49.6
Apr	3	Late	1.01	4.6	46	4.6	46
May	1	Late	0.87	4.1	41	4.1	41
Totals					463	463	

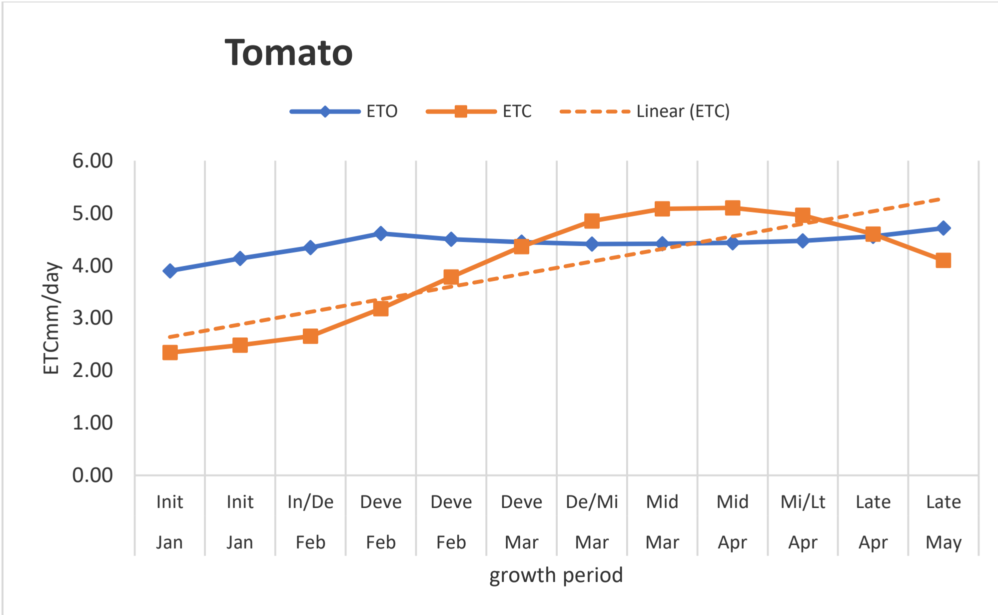

Figure 2. Temporal Crop evapotranspiration (ETc) and Reference crop Evapotranspiration (ETo) of Tomato

The total tomato crop water requirement was 463 mm/dec (Table). The resulting agreement with (Ahmed *et al*., (2020): Brouwer & Heibloem (1986)) reported that the total water requirement after transplanting of tomato crop grown in the field for 90 to 120 days is 400 to 600 depending on the climate.

Tomato Yield and Yield Parameter: The trend of PH, NMF, and NUMF growth yield parameters in the first year and second year for tomatoes was illustrated for the application of different amount levels of water depth (Table 6). In the first year, the maximum values of PH, NMF, and NUMF in the treatment of 125% ETc before the 3-day interval, 125% ETc, and 100% ETc before the 3-day interval, and the minimum values parameters 50% ETc before the 3-day interval, 50% ETc after the 3-day interval and 150% ETc before 3-day interval respectively.

Table 6. The response of plant height, number of marketable fruits, non-marketable fruit, on the application of the different amounts of water in two years

	First-year			second year		
Treatment	Ph cm	NMf /ha	NUMf /ha	Ph cm	NMf/ha	NUMf /ha
50% ETc	63[fgh]	479369	96428.57	84.33	338892.9	47226.19
75% ETc	65[efgh]	478179	99607.14	75.87	267059.5	35714.29
100% ETc	77[ab]	537702	106345.2	80.27	194440.5	25000
125% ETc	70[cdef]	525000	142857.1	89.2	244440.5	34916.67
150% ETc	62[gh]	490083	95238.1	85.6	319047.6	36511.9
50% ETc before 3-day interval	60[h]	448809	67464.29	85.47	233726.2	22226.19
75% ETc before 3-day interval	64[efgh]	489678	99202.38	74.93	304369	41666.67
100% ETc before 3-day interval	76[ab]	475797	130559.5	78.07	216666.7	26988.1
125% ETc before 3-day interval	82[a]	494845	130321.4	84	196273.8	36904.76
150% ETc before 3-day interval	72[bcd]	416512	74607.14	83.47	188571.4	28571.43
50% ETc after 3-day interval	74[bcd]	399202	85714.29	85.2	278964.3	36107.14
75% Etc after 3-day interval	70[cdef]	525000	85321.43	83.93	297619	36511.9
100% ETc after 3-day interval	67[defg]	402143	109916.7	67.67	244845.2	39678.57
125% ETc after 3-day interval	65[efgh]	473417	84607.14	95.2	311904.8	33726.19
150% ETc after 3-day interval	68[defg]	473012	86904.76	76.07	263488.1	32535.71
CV (%)	5.41	10.55	17.51	16.1	30.34	28.6
LSD (0.05)	2.79	NS	10.96	NS	NS	NS

In the second year the maximum values of the parameters 125% ETc after the 3-day interval, 50% ETc, and 50% ETc, and the minimum values also 75% ETc before the 3-day interval, 150% ETc before the 3-day interval, and 50% ETc before 3-day interval respectively the difference occurs due to the application level of water and the days of interval.

But statistically shows that the analysis of variance of the tomato crop growth yield distribution for treatments, which indicated that there was a highly significant difference among the plant height, number of unmarketable fruit at ($P \leq 0.01$) level of significance and there was no significant difference among number of marketable fruit at 5 % level of significance in the first year while there was no significant difference among plant height, number of marketable fruit and number of unmarketable fruit at 5 % level of significance in the second year.

The response of MYF, UNMYF, and TYF yield parameters and total application water application and water use efficiency for tomato was illustrated with the respect to each treatment in (Table 7).

The maximum values of MYF, UNMYF, and TYF were in the 125% ETc, 125% ETc before the 3-day interval, and 125% Etc. And the minimum values of the yield parameters were in the 50% ETc, 50% ETc before 3 days interval, and 50% ETc respectively. The maximum and minimum water application amount in the treatment of 150% ETc after the 3-day interval and 50% ETc respectively due to the application difference level and the time interval. Table 8, statically show that the analysis of variance tomato crop yields distribution for treatments, which indicated that there was a significant difference among the marketable yield, total yield, and water productivity of crop at 5 % level of significance and there was no significant difference among the total number of fruits, unmarketable fruit yield at 1 % level of significance. The highest yield was 54.49 tha^{-1} while the lowest was 37.89 tha^{-1}. Statically 48.5 t/ha yield in the amount of irrigation water 376.71 mm depth with the water use efficiency 10.79 Kgm^{-3} and safe $3127.33m^{-3}$ water from one hectare and get 0.59 ha additional irrigation land. The study coincides with FAO (1986) reported that a good commercial yield of tomato under irrigation is 45-65 tha^{-1} fresh fruits and the water utilization efficiency for harvested yield for fresh tomato is 10-12 Kgm^{-3}. The study coincided with the previous findings reported that the fresh yield of tomato in the range of 45-65 t/ha (Nuruddin, (2001): El-Naggar, A. (2020)).

Table 7. The response of marketable fruit yield, unmarketable fruit yield and total fruit yield on the Application of different amount of water

Treatment	MYF tha^{-1}	UNMYF tha^{-1}	TYF tha^{-1}	WUE Kgm^{-3}	TW m^3ha^{-1}
50% ETc	31.11^{f}	6.78	37.89^{e}	9.42^{bc}	3931.81
75% ETc	39.39^{bcde}	5.79	45.19^{bcde}	8.46^{cd}	5244.2
100% ETc	43.00^{abcd}	6.04	49.04^{abcd}	7.39^{de}	6546.25
125% ETc	47.62^{a}	6.88	54.49^{a}	7.24^{de}	7559.27
150% ETc	44.84^{ab}	6.69	51.53^{ab}	5.87^{e}	9227.11
50% ETc before 3-day interval	33.56^{f}	4.97	38.52^{e}	11.28^{a}	3389.96
75% ETc before 3-day interval	41.66^{abcde}	7.29	48.95^{abcd}	10.79^{ab}	4431.94
100% ETc before 3-day interval	38.65^{bcdef}	7.01	45.66^{bcde}	8.10^{cd}	5465.34
125% ETc before 3-day interval	39.00^{bcdef}	7.04	46.05^{abcde}	6.97^{de}	6505.11
150% ETc before 3-day interval	37.38^{bcdfe}	6.18	43.56^{de}	5.99^{e}	7460.39
50% ETc after 3-day interval	35.98^{cdf}	6.26	42.25^{de}	9.27^{bc}	4473.65
75%ETc after 3-day interval	42.78^{abcd}	6.50	49.29^{abcd}	8.52^{cd}	5641.17
100 ETc% after 3-day interval	39.36^{bcde}	7.06	46.42^{abcde}	6.31^{e}	7624.39
125% ETc after 3-day interval	43.57^{abc}	6.56	50.13^{abc}	5.73^{e}	9254.32
150% ETc after 3-day interval	35.20^{def}	6.06	41.26^{cde}	3.72^{f}	10970.1
CV (%)	15.37	26.58	14.14	17.79	
LSD (0.05)	2564.1	NS	2743	0.58	

The yield and land opportunity which got from saving water in the application of water through time interval illustrated in Figure . The highest land and yield got from treatment six which saving 4169.31 $m^3$of water and 0.81 ha of additional irrigation land to get the 31.4 tha^{-1} yield of tomato. The lowest land and water were in the treatment fifteen. But statistically the relationship between yield and land opportunity (land which develops by saving water) shows that treatment seven (75% ETc before the 3-day interval) was a better land opportunity which safe 3127.33m^3 of water amount and 0.59 ha additional irrigation land to get 29.00 tha^{-1} yield for the user without high yield penalty.

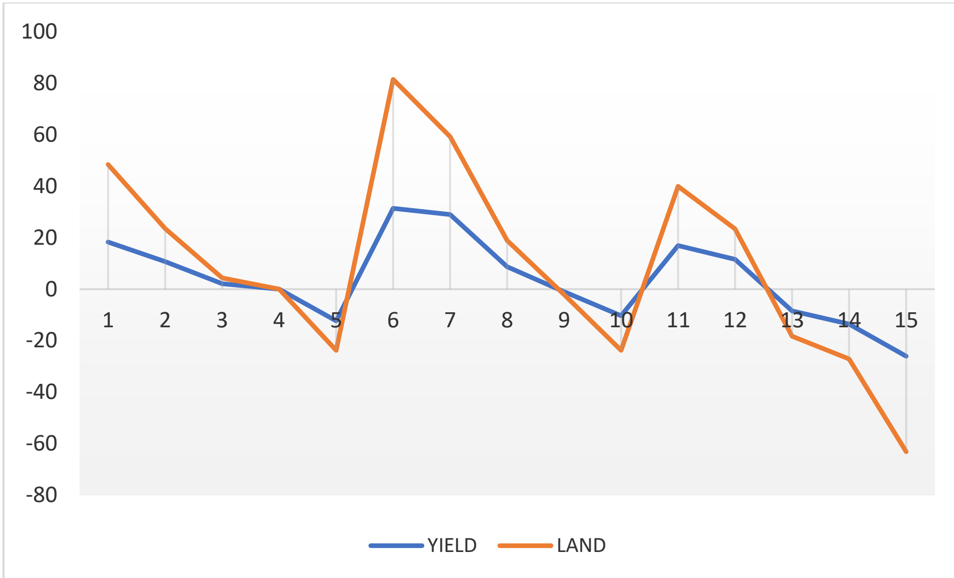

Figure 3 the yield and land opportunity

Tomato Yield- Water Use Function: Table 8 reveals that tomato yields increased with the depth of water applied up to an optimum value of 54.49 t/ha and thereafter decreased with more water. The result of this study corroborates that of Muchovej *et al.* (2008) who reported that the high quality and yield of vegetable crops are directly associated with proper water management. It is observed that the water use efficiency decreases with an increase in water depth.

Correlation Functions of the Growth and Yield Parameters: The relation function of the growth and yield parameters illustrated in Table 9. The highly positively correlated between all growth and yield parameters which indicated that the relation is above 0.70 correlation value. The water amount and the correlation of the parameters were less than 0.7 and less positively correlated.

Table 8. Correlation

	NMY*	NUMY	MY Kgha^{-1}	UNMY Kgha^{-1}	TY Kgha^{-1}	water amount m3ha^{-1}
NMY	1					
NUMY	0.809	1				
M Y (Kg)/ha	0.835	0.798	1			
UNMY (Kg)/ha	0.772	0.894	0.729	1		
TY (Kg)/ha	0.862	0.859	0.988	0.826	1	
water amountm3/h	0.489	0.509	0.562	0.511	0.578	1

**Number of marketable yields, number of unmarketable yields, marketable yield, unmarketable yield, total yield, water amount*

Conclusions and Recommendation

The crop yield increase with an increase in depth of water applied up to an optimum value beyond which it tends to reduce crop yield in the experimental area which is predominantly clay loam in texture. Statistically, the total depth of the water during the growth period of tomato at Ataye and the same agroecology was 4431.94m^{3}ha^{-1} to get 48.95tha^{-1} tomato yield gave an additional irrigation land without high yield penalty. The application of water in each stage was initial 33.64 mm with 5 days interval, development-one 60.54 mm with 9 days interval, development-two 94.18 mm with 14 days interval, mid 94.18 mm with 14 days interval and late 94.18 mm with 14 days interval water application used. This research result could be verified for confirmation and it works should be carried out using different tomato variety and irrigation method.

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III) Watershed-based Soil and Water Conservation

1. Sensitivity of Stream Flow to Meteorological Drought in Andit-Tid Watershed, Central Highland of Ethiopia

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Abstract

Drought is identified as one of the environmental phenomena, and is an integral part of climate change that can happen in any geographic area. Drought can be expressed in different forms, including meteorological, hydrological, agricultural, and socioeconomic droughts. The main objective of this study was to identify the potential mechanisms through which meteorological droughts can lead to hydrological drought. DrinC software has been used to generate the indices required to examine how hydrologic variables responded to drought and climate change. Rainfall, minimum and maximum temperature have been the inputs used to calculate the indices. Evapotranspiration and future projection of stream flow, rainfall and temperature have been computed using the Hargreaves method and the ARIMA model, respectively. The findings of this study confirmed that the study area had both hydrological and meteorological droughts in 1987, 2003, and 2015. The results of index-based drought analysis showed a significant (P<0.05) correlation between hydrologic and meteorological droughts. Particularly, it was determined that there was a better association between the stream flow drought index and reconnaissance drought index than is between the standardized precipitation index. This shows how strongly evapotranspiration affects stream flow, a factor that the reconnaissance drought index takes into account while calculating its value. According to the projected scenarios for stream flow and climatic factors, all variables in the watershed will decline in the coming ten years. Investigating index-based droughts is essential to warn the public and decision-makers about coming toward droughts and help them put mitigation and adaptation plans for water management into action.

Keywords: Evapotranspiration**,** hydrological, meteorological, risk, temperature

Introduction

Drought is a complex term thathas various definitions, depending on individuals' perceptions. E.g. in a farmer's language it is "a shortage of rainfall or a long time without any rainfall during the growing season", or a period of below-average rainfall or a prolonged period of dryness that can cause damage to plants. The glossary of meteorology defines drought as a period of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious hydrological imbalance in the affected area (Wilhite *et al.*,, 1987). Drought can occur virtually in all climatic zones, with its characteristics varying significantly from one region to another. It is an insidious hazard of nature. Though droughthas attracted less scientific attention than flood or cyclone, several authors found that the impact of drought can be more defenseless than flood and cyclone (Rahdari, 2016).

Droughthas been identified as one of the environmental phenomena and in fact, is an integral part of climate change that can happen in any geographical area. This phenomenon has various types such as meteorological, hydrological, and agricultural as well as groundwater drought (Shahid & Behrawan, 2008). Meteorological droughts are expressed as the basis of the degree of dryness (often in comparison to some 'normal' or average amount) and are usually measured for long-term daily or monthly records. While agricultural droughts are specifically concerned about the effects of water shortages on the growth of crops, grass, and other forage species. Therefore, agricultural drought is most closely associated with insufficiency of soil moisture that leads to losses in yield. Agriculture is usually the first sector to experience the devastating effects of drought.

Groundwater drought is a new concept introduced to emphasize the understanding of complicated hydrogeological processes concerning the change in dynamics of hydro-meteorological variables with changes in the land (Haile *et al.,* 2020; Kumar *et al.,* 2016). Hydrological droughts are more concerned with the effects of periods of precipitation shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater, etc.) rather than with precipitation shortfalls. Hydrological droughts are usually out of phase or lag the occurrence of meteorological and agricultural droughts. Water in storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes, further complicates the sequence and quantification of impacts. Hydrological drought is determined by the propagation of meteorological drought through the terrestrial hydrological cycle and is therefore influenced by the properties of the hydrological cycle (Bhardwaj *et al.,* 2020; Lanen, 2006; Loon, 2015).

Even though the drought starts with a rainfall deficit, it ultimately translates into a hydrological drought which indicates the reduced water availability in the rivers and groundwater aquifers. The scientific analysis of the hydrological drought is one of the many primary necessities for the development of an effective drought management plan for a region. The investigation of the hydrological drought is important due to the dependence of most of the activities (including industrial, water and power plants) to surface water resources (Faiz *et al.*, 2021; Zakhem & Kattaa, 2016). For example, the duration of drought in stream flow is crucial for hydropower production, particularly the missing volume of water compared to normal conditions (deficit volume) is more relevant. The results of hydrological drought analysis can be useful for proper water resources management including better planning for water supply and demand.

A pivotal step towards reducing the risk of stream flow drought impacts is the monitoring and analysis of the stream flow droughthazard. Traditionally quintile-based approaches such as stream flow percentiles on the threshold level method have been used to characterize the droughthazard of ongoing and past stream flow drought events. More recently the use of Standardized Drought Index (SDI) has become more popular. However, there are other approaches to computing the SDI and up to now, no consensus has been reached on which procedure is preferable (Tijdeman *et al.*, 2018). The study watershed has long-term primary meteorological and other hydrological data which have been collected since 1982. Using these data, this study aimed to investigate the relationship between drought in different periods to determine the relationship between meteorological and hydrological drought using Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), and Standardized Drought Index (SDI) in the Hulet Wenz river catchment. This study was expected to help in establishing basin-specific drought monitoring by advancing the understanding of how much the stream flow is sensitive to drought events. The main objectives of the study were: (1) to anticipate the Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), and Standardized Drought Index (SDI) due to the wide range of possible climate change and (2) to predict the likely proportional change in the annual stream flow available for the downstream in response to other climatic parameters.

Material and Methods

Description of the Study Area: This study was conducted at Andit Tid watershed, which is one of the Soil Conservation Research Project (SCRP) research stations (Fig. 1). It is situated on 39°43’E longitude and 9°48'N latitude 180 km northeast of the capital city, Addis Ababa. The watershed covers a total area of 477.6 ha, and the altitude of the catchment ranges from 3040 to 3550 m.a.s.l. The watershed is located in moist and humid agro-climatic zone. Its mean annual rainfall is 1581mm; minimum and maximum temperatures respectively are 7.5 and 17.6°C; and minimum and maximum average soil temperatures are 7.9 and 20.5°C respectively.

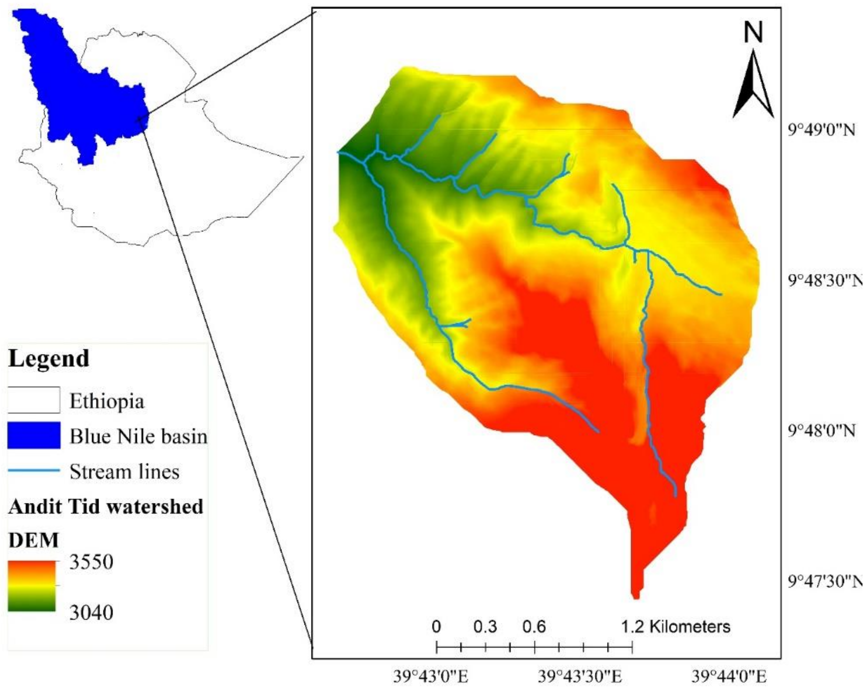


Figure 1. Location map of the study area

Methods of Data Collection and Analysis: This study was conducted by analyzing the time series of hydrologic and meteorological drought indexes. A drought Index is typically a single value used for indicating the severity of a drought and is far more useful than raw data in understanding the drought conditions over an area. SPI (standardized precipitation index) and RDI (Reconnaissance Drought Index) were two drought indices to monitor and quantify Meteorological drought while the sensitivity of stream flow to drought was identified by doing SDI (stream flow drought index).

Standardized Precipitation Index (SPI): The SPI is a measure of the likelihood of precipitation for any given period. It may be calculated for several time scales, making it applicable for both long-term hydrological applications and short-term agricultural uses. These time frames demonstrate how drought affects the availability of various water resources. Short-term precipitation anomalies affect soil moisture conditions; longer-term precipitation anomalies are reflected in groundwater, subsurface flow, and reservoir storage (Zakhem & Kattaa, 2016). The SPI can provide early warning of drought and helps for assessment of drought severity. Because of its standardization, it is particularly suited to compare drought conditions among different periods, and regions with different climatic conditions (Bonaccorso *et al.*, 2003). Due to its intrinsic probabilistic nature, SPI is the ideal candidate for carrying out drought risk analysis (Rossi & Cancelliere, 2002).

The SPI is calculated based on the long-term precipitation record for the desired period (1986 to 2020). This long-term record is fitted to a probability distribution such as gamma distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Koudahe *et al.*, 2017; McKee *et al.*, 1993). Positive SPI values indicate the values that are greater than median precipitation, and negative SPI indicate the values are less than median precipitation. Since the SPI is normalized, wetter and drier climates can be represented in the same way, and thus, wet periods can also be monitored using the SPI. Computation of the SPI involves fitting of a gamma probability density function to a given frequency distribution of precipitation. The parameters α and β of the gamma probability density function were estimated for the precipitation monthly time series (1, 3, 6, and 12) as analyzed by (Karavitis *et al.*, 2011; Lee *et al.*, 2023). It was developed on the basis that precipitation deficithas different impacts on groundwater, reservoir storage, soil moisture and stream flow (McKee *et al.*, 1993). The drought trend of SPI at 1, 3, 6, and 12 month time scales have been analyzed in the study area. The complete calculation procedure for the SPI can be found in McKee *et al.*, (1993), and some details are provided in Equation (1):

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} x^{z-1} e^{\frac{-x}{\beta}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, β is a scale parameter, α is a shape parameter, g(x) is the gamma probability density function, e is Euler's number for exponentiation and $\tau(\alpha)$ is the ordinary gamma function of α. Detail information about the estimation of β and α is stated by McKee *et al.*, (1993).

Reconnaissance Drought Index (RDI): The Reconnaissance Drought Index (RDI) has been introduced by Tigkas *et al.*, (2016) and Tsakiris (2013) as a physically based, universal and comprehensive index for the assessment of meteorological drought. It utilizes two parameters, cumulative precipitation (P) and potential evapotranspiration (PET) for specified reference periods. Recent studies have shown that temperature methods for estimating PET can be sufficient for the calculation of RDI in various regions (Tigkas *et al.,* 2013; Tigkas *et al.,* 2016). Therefore, the data requirements are limited to precipitation and temperature. Over the last decade, the RDI has been widely used in several applications worldwide (Tsakiris *et al.,* 2013). The RDI can be expressed in three forms. The initial form of the index (Ị) within a year for a reference period of k months is calculated as Equation (2) and Equation (3) (Tigkas *et al.,* 2016; Tsakiris *et al.,* 2007).

$a_{k^i}=\sum_{j=1}^{k} pij/\sum_{j=1}^{k} PET_{ij}$..(2)

$RDI_{n^{(i)}}= (a_k/a_{k-1})$.. (3)

Where, P is precipitation in mm; PET is potential evapotranspiration; $a_k$is the arithmetic mean of the initial expression of RDI for k^{th} month (Thomas *et al.,* 2015)

There are three basic ways of generating Eto namely, penman Monteith, Priestly Taylor, and Hargreaves method. Due to the ease of required input data in this experiment estimation of potential evapotranspiration used in the calculation of RDI was obtained through DrinC by using the Hargreaves method as Equation (4) (Wu, 1997);

$ET_0 = a + b * \frac{1}{\lambda} * 0.0023 * \left(\frac{T_{max}+T_{min}}{2} + 17.8\right) * \sqrt{T_{max} - T_{min}} * R_a$.........(4)

Where, T_{max}(°C) is the maximum average air temperature; T_{min}(°C) is the minimum average air temperature; Ra (MJ m^{-2} d^{-1}) is the extra-terrestrial solar radiation; the parameters (mm d^{-1}) and b are calibrated coefficients, determined on a monthly or yearly basis by regression analysis or visual fitting; an unadjusted version of Hargreaves equation (given by default) is given with a=0 and b=1.

However, the total precipitation cannot usually represent sufficiently the amount of precipitation that enters a reservoir, the percentage of the precipitation that contributes to groundwater recharge, the amount of water that can be used by the root system of the plants, etc. For this reason, the use of effective precipitation instead of total precipitation is proposed for RDI modification. In its processing wizard, the DrInC program offers the option to select whether to use the effective or total rainfall.

Stream Flow Drought Index (SDI): Stream flow Drought Index calculation was started according to Equation (5) (Emiru *et al.*, 2021; Wu *et al.*, 2016; Rahdari, 2016; Zeng *et al.*, 2015). If a time series of monthly stream flow volumes is available, in which i denotes the hydrological year and j represents the month within that hydrological year (j = 1 for October and j = 12 for September).

$$V_{i,k} = \sum_{j=1}^{3k} Q_{ij} \quad (5)$$

Where, i = 1,2, …N, j = 1, 2…,12 and k = 1,2,3,4. V is the cumulative stream flow volume for the i[th] hydrological year and the k[th] reference period, k = 1 for October-December, k = 2 for October−March, k = 3 for October-June and k = 4 for October-September. Based on the cumulative stream flow volumes, the Stream flow Drought Index (SDI) is defined for each reference period k of the i[th] hydrological year Equation (6)

$$SDI_{i,k} = (V_{i,k} - \bar{\nabla}_k)/S_k \quad (6)$$

Where, i = 1, 2… N and k = 1,2,3,4, $\bar{\nabla}_k$ and S_k are the mean and the standard deviation, respectively, of the cumulative stream flow volumes of the reference period k, as these are estimated over a long time. In this definition, the truncation level is set to $\bar{\nabla}_k$, although other values based on rational criteria will also be used.

Stream flow may follow a skewed probability distribution, which can be approximated well by the family of gamma distribution functions (Blum *et al.*, 2017 & Hamasha *et al.*, 2023). The distribution is then transformed to normal. Using the two-parameter log-normal distribution (for which the normalization is simply reclaiming the natural logarithms of stream flow), the SDI which is defined in Equations (7) and (8) are the natural logarithms of cumulative stream flow with mean $\bar{Y}_k$and SD$S_{y,k}$, as these statistics are estimated over a long period by (Tigkas *et al.*, 2016).

$$SDI_{i,k} = (y_{i,k} - \bar{Y}_k)/\, S_{y,k} \quad (7)$$

Where, i = 1, 2… N and k = 1,2,3,4 and:

$$y_{i,k} = \ln\,(V_{i,k}) \quad (8)$$

where, i = 1,2… N and k = 1, 2, 3, 4

The annual SDI was computed for more than 34 years between 1986 and 2020. Quantities and descriptive situations of the SDI and SPI indices, which are provided in Tsakiris, (2013), have been considered in this paper to provide a better representation of drought in spatial distribution mapping. In this study, the calculations were performed using DrinC and R software (Tsakiris, 2013). DrinC has been recently used in several studies for drought assessment and monitoring. The precipitation and runoff data were fitted to the log-normal distribution function in the computation process. DrinC aims at providing a user-friendly interface for the calculation of several drought indices, with emphasis on two recently developed ones: the Reconnaissance Drought Index (RDI) and the Stream flow Drought Index (SDI). Also, the widely used Standardized Precipitation Index (SPI) was calculated. The common characteristic of the selected indices was that they require a relatively small amount of data for their calculation and the results can be easily interpreted and used in water resource management strategic planning and operational applications. The classification of drought was done following the (McKee, 1993) as presented in table below.

Table 1. Classification of drought conditions based on the standardized precipitation Index (SPI), reconnaissance drought index (RDI) and Stream flow Drought Index (SDI)

Class	Drought category	SPI, RDI and SDI values
1	Extremely wet	≥2.00
2	Very wet	1.5 ≤ (SPI, RDI and SDI) < 1.99
3	Moderately wet	1≤ (SPI, RDI and SDI) < 1.49
4	Near Normal	-0.99 < (SPI, RDI and SDI) < 0.99
5	Moderately dry	-1.49 < (SPI, RDI and SDI) ≤ -1.00
6	Severely dry	-1.99 < (SPI, RDI and SDI) ≤ -1.50
7	Extremely dry	(SPI, RDI, and SDI) ≤ -2.00

Frequency of Droughts **(F) :** The cumulative frequency (F) of drought gives an idea of the occurrence of dry sequences over a while (Caloiero *et al.*, 2016). It is obtained by reporting the cumulative number of dry sequences considering the total number of rainfall and flow data (Koffi *et al.*, 2020). The frequency of drought was computed following the Equation.

$$F = \frac{\int n}{N} * 100 \ldots (9)$$

Where, $\int n$: Cumulative dry sequence size; N: total size of data.

Analysis of Correlation **(r):** To analyze the relationship between meteorological and hydrological droughts in the Hulet Wenz river catchment, the Pearson correlation coefficient between the SPI, RDI and SDI indices was calculated. The Pearson correlation coefficient is a very effective method for the analysis of potential relationships between two independent variables (López-Moreno *et al.*, 2013; Zeng *et al.*, 2015). This coefficient was calculated using R software.

Data Collection and Analysis: The 34 years of rainfall, atmospheric temperature and runoff data were collected from the study catchment station. All the indices were analyzed by using DrinC software version 1.5.73. DrinC was developed by the National Technical University of Athens Lab. of Reclamation Works & Water Resources Management in, 2007 to facilitate the procedure of the calculation of drought indices. DrinC software has been developed aiming to provide the means for the consistent calculation of various drought indices for drought analysis in research and operational applications (Tsakiris, 2013). A special routine has been added to DrinC software that can be used for the calculation of the modified RDI. The precipitation and runoff data were fitted to the log-normal distribution function in the computation process. The calculation process is performed through a graphical user interface and several options can be used for the characterization of drought. The future forecast for stream flow due to climate change was computed by using R-software by applying the Autoregressive integrated moving average (ARIMA) function. The correlations among indexes were done by using R-software.

Seasonal Forecast with ARIMA: We have restricted our attention to non-seasonal data and non-seasonal ARIMA models. However, ARIMA models are also capable of modeling a wide range of seasonal data. A seasonal ARIMA model is formed by including additional seasonal terms in the ARIMA models we have seen so far (Hyndman & George, 2014). It is written as follows:

ARIMA (p,d,q) (P,D,Q)m;

Where, m= number of observations per year. We use uppercase notation for the seasonal parts of the model, and lowercase notation for the non-seasonal parts of the model.

The results of ARIMA are measured in terms of forecast accuracy. Observed data is divided into two sets; a training set to be used in estimating the parameters and a test set to be used in measuring the accuracy of the forecast. Forecast error is the difference between the observed value (y_t) and its forecast ($\bar{y}_t$) (Alabdulrazzaq *et al.*, 2021; Athanasopoulos, 2018). The most commonly used scale-dependent measures of forecast accuracy are Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) defined in Equation (10) and Equation (11), respectively. As for scale-independent measures, the most commonly used one is Mean Absolute Percentage Error (MAPE), defined in Equation (12) (Rebelob, 2015).

$$MAE = \frac{1}{n-m}\sum_{t=m+1}^{n}|y_t - \bar{y}_t| \qquad (10)$$

$$RMSE = \sqrt{\frac{1}{n-m}\sum_{t=m+1}^{n}(y_t - \bar{y}_t)^2} \qquad (11)$$

$$MAPE = \frac{1}{n-m}\sum_{t=m+1}^{n}\left|\frac{y_t-\bar{y}_t}{y_t}\right| * 100 \qquad (12)$$

Where, n is the number of sample months; y_t= is the actual observation of t^{th} month; $\bar{y}_t$= is the forecasted data value of t^{th} month; and m= number of observations per year (12).

If the data contain zeros, the MAPE can be infinite as it will involve division by zero. If the data contain very small numbers, the MAPE can be huge (Hyndman & George, 2014). The MAPE assumes that percentages make sense; that is, the zero on the scale of the data is meaningful. The mean absolute percentage error (MAPE) is one of the most widely used measures of forecast accuracy, due to its advantages of scale-independency and interpretability. However, MAPE has the significant disadvantage that it produces infinite or undefined values for zero or close-to-zero actual values.

Results and Discussion

Estimation of Drought Indices with Different Time Scales

Standardized Precipitation Index (SPI)

Three-Month Standardized Precipitation Index (SPI-3): The three-month standardized precipitation index (SPI-3) is presented in (Figure 2). From the analysis, it was found that October to December experienced seasonal droughts in 1990, 2003, 2012, 2015, and 2018. There were droughts from January to March in 2000, 2003, 2008, 2012, 2015, and 2018. Drought from April to June struck in 1988, 1990, and 2003. There were droughts from July to September in 1987, 1989, 2003, and 2015. Generally, 2003 and 2015 experienced drought in every season, out of all the documented seasonal droughts that occurred in the watershed. The 2015 drought in Ethiopia was also reported by another scholars (Philip *et al.*, 2018; Sjoukje *et al.*, 2017)

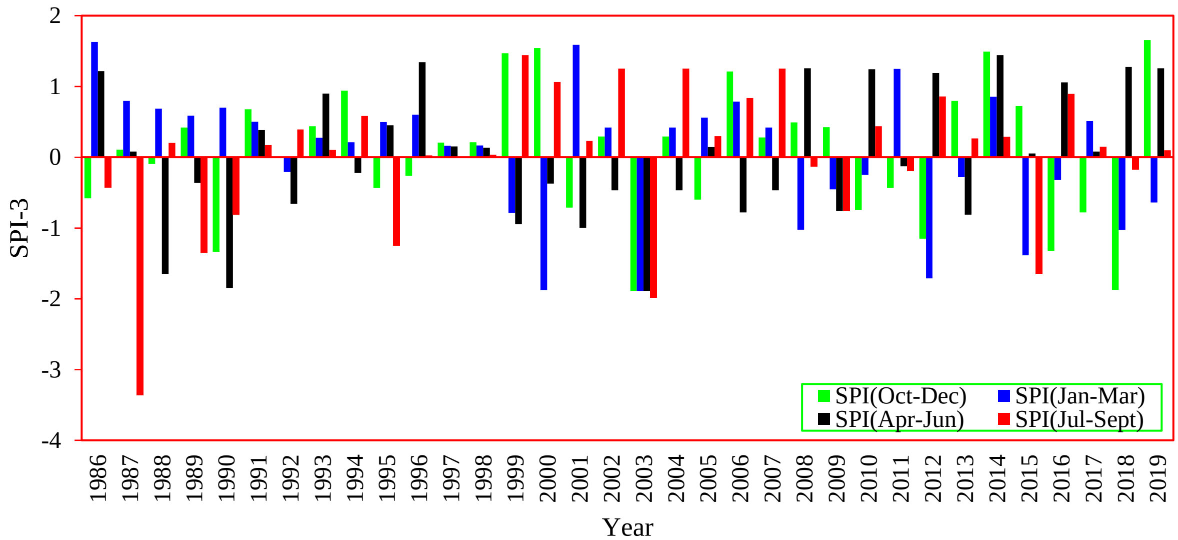


Figure 2. Three-month standardized drought index (SPI-3) of the watershed

Six-Month Standardized Precipitation Index (SPI-6): The Six-month standardized precipitation index (SPI-6) is presented in (Figure 3). Based on a 6-month time step SPI analysis, an extreme drought occurred from April to September in 1987 and 2003. The year 1987 was classified as a dry year of Ethiopia (Richman *et al.*, 2016). Drought also happened from October to March of 2003, 2012, 2015 and 2018 (Figure 3). The year 2016 (October-march) and 2009 (April-September) were affected by a moderate drought.

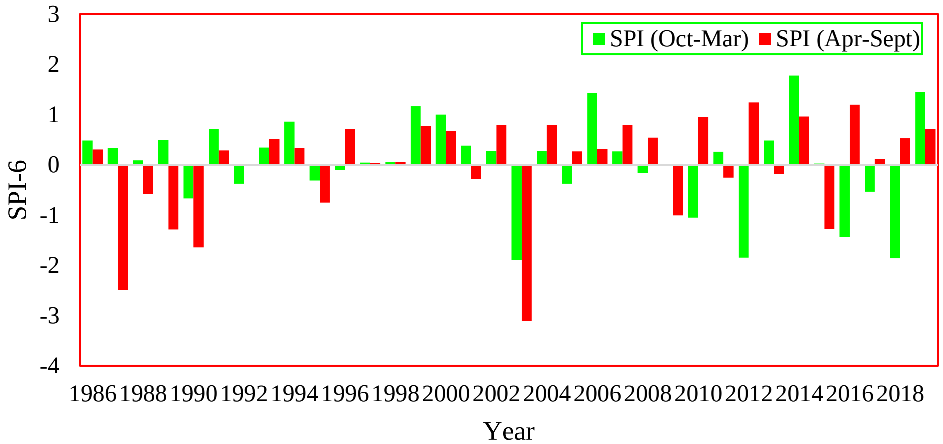


Figure 3. Six-month standardized drought index (SPI-6) of the watershed

Annual Standardized Precipitation Index (SPI-12): The historical trend of the annual standardized precipitation index is presented in (Figure 4). According to the findings, the watershed had an extreme drought with SPI<-3.74 in 2003. Furthermore, with SPI values of (-1.83) and (-1.67), respectively, it was determined that 1987 and 1990 were exceptionally dry years in the watershed's history. This result was supported by another study reported the same finding (Mattsson & Rapp, 1991). Thirdly, the SPI value for 2015 indicated that it was a moderately dry year for the watershed (-1.07). The year 1999, 2014, and 2019 were identified to be moderately wet years of the watershed. The watershed had climates that are generally close to normal for approximately 28 years, with SPI values that vary from (-1 to 1).

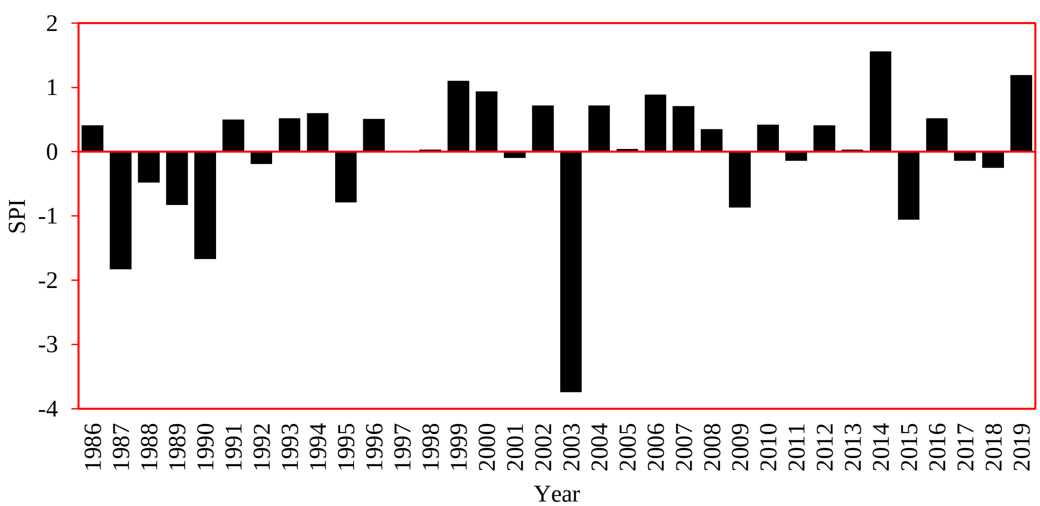


Figure 4. Annual standardized precipitation index (SPI-12) of the study watershed.

Reconnaissance Drought Index (RDI)

Three-Month Reconnaissance Drought Index (RDI-3): The three-month drought analysis with this index indicated July to September was the wettest season of the watershed. This season was the main rainy season. The remaining three seasons were moderately normal and normal. This index is generally not sensitive to seasonal drought identification for the study watershed, which is humid.

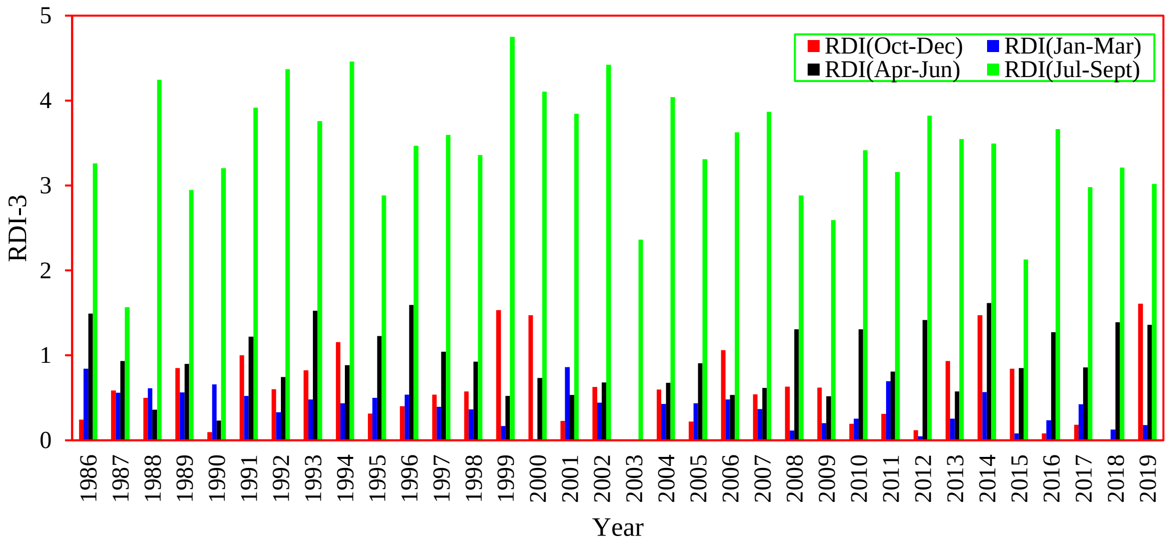


Figure 5. Three-month reconnaissance drought index (RDI-3) of the watershed

Six-Month Reconnaissance Drought Index (RDI-6): Based on RDI-6 analysis, 2003 was affected by extreme and 1987 was affected by a moderate drought**.** While the most severe dryness was observed in October-March of 2003, 2012 and 2018 (Figure 6). It was also observed that 2016 (October-march) and 2009 (April-September) were affected by severe drought. Generally, October to March is much drier than April to September in the study watershed. Similar study on the temporal drought analysis by Burka *et al.,* (2023) reported the occurrence of major drought events in the years: 1984/85, 1999/2000, 2002/3, and 2009.

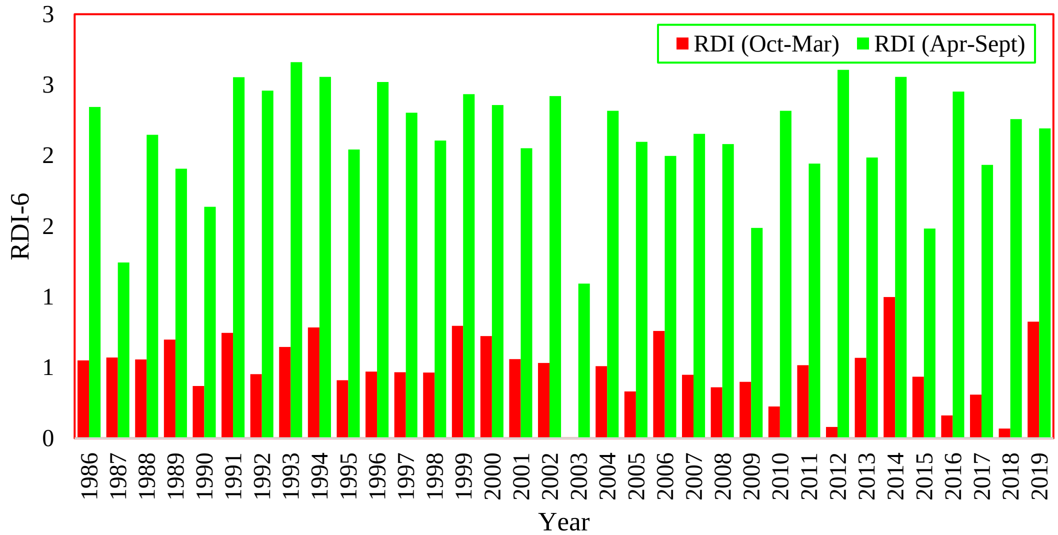


Figure 6. Six-month reconnaissance drought index (RDI-6) of the watershed

Annual-Reconnaissance Drought Index (RDI-12): The annual Reconnaissance drought index (RDI-12) is presented in (Figure 7). This index indicated that 2003 was found to be an extremely dry year of the watershed since 1986 with an RDI of (-3.65). Similarly, 1987 was found to be a severely dry year with an RDI value of (-1.68). similarly, the study on Drought sensitivity characteristics and relationships between drought indices over Upper Blue Nile basin by Kebede *et al.*, (2019) reported severe drought at Deberberehan in 1987 and 1989. The year 1990, 2009, and 2015 were found to be moderately dry years with RDI values of, (-1.09), (-1.45), and (-1.38) respectively. These years were classified as a drought affected years of Ethiopia (Karavitis *et al.*, 2011; Lee *et al.*, 2023; Richman *et al.*, 2016; Sjoukje *et al.*,, 2017). The remaining years were found to be free of drought and excess moisture. For example, the year 1991, 1993, 1994, 1999, and 2014 were found to be moderately wet years. These drought indices were found to be in a similar pattern to the standardized precipitation index.

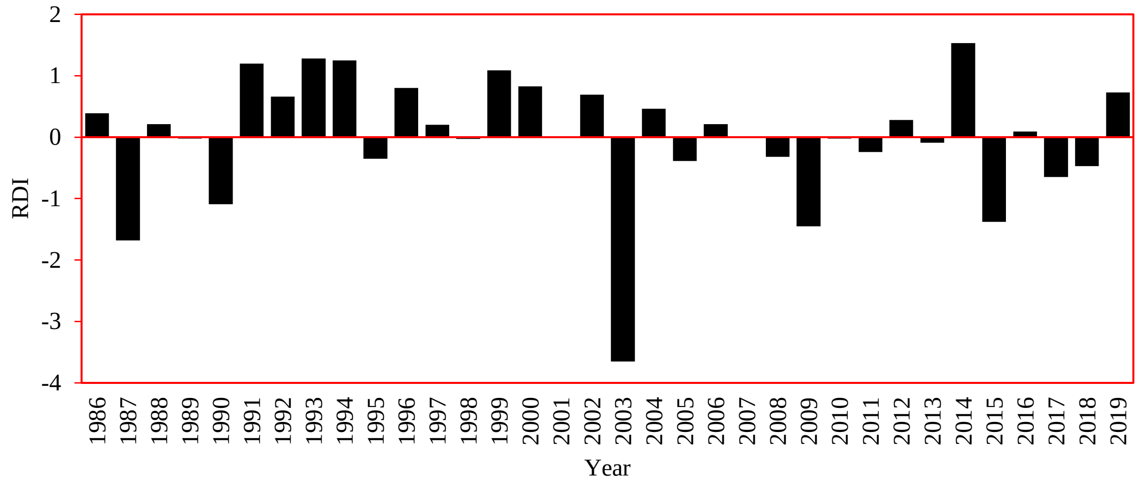


Figure 7. Annual-reconnaissance drought index (RDI-12) of the study watershed.

Standardized and Reconnaissance Drought Indices as Meteorological Drought Indices

Droughthas occurred at different times in the watershed assured by analyzing the long-term historic metrological and hydrological data. Metrological droughts were characterized by SPI and RDI indices using 1, 3, 6 and 12 month time steps. The analysis of the 1-month time scale revealed that the extreme drought occurred in the years 1987 and 2015 in July. Similarly, severe droughthappened in 1987(June), 1990 (May, June, and August), 1995 (September), 2003 (October, March, April, May, June, August, and September), 2008 (March), 2009 (September), 2015 (April) and 2018 (October). Moderate drought was also pronounced in 1988 (March and May), 1989 (May and august), 1993 (June and august), 1999 (April), 2000 (March), 2002 (May), 2004 (May), 2005, and 2006 (April), 2007 (May), 2009 (May), 2011 (October), 2012 (October and March), and 2019 (August).

Based on the 3, 6 and, 12-month time step SPI and RDI indices analysis, a higher pick of the drought was observed in the watershed in 1987 and 2003. Concerning the 3-month time scale, it was better to see the drought effects on the main rainy seasons (kiremit) and the short rainy season (B*elg*) of the watershed. The only extreme drought occurred in 1987 (July- September). Similarly, the most severe dryness has experienced in 2003 and 2015 and moderate dryness was also pronounced in 1995 in kiremit months (July- September). In agreement with this, Segele & Lamb (2005) and Viste *et al.*,(2013) reported that the kiremt season of 1987 was severely dry over

Ethiopia, particularly in the northeastern half of the country, which was primarily caused by the missing of rain in July and August. So, those incidents would have a higher risk in the study area. According to Mekonen *et al.,* (2020) the drought risk intensity was more weighted during the months of kiremt. Segele & Lamb (2005) also revealed that the greatest damaging droughts in Ethiopia are connected with the failure of kiremt rains. In the short rainy seasons also the most severe drought occurred in 2003 and 2012 (January-march).

This result mostly agreed with the ground facts of the historic drought events during the years 1970-2010 in Ethiopia presented by the EM-DAT International Disaster Database center (Yared *et al.*, 2018). According to the center, a drought occurred from June 1987 (Shewa, Wollo, Tigray, etc), from October 1989-1994, 2003-2004, and May 2008-October 2009 (Tigray, Amhara, Oromiya, etc put on as region). This depicts the performance of the drought indices' abilities in indicating historic drought events. In 2008/2009 all regions of Ethiopia and in 2015/2016 in the north, east, and southwest Ethiopia, a drought occurred and millions of people were affected (Mohammed *et al.,* 2018).

Generally, based on the above result, both indices did not show a large difference (Figure.2-7) which was similarly reported by Alemu *et al.,* (2021). Nevertheless, the RDI is more advantageous than SPI since the RDI incorporates both temperature (evapotranspiration) and precipitation data in a single index whereas the SPI includes only precipitation (rainfall) data. Similar to this study, for drought monitoring in given stations, Jamshidi *et al.,* (2011) showed that the RDI is more sensitive than the SPI to climatic conditions and therefore, the RDI was more recommended for meteorological drought monitoring. Alemu *et al.,* (2021), also reported the role of evapotranspiration is very important in drought assessment and should not be ignored. However, many scholars from different countries such as Algeria, India, the USA, Nepal, Tunisia, Kuwait, etc., also recommend the importance and suitability of SPI and RDI indices for drought monitoring, assessing and comparing meteorological and hydrological droughts (Thilakarathne & Sridhar, 2017).

Streamflow Drought Index (SDI): Based on the 35 years' time series stream flow data, the SDI has been analyzed for the reference periods, SDI-3, SDI-6, and SDI-12 described in the following subheadings.

Three-Month Stream Flow Drought Index (SDI-3): Based on the SDI-3 value the station experienced droughts during the reference period October-December in the years 1996, 1998, 2008, 2015 and 2017 (mild drought), 2003 and 2007 (moderate drought), 2001, 2012 and 2016 (severe drought), 2002 and 2005 (extreme drought). From the January-march reference period in the years 2015, 2012, 2003, 2000, and 1999 (moderate and severe droughts) have appeared. In the reference period from April-June mild and moderate droughthas been observed. However, 2013 and 2006 experienced severe and extreme drought with SDI-3 values of -1.77 and -2.16 respectively. From July to September in comparison to other periods, most of the droughts were mild. Two years, 1987 and 2015 were affected by extreme drought with SDI-3 values of -2.09 and -2.87 respectively. This may be a result of extreme and severe droughts in a similar reference period indicated above in SPI drought analysis to assure metrological drought impacts on hydrological droughts (Wale *et al.*, 2018).

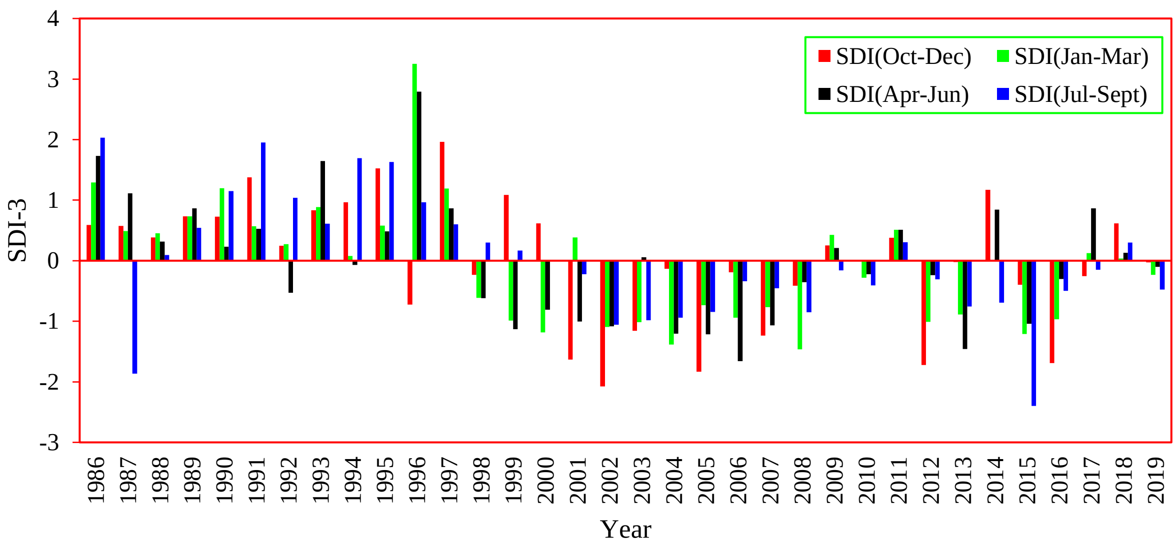


Figure 8. Three-month streamflow drought index (SDI-3) of the watershed

Six-Month Stream Flow Drought Index (SDI-6): The six-month streamflow drought index is presented in (Figure 9). For the last 35 years, drought incidents have occurred from October-March in 14 years (41.2%). From there, the years 2003, 2012, and 2016 were affected by extreme droughts with SDI-6 values of -2.55, -20.7, and -2.01 respectively, and 2005 was affected by severe droughts with SDI-6 values of -1.91. Similarly, from April-September, more droughts (50%) have occurred. However, only one extreme drought in the year 2015 with an SDI-6 value of -2.95 was experienced and the others were only moderate and mild. The SDI-6 series showed a more remarkable decrease in stream flow during the October-March period as compared with the April-September period. According to Basin & Ozkaya, (2019), a decrease in stream flow and water losses resulted in reduced use of irrigation water, because the requirement for crop irrigation was the highest at the time.

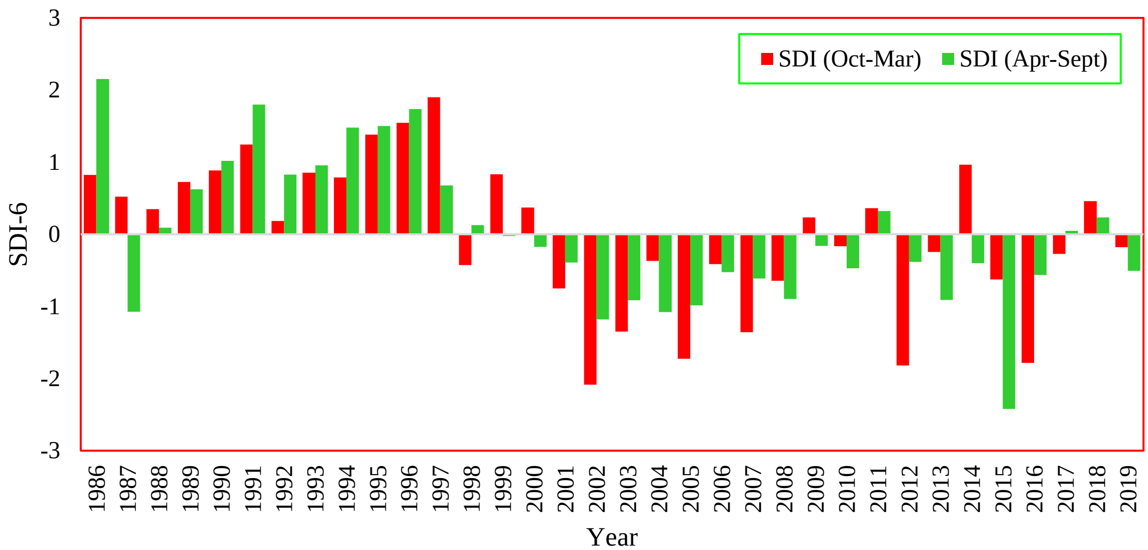


Figure 9. Six-month streamflow drought index (SDI-6) of the watershed

Annual Streamflow Drought Index (SDI-12): The annual drought index for streamflow is shown in (Figure 10). From 34 years data the annual drought (SDI-12) analysis result depicted 16 years (47%) droughthas appeared in the watershed. From these 16 years, one year (2015) got extreme drought with an SDI-12 value of -2.61 and four years (2002-2005) experienced severe drought with SDI-12 values of -1.43, -1.10, -1.05, and -1.2 respectively and the rest were mild droughts. This indicates that there was decreasing or blow average stream flow recorded in all SDI analyzing time steps. The years 1986, 1991, 1995, and 1996 were determined to be very wet years, whereas 1990, 1994, and 1997 were found to be moderately wet years, as is shown in the chart below. These wet years of streamflow had dry weather, as determined by the standard precipitation index and reconnaissance drought index.

For instance, the standardized precipitation index classified 1990 as a moderately dry year, but there was a water deficit in the stream. Such events might occur since there are insuffcent structures to facilitate water infiltration into the ground. As a result, rainwater directly transforms into runoff and flow. But beginning in 1998, the watershed's hydrologic conditions almost always showed signs of being fairly dry. The absence of excessive rainfall is the primary cause, but it is also anticipated that the rainfall is not instantly converting in to runoff. Since there have been several attempts to conserve soil and water in the watershed since 1995, these intervention activities may have an impact on the streamflow (Dile *et al.,* 2018; Sultan *et al.,* 2018).

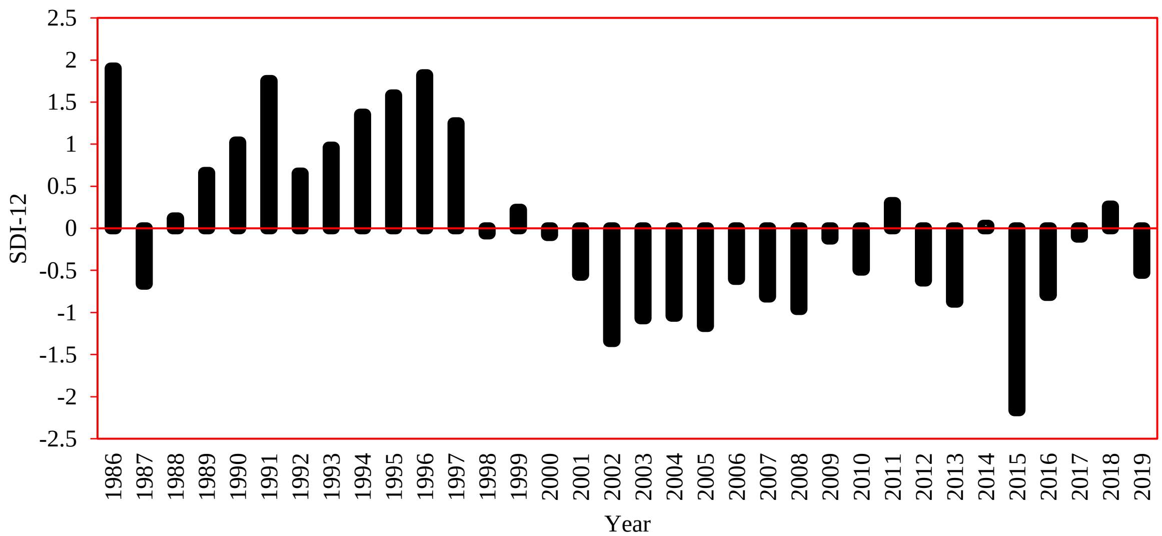


Figure 10. Annual-streamflow drought index (SDI-12) in the study watershed

Sensitivity of Streamflow to Drought: For sensitivity analysis, it was better to investigate the relationship of stream flow with drought and climatic parameters (Basijokaite & Kelleher, 2021; Malede *et al.,* 2022). The impacts of drought on stream flow were analyzed with establishing a correlation between annual stream flow data and annual SDI values.

Relationship between Meteorological and Hydrological Droughts: To analyze the relationship between climatic and hydrological droughts in a basin, the correlation coefficients between the SPI, RDI, and SDI were calculated for different time scales. Similar findings by Boudad *et al*., (2018); Lohpaisankrit & Techamahasaranont, (2021) reported positive relationship between meteorological and hydrological droughts. The correlation coefficient between the RDI and SPI was found to be the highest ranging from 87% to 99% in all time scales. The occurrence of climatic droughts is one or two months earlier than the hydrological droughts in the watershed. Hence, the occurrence of a meteorological drought two months earlier could be an early warning signal of a hydrological drought, and the occurrence of a meteorological drought one month earlier usually could cause the occurrence of hydrological drought.

The correlation between the 3-month drought indices, SPI, RDI and SDI were found to be significantly correlated (Figure 11). January to March seasonal analysis confirmed that the watershed was equally affected with both meteorological and hydrological droughts. July to September, the streamflow was not affected by meteorology as illustrated in Figure 11. Since these were the watershed's primary rainy months, there may be more factors besides climatic ones that affect streamflow. The biophysical characteristics of the watershed may have an impact on the proportional change in streamflow caused by meteorological factors (Lv *et al*., 2021).

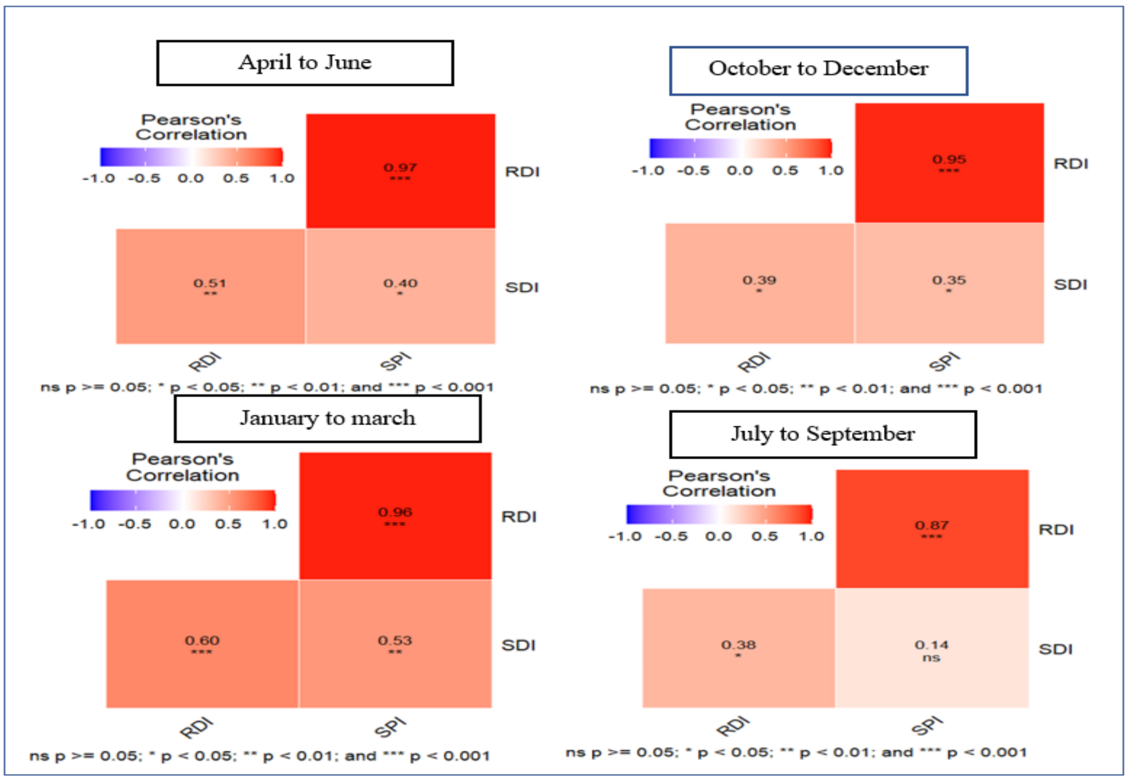


Figure 11. The correlation chart of three-month drought indices

The six-month drought analysis indicates that all drought indices were found to be significantly correlated, even though, the SPI and SDI were found to be highly correlated than Standardized Precipitation Index (SPI) and Stream flow Drought Index (SDI) and Reconnaissance Drought Index (RDI) (Figure 12). However, there was no noticeable relationship between SDI and SPI from April to September. Compared to reconnaissance drought index, streamflow drought index shows weaker correlation with standardized precipitation index. Reconnaissance drought index, which takes evapotranspiration into account while calculating streamflow, is said to be more cautious than standard precipitation index.

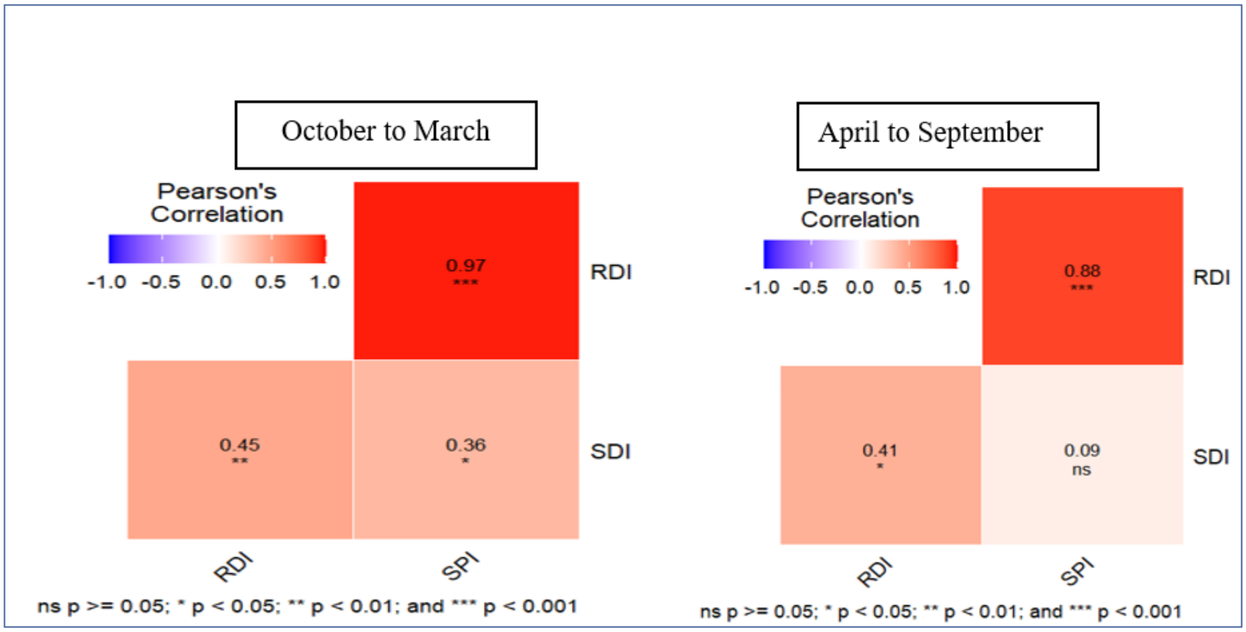


Figure 12. The correlation chart of six-months drought indices

Correlation coefficients for 12 months between SPI and SDI were not significant but there has been a significant correlation between SDI and RDI (Figure 13). The correlation coefficient for 12 months between SPI and SDI was around 10%, which is the smallest among the four different time scales. The higher values indicate that climate has a significant impact on the hydrological process on the annual time scale. However, human activities would clearly have an impact on hydrology and water supplies at shorter time spans. Similarly, streamflow is more heavily influenced by the reconnaissance drought index than the standardized drought index in the annual drought analysis. While there was a weak correlation between the streamflow drought index and the standardized drought index, the correlation between the streamflow drought index and the reconnaissance drought index was rather significant (Figure 13).

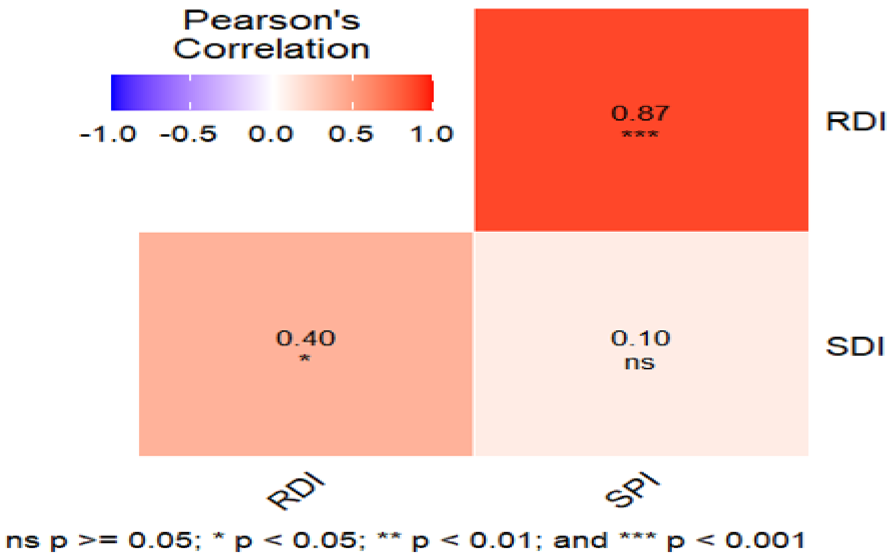


Figure 13. The correlation chart of annual drought indices

In all time correlation analyses (Figure 11-13); 1, 3, 6, and 12 months, RDI and SDI have better correlation and all correlations are significant (P<0.05). This is the result of the inclusion of many climatic parameters like Eto during the calculation of RDI. RDI by utilizing the Eto can be very sensitive to climatic variability, utilization of the RDI would seem to serve a better purpose (Khalili *et al.*, 2011; Memon & Shah, 2019). From the result of the correlation between SDI and RDI, we can confirm that the stream flow is highly affected by evapotranspiration.

Compared to correlations between other pairs of meteorological indices, correlations involving SDI were generally low. According to Yared *et al.*, (2018), it is based on river flow, which is a combination of surface flow, interflow, and base flow (or groundwater flow), and is expected to have a certain lag time with meteorological droughts. This might be one of the possible reasons of the absence of correlation with other drought indices.

The change in climatic parameters also plays a crucial role in the station stream flow change. According to Turoglu, (2016), the changes in annual and seasonal mean values of temperature and precipitation have a direct impact on surface runoff and therefore flow characteristics of rivers are likely to be very sensitive to climate changes. Regression analyses were carried out to understand the relationship between climatic parameters (precipitation, temperature and calculated evapotranspiration) and the resulting stream flow. Based on the analysis, annual stream flow was negatively correlated with temperature (-0.19) and potential evapotranspiration (-0.63) and positively correlated with precipitation. The watershed stream flow was more sensitive to evapotranspiration than rainfall and temperature.

Prediction of Future Stream Flow and Climatic Variables: The annual rainfall, temperature and stream flow trends have been forecasted using Autoregressive Integrated Moving Average (ARIMA) model (Figure 14 to 16). Hydrological drought prediction has a representative role in water resource management. Alawsi *et al.,* (2022) reported that drought forecasting is a critical component of drought hydrology which plays a vital role in risk management, drought preparedness and mitigation. Based on Autoregressive Integrated Moving Average (ARIMA) model, hydrological drought could project for the coming near future periods. As shown in (Figure 14) the stream flow of the study watershed will be decreasing in the coming ten years. The blue color in the graph represents the future projected streamflow using the black colored observed historical streamflow.

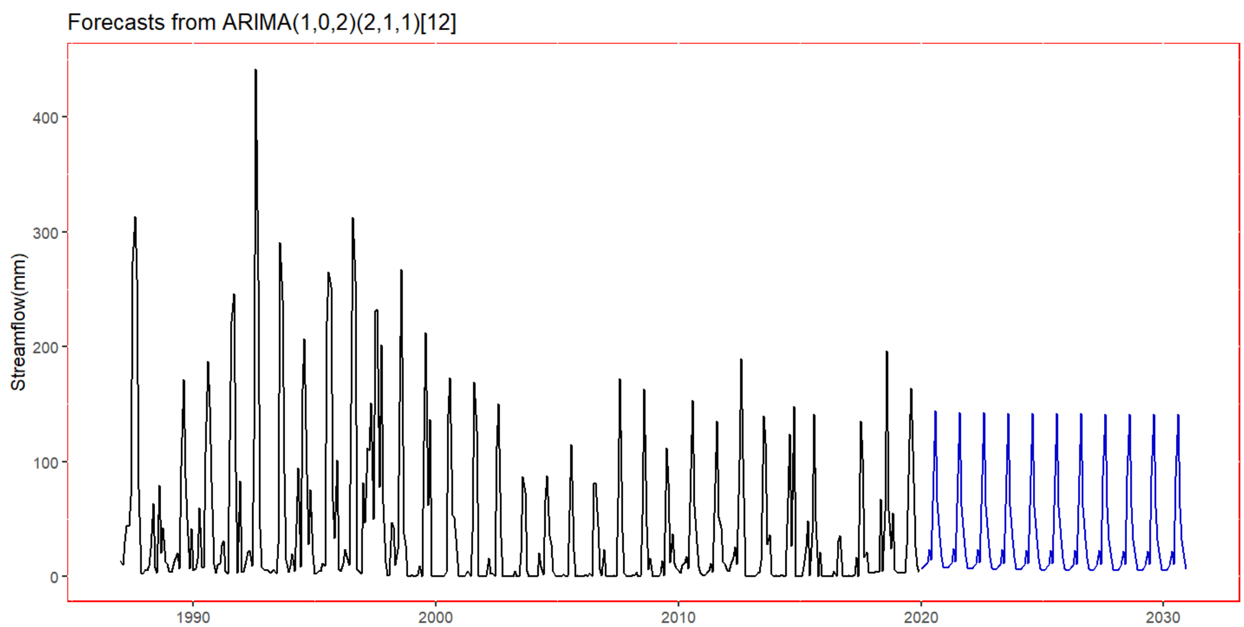


Figure 14. The historical (black line) and the future projected (blue line) streamflow of the study watershed

The rainfall of the watershed also indicated decreasing trend for the coming ten years, as illustrated in (Figure 15).

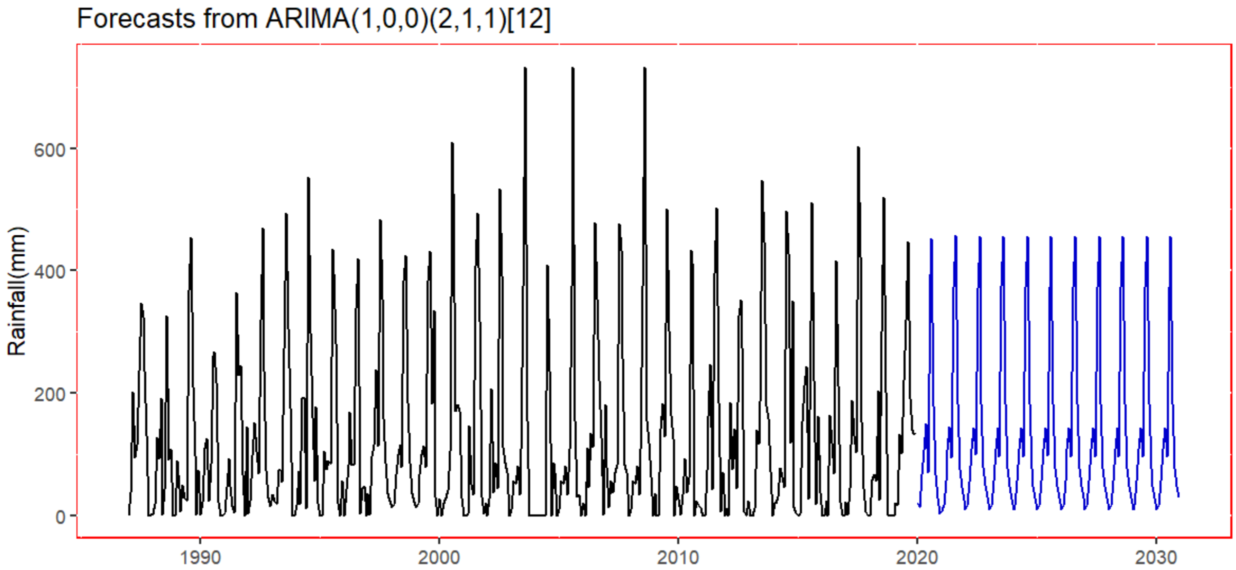
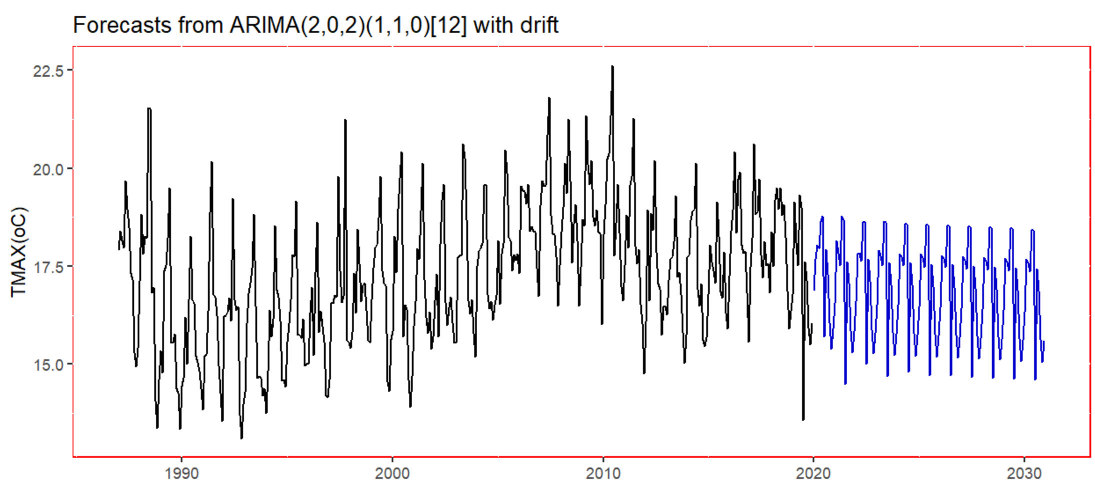


Figure 15. The historical (black line) and the future projected (blue line) rainfall of the study watershed

Additionally, it was determined that the maximum and minimum temperatures would be decreasing over the coming ten years. However, the rate of decrease is not remarkable.



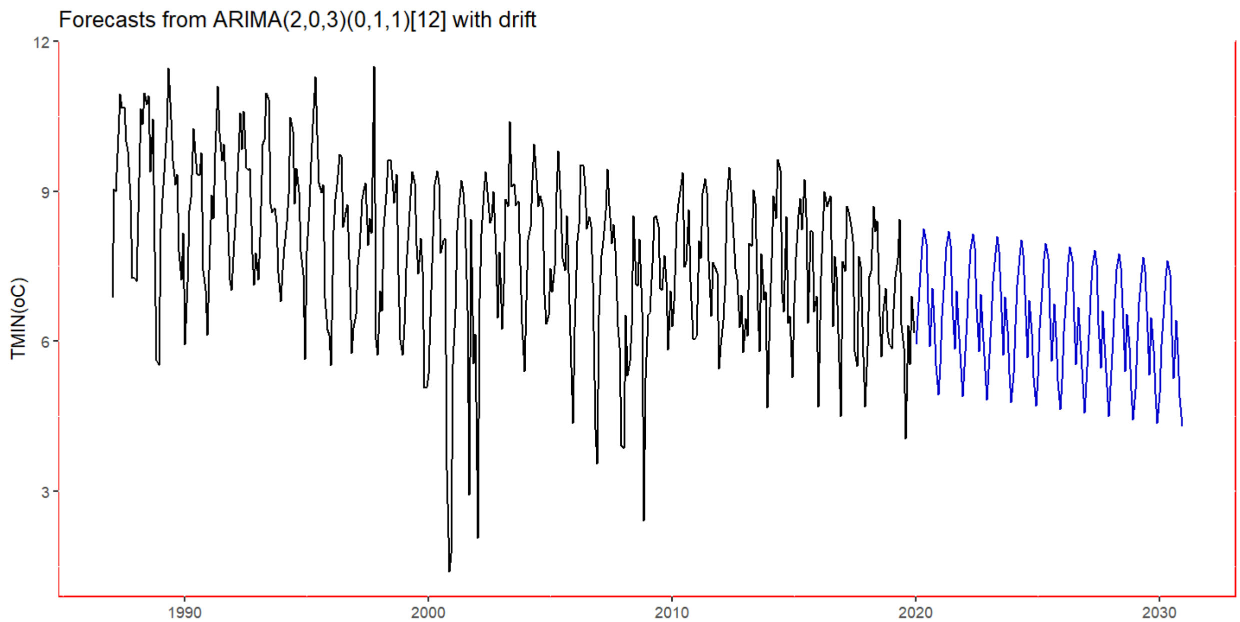


Figure 16. The historical (black line) and future projected (Blue line) minimum and maximum temperature of the study watershed

As indicated below the future predicted stream flow showed a decreasing trend proportionally to the observed data trends that help for the proper use and management of the resource. Datta *et al.*, (2021), reported that accurate prediction helps water managers with proper planning, utilization of limited water resources and distribution of available water to different sectors and avoid catastrophic consequences.

Prediction Accuracy Assessment: MAPE value of 4.4% and 10.1% in forecasting maximum and minimum temperature means that the average difference between the forecasted value and the actual value is 4.4% and 10.1% respectively (Table 2). With this metrics, the prediction model can be considered as a very accurate model. Similarly, the RMSE and MAE values of these two climatic parameters are very small; this is an indicator for the accuracy of the prediction model. Whereas the infinity and maximum value of MAPE is the result of '0' or near'0' values in our actual observed rainfall and runoff data respectively. As indicated in the equation, ithas a division for the actual value, at this time if there is '0' value in the actual data, therefore there will be undefined (infinity) value for MAPE.

Table 2. Statistics measuring the forecasting accuracy of ARIMA model

Forecasted parameters	Forecasted years	RMSE	MAE	MAPE
Rainfall (mm)	10	72.91	49.21	∞
Streamflow (mm)	10	37.08	21.65	1884.83
Minimum Temperature (oC)	10	0.87	0.61	10.10
Maximum Temperature (oC)	10	1.02	0.75	4.40

Conclusion and Recommendation

The sensitivity of streamflow to meteorological droughts was investigated using 35 years of rainfall, temperature and stream flow data in Andit Tid watershed. Standardized precipitation index (SPI) and Reconnaissance drought index (RDI) were used to analyze metrological drought and Stream flow drought index (SDI) which was used for hydrological drought analysis. Data were analyzed using DrinC, R software and Microsoft Excel. Based on the analysis both metrological and hydrological droughts were experienced in the study watershed at different periods (1, 3, 6, and 12 months). From different periods of drought analysis 1986, 2003, and 2015 were identified to be extremely dry years in the watershed. The results of a correlation analysis between drought indices showed that metrological drought indices had higher correlations between one another. There is also a strong correlation between the hydrological and meteorological droughts indices at (P 0.05). The correlation between the streamflow drought index (SDI) and reconnaissance drought index (RDI) was higher than that between the standardized precipitation index (SPI). This streamflow behavior demonstrated its high reaction to evapotranspiration than the actual temperature. Generally, the drought indices in the watershed were better correlated during dry seasons than during wet seasons. It was determined through analysis of the watershed's future hydrologic and meteorological conditions that all streamflow, rainfall, and temperature will decrease during the next ten years. Given the aforementioned results, it is preferable to take action to reduce climate change through water harvesting and management strategies.

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2. Comparative Evaluation of Conservation Agriculture and Other Management Practices to Improve Productivity of Vertisols

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Abstract

Vertisols are dark-colored clays that develop cracks when expanding and contracting with changes in moisture content. In the highlands of Ethiopia, tillage methods and frequency affect drainage, soil erosion, moisture conservation, weeding, and harvesting of crops. Five tillage methods namely broad bed and furrows (BBF); permanently raised bed with no-tillage (PRB+NT); permanently raised bed with no-tillage and 30% stubble retention (PRB+NT+M); Flatbed with no-tillage (Flat+NT) and a flatbed with no-tillage and 30% stubble retention (Flat+NT+M) were evaluated for their effects on the productivity of vertisol. The study was conducted in Moretna Jiru wereda, Enewari for seven years (2015 to 2022) in the central highland of Ethiopia. In this study, the soil indicaters such as moisture content, bulk density, organic carbon, PH, available Phosphorous, extractable Potassium, electrical conductivity, and total Nitrogen, and productivity indicators namely the plant height; grain yield, and straw yields were measured. The result indicated, Flat+NT+M and Flat+NT significantly increased the grain yield of wheat by 13.4% and 11.2% respectively as compared to BBF for the experimental years 2015/16 and 2017/18. However, in experimental years 2019/20 and 2021/22 the wheat yield was high on BBF compared to other conservation agriculture practices. On the other hand, BBF gave the highest grain yield of Faba bean as compared to the conservation agriculture practices. A soil property data implies that PRB+NT+M, Flat +NT, and Flat+NT+M could improve the total N, soil PH, Organic C, moisture holding capacity, and extractable Potassium. Economically, Flat+NT was the most profitable practice with 1147.6% marginal rate of return (MRR). Based on the agronomic, economic, and soil property results, the best combinations of crop and land preparation methods were: Flat+NT and Flat+NT+M for wheat production in dry years. Effective drainage method like BBF has an advantage for better production of Faba bean on Vertisols.

Keywords: BBF, flat bed; no tillage; Moretna Jiru; Enewari; permanently raised, stubble

Introduction

Vertisols are dark-colored clays that develop cracks when expanding and contracting with changes in moisture content(Wubie, 2015). It is the fourth most important soil in Ethiopia in terms of area coverage, constituting 7.6 million ha in the central highlands(Jutzi and Mesfin, 1987). Vertisols is a very fertile soil and it can be productive enough if properly managed. The problem of vertisols is believed to be emanated from the intensity of seedbed preparation (frequent plowing even during the muddy time) and the grazing practices in wet conditions. Frequent tillage and delayed planting not only substantially reduce the growing period and crop productivity, but also exacerbate soil erosion, which is already among the devastating environmental problems of the Ethiopian highlands(Astatke *et al.*, 2002). The higher tillage frequency increases the loss of soil organic matter because of the mixing of the soil and crop residues, disruption of aggregates, and increased aeration (Doran and Smith, 2015). The soils remain bare during the peak rain season with occasional tillage operations enduring vulnerability to soil erosion. These practices are also supposed to cause compaction and pan formation that hinder hydrological conductivity and create perched water on the surface which is usually seen in water logging. Even after repeated cultivations, the seedbed is rough. These lead to the deterioration of the physical, chemical, and biological quality of the soil over the long term, and vertisols are no exception.

As a solution for mentioned problems experiences from countries like India and Australia shows that proper knowledge and management of vertisols have resulted in increased yields. Hence the proper management applications of the technology for Vertisols are believed to increase productivity and food security levels in Ethiopia. Among the options surface drainage method, known as broad bed and furrow (BBF) constructed by broad bed maker (BBM), which was developed at ICRISAT in India(El-Swaify *et al.,* 1985) and other known traditional methods (like Shuribie in North Shewa) are some of the experiences that can be mentioned. Several authors reported increased yields of some crops grown on vertisols due to the use of the BBF as compared to the flat seedbeds (Astatke, Mohamed Saleem and El Wakeel, 1995; Haque, Lupwayi and Luyindula, 1996). Despite the yield advantage it is better to test and amend alternatives on existing various technologies and other experiences from around the world for their economic effectiveness; draining excess water; environmentally friendly and ease of use by the farmers.

Therefore, this study aimed to evaluate the effectiveness of integration of conservation agriculture with different land management practices for the improvement of productivity of Vertisols and to introduce cheap and environmentally friendly methods of land management for Vertisols.

Materials and Methods

Description of the Study Area: The study was conducted at Moretna Jiru woreda North Shewa, Ethiopia. Enewari is situated at 39°9.5'E longitudes and 9°53'N latitudes and 198 km Northeast of the capital city Addis Ababa (Figure 1). The altitude of the experimental site is 2664m. Ithas a unimodal type of rainfall distribution with a mean annual rainfall of 1142.1mm, while the minimum and maximum temperatures are 9.43°C and 21.14°C, respectively. June, July, and August receive large shares of the annual rainfall. Moretna Jiru woreda is dominantly covered with heavy clay soil (pellic Vertisols) and extremely constrained by water logging problems. The dominant land use of the wereda is seasonal crops; those are wheat (Tritium aestivum L.), tef (Eragrostis tef), lentil (Lens culinaries Medik) and Faba bean (Vicia faba) while the marginal lands along the roadsides, gully bottoms, and flood plains are the major grazing ground.

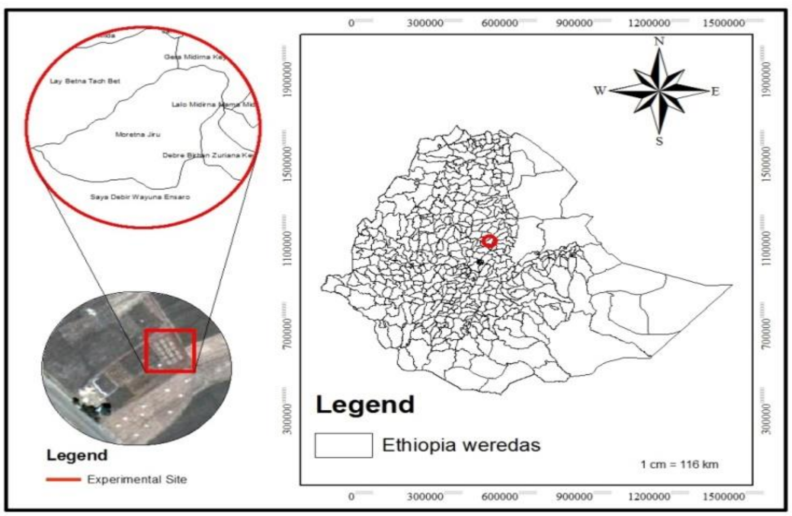

Figure 1. The location map of the experimental site

Experimental Procedures and Treatment Description: The experimental layout was a randomized complete block design with three replications, and the plot size was 4m by 4.8m. The total area of the experimental area was 18m by 30m. The tillage plowing was done with a hand-made digging hoe. The first plowing is started in mid-April based on the availability of moisture for all experimental years for BBF treatment. Seeds were sown by hand drilling seed 20cm between row spacing for wheat and the rotation after wheat grown in the second production season Faba bean seed was sown with 10cm between plants and 40cm between row spacing. The variety of the test crop were used Menzie and Lalo for Bread wheat (*Triticum durum Desf.)* and Faba bean (*Vicia faba*) respectively. The seed rate of the test crop was 131.25 Kgha^{-1} for wheat (*Triticum durum Desf.)* and with 10 cm spacing between plants for faba bean (*Vicia faba*). The fertilizer rate used for this experiment was 275Kgha^{-1} urea and 272.36 Kgha^{-1} NPS for wheat (*Triticum durum Desf.)* and 121 Kgha^{-1} NPS for faba bean (*Vicia faba*).

The evaluated tillage practices were described as:

- **a.** *Broad bed and furrows (BBF):* Broad beds and furrows were constructed by the broad bed maker (BBM), which is an oxen-drawn traditional wooden plow, modified for the construction of raised beds and furrows. With an effective bed width of 80 cm and 40 cm of bed furrows, it is intended to facilitate surface drainage through the furrows between the beds so that the crops grow on the beds. This practice was introduced in the study area formerly and due to this the broad bed and furrows are the control treatment of this experiment.
- **b.** *Permanently raised bed with no-tillage (PRB+NT):* These beds were prepared with a 1.2 m bed width and 40 cm furrow at the start of the experiment. After the beginning of the experiment, plots were kept intact fallow until they were perforated in small slots for sowing. The seeds were drilled and covered by a single tillage operation using the local peg for both testing crops wheat and faba bean. The practice was aimed at minimizing pre-sowing soil disturbance, reducing oxidation of SOM, and maintaining some surface cover to reduce soil erosion. The treatments were kept permanent while two crops: wheat (*Tritium aestivum* L.), faba bean were rotated following their traditional sequence. In this treatment, the bed and furrow were permanently untouched for draining the excess water from the field. All the cultural practices other than the treatments were implemented according to the recommendation for the respective crops.
- **c.** *Permanently raised bed with no-tillage and 30% stubble retention (PRB+NT+M):* This treatment was kept similar to a permanently raised bed with no-tillage (PRB+NT) except for 30% stubble retained in the field. The stubble retention in this experiment was performed by cutting the test crop at 30% height during harvesting.

d. *Flatbed with no-tillage (Flat +NT):* This treatment kept the field flat and not tilled over all periods of the season. The test crops were grown by perforating small slots. The seeds were drilled and covered by a single tillage operation using the local peg for both testing crops (Faba bean & wheat). This practice was aimed at minimizing pre-sowing soil disturbance, reducing oxidation of SOM, and maintaining some surface cover to reduce soil erosion. All the cultural practices other than the treatments were implemented according to the recommendation for the respective crops. The flat land untouched in this treatment was proposed as an agent for aggregate stability and biological tillage through developing favorable conditions for micro-organisms.

e. *Flatbed with no-tillage and 30% stubble retention (Flat+NT+M):* This treatment was kept similar to the flatbed with no tillage except 30% stubble retained in the field at the time of harvesting. The stubble retention in this experiment was performed by cutting the test crop at 30% height during harvesting.

Data Collection and Analysis: Composite soil samples before sowing and after harvesting of test crops were collected from each plot at 0 to 20 cm depths for physic-chemical property analysis. Soil core samples were collected at 0 to 30 cm depths for BD measurement (Blake and Hartge, 1986; Arshad, Lowery and Grossman, 1996).Correspondingly, auger sampling was made to determine gravimetric moisture content(Lowery *et al.,* 2015). Grain yield and other agronomic data having a response to crop yield were collected for each experimental year. Labor and other economic data were also collected.

The collected data were subjected to analysis of variance using R software version 4.1.3 to determine treatment effects. Wherever the difference among treatment means was compared using Fisher's least significant difference test at 5% (P=0.05).

Selection of treatments for further experimentation and for developing farmer recommendations partial budget analysis was done by following the CIMMIT manual (CIMMYT, 1988).

Results and Discussion

Effect of Conservation Agriculture on Yield and Yield Component of Wheat: The agronomic and yield-related impacts of conservation agriculture during wheat production years shown in Table 1, Flat+NT and Flat+NT+M gave marginally higher wheat yields for the first two experimental years 2015/16 and 2017/18. During these experimental years, there was no rainfall in October and November showed in Figure 2. As a result, conservation agriculture, (Flat+NT and Flat+NT+M) was more advantageous compared to farmer's practice. Because of conservation agriculture conserve more soil moisture compared to farmer practices. Taking all specific practices as an overall effect, conservation agriculture significantly increased wheat crop yield by 4.37%-13.4% as compared to the conventional farming system (BBF). There were statistical differences in specific effect sizes among the conservation agriculture practices ($P < 0.05$). Flat +NT +M and Flat +NT gave statistically highest wheat grain yield than other treatments, they have 13.47% and 11.2% yield advantage compared to conventional tillage (BBF) respectively. This was in line with the study reported by (Erkossa, Stahr and Gaiser, 2006), who stated that the BBF significantly decreased the grain yield of wheat by 35% in some parts of Ethiopian highlands. Similar to our result, among the conservation agriculture methods applied in China, straw retention showed a significant positive effect on crop yield. Another study found by(De Vita *et al.*, 2007; Li *et al.*, 2010), reported significantly higher wheat yield under straw retention than under conventional tillage only in dry years.

However, the wheat yield for the next two experimental years 2019/20 and 2021/22 become lower in Flat+NT and Flat+NT+M compared to PRB+NT+M, PRB+NT, and BBF as shown in Table 1. The rainfall in those cropping seasons was high compared to the previous experimental year as shown in Figure 2. There was no moisture deficiency up to the harvesting time. In that case, farmer practice (BBF) was more advantageous compared to conservation agriculture. According to field observation, there was a water logging problem on Flat +NT+M and Flat+NT as compared to BBF, PRB+NT, and PRB+NT+M. Taking all specific practices as an overall effect, conservation agriculture practices lowered wheat crop yield by 1.9% to 19.3% as compared to the conventional farming system (BBF). This was disagreeing with the study reported by (Erkossa, Stahr and Gaiser, 2006) BBF significantly decreased the grain yield of wheat by 35% in some parts of Ethiopian highlands. Another study was found by (De Vita *et al.*, 2007; Li *et al.*, 2010), who reported significantly higher wheat yield under straw retention than under conventional tillage only in dry years.

Table 1. Effects of conservation agriculture practices on wheat yield

Treatments	2015/16		2017/18		2019/20		2021/22	
	GY*	ST	GY	ST	GY	ST	GY	ST
BBF	5245.4ab	8000.9ab	4500b	7541.7	3743.1a	5861.1a	4566	5854.2a
PRB+NT	5007.8b	7518.7bc	5240a	8171.9	3519.5ab	4617.2c	4593.8	5480.5a
PRB+NT+M	5130.2b	7247.6c	5040.7ab	8341.2	3304.7bc	5317b	4566.4	4132.8b
Flat+NT	5420.1a	8344.5a	5416.7a	8891.7	3203.1bc	4250c	4479.2	6208.3a
Flat+NT+M	5520.8a	7985.6ab	5537.5a	9271.7	3020.8c	4732.1c	3849	3833.3b
CV (%)	2.9	4.3	6.9	8.4	6	5.3	7.8	9.7
LSD (0.05)	286.9	627.8	664.9	ns	379.6	503.2	ns	927

**GY: grain and SY: straw in Kgha-1 and PH: plant height (cm)*

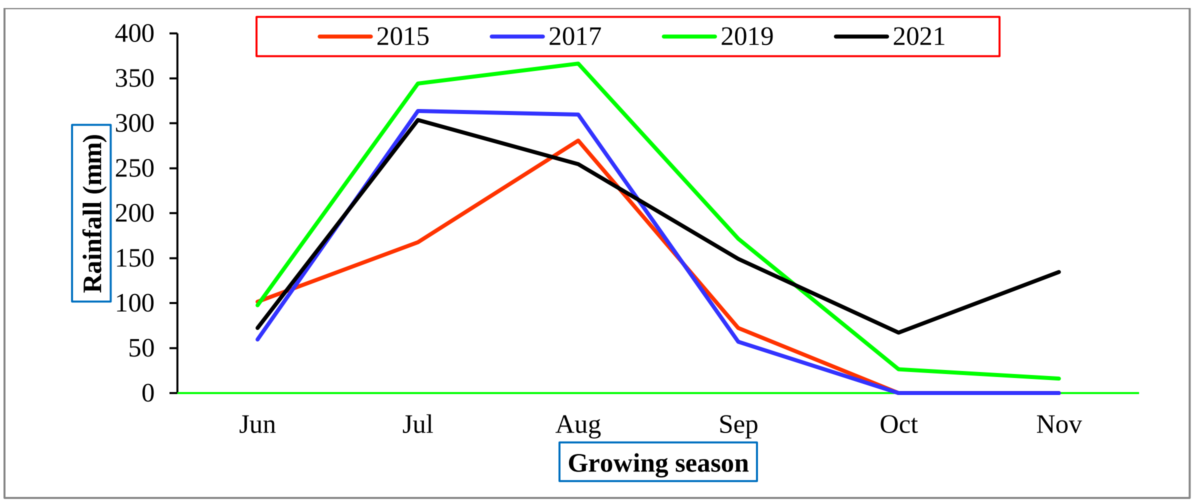

Figure 2. The distribution of rainfall during the growing seasons of the experiment

Effect of Conservation Agriculture on Yield and Yield Component of Faba Bean: The agronomic and yield-related impacts of conservation agriculture during Faba bean production years shown in Table 2 revealed that there was statistically lower Faba bean grain yield in all conservation agriculture practices compared to farmer practices. Even though it was not significant at ($p<0.05$), the growth parameter (plant height) was high in BBF. In the study area for three experimental years, there was 372.2mm, 385.8mm, 75.9mm, and 29.1mm average rain in July, August, September, and October respectively. This might influence the performance of Faba bean in mulched treatments. Based on field observation in the experimental years' stubble retention is caused to excessively increasing soil moisture, this may lead to lower yield. In line with our study, BBF has 98% yield advantage over flatbed tillage system (Agegnehu G and Ghizaw A, 2004). In other scholars, stubble retention could also depress crop growth by nutrient immobilization in soil microbes and increase residue-borne diseases. Straw retention improves soil moisture conditions by improving soil structure and reduces soil water evaporation, thus benefiting crop growth under dry conditions; however, straw retention in areas with high rainfall may lower crop yield owing to water logging (Rusinamhodzi *et al.*, 2011).

Table 2. Effects of conservation agriculture on Fababean yield

	2016/17			2018/19			2020/21		
Treatment	GY*	ST	PH	GY	ST	PH	GY	ST	PH
BBF	3943.3	4063.7	101.8a	3158	2887.5	87a	2178.8a	1149.3	69.7a
PRB+NT	3541.7	3807.3	99.2a	2650.7	2427.7	77.8b	1505.2b	903.6	68.1a
PRB+NT+M	3828.1	4259.7	99.9a	2185.6	2915.8	76.5b	1466.1b	882.8	65.8a
Flat+NT	3507	3652.8	91.2b	2393.2	2447.9	72.9bc	1597.2b	1024.3	65.7a
Flat+NT+M	3763.9	4221.2	92.1b	1953.2	3192.7	69.7c	1927.1ab	871.5	57.2b
Mean	3716.8	4000.9	96.8	2468.1	2774.3	76.7	1734.9	966.3	65.3
CV (%)	4.6	7.5	3.04	18.6	14.1	4.59	15.8	16.7	5.1
LSD (0.05)	ns	ns	5.55	ns	ns	6.64	516.9	ns	6.3

**GY: grain and SY: straw in Kgha^{-1} and PH: plant height(cm)*

Effect of CA on Selected Soil Physiochemical Properties

Effect of Conservation Agriculture on Selected Soil Chemical Properties: As shown in Table 3, the soil result indicates that the available Phosphorus was improved on BBF and PRB+NT+M as compared to PRB+NT, Flat+NT, and Flat+NT+M. Soil available P content was increased by crop harvest possibly due to the residual effects of fertilizer applied for the test crop. Soil P increases reported in this study following crop fertilization agree with earlier findings (Ishaq, Ibrahim and Lal, 2002). The PH for all treatments ranged from 6.6 to 6.7. The pH range of 6.0 to 6.8 is ideal for most crops because it coincides with the optimum solubility of the most important plant nutrients. PRB+NT+M, Flat+NT, and Flat+NT+M resulted in a net increase of 0.64–1.27% in soil organic carbon content and organic matter over conventional tillage (BBF). In line with our study (Li *et al.*, 2020) indicates that no-tillage with residue retention and reduced tillage with residue retention increase soil organic carbon stock by 29% and 27% respectively compared to conventional tillage. Similarly (Bravo *et al.,* 2007; Meena *et al.,* 2015), reported that zero tillage resulted in a net increase of 16–27% in soil carbon content over conventional tillage. And also PRB+NT and PRB+NT+M could better conserve soil total Nitrogen (N %). PRB+NT and PRB+NT+M could also improve the total N by 0.64% and 3.18% as compared to the BBF. In this study, the result of electrical conductivity (E.C ds/m) was a similar range for all tillage treatments which is normal and free from salinity problems. Flat +NT+M and Flat +NT could improve exchangeable Potassium by 5.6% and 26.1% respectively compared to farmer practices. Similarly, other studies revealed that the level of extractable K increases at the soil surface with no tillage as tillage intensity decreases and residue retention increases(Ismail, Blevins and Frye, 1994; Govaerts *et al.,* 2007). The effect of conservation tillage on enhancing SOC sequestration has been reported by several researchers(Potter *et al.,* 1997; Post and Kwon, 2000; Lal, 2001, 2004). There was a significant ($P<0.001$) difference in mean pH, total mineral N, and percent organic and microbial biomass C contents obtained after harvest(Kutu, FR, 2012).

Table 3. Effect of conservation agriculture on selected surface soil (0-20 cm) chemical properties

Treatment	Available P(ppm)	E.C(ds/m)	K (cmol/Kg of soil)	PH (kcl)	SOC (%)	SOM (%)	Total N (%)
BBF	16.65	0.13	0.88	6.6	0.785	1.35	0.0785
PRB+NT	15.25	0.12	0.83	6.6	0.725	1.247	0.079
PRB+NT+M	16.4	0.12	0.86	6.6	0.79	1.359	0.081
Flat+NT	12.6	0.22	1.11	6.7	0.795	1.367	0.07
Flat+NT+M	13.25	0.11	0.93	6.7	0.795	1.367	0.076

Effect of Conservation Agriculture on Soil Moisture Content: During experimentation in the study area (for moisture samples taken years) there was no shortage of rainfall. Due to this, it was difficult to see the effect of conservation agriculture tillage practice on moisture as visually on crop yield. According to soil sample analysis, the three-year moisture data indicates conservation agriculture tillage practice shows some improvement in soil moisture compared to that of farmer practice. As shown in Figure 3, Flat+NT, Flat+NT+M, PRB+NT, and PRB+NT+M improve soil moisture by 3.4%, 6.9%, 3.4%, and 5.8% respectively as compared to that farmer practice. This might be important in moisture deficit years. In line with our studies, other scholars' studies show soil moisture content was improved with increased use of crop residues as a soil cover (Akilapa *et al.*, 2020).

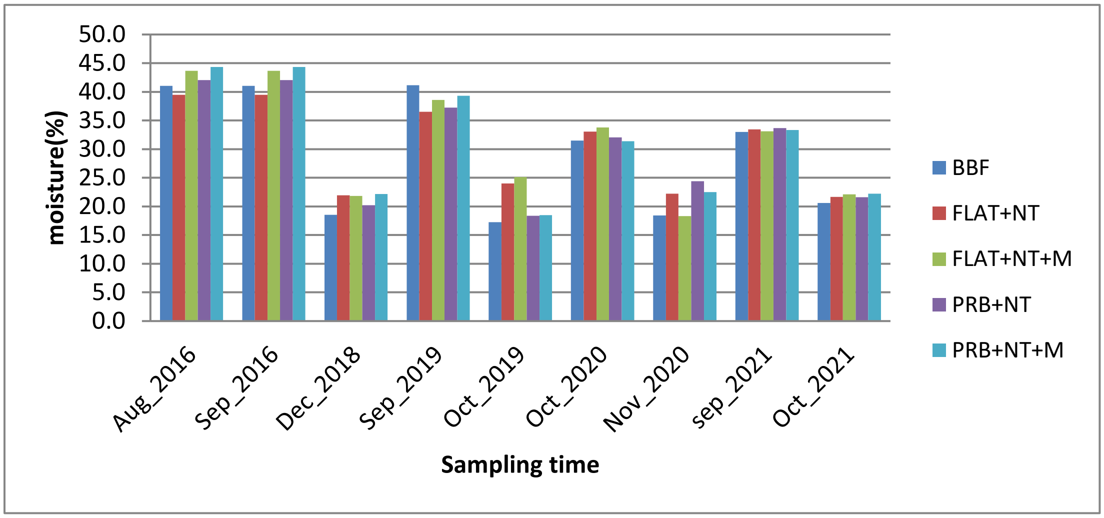

Figure 3. Effect of conservation agriculture on soil moisture content

Effect of Conservation Agriculture on Soil Bulk Density: As shown in Figure 4, the result of bulk density analysis (gcm^{-3}) indicates that conventional tillage practice could minimize surface compaction and bulk density to a small extent compared to conservation agriculture tillage treatments. In line with our study, other scholars (Bhattacharya *et al.*, 2020) indicate that the bulk density of surface soil (0-15cm) in conservation agriculture is 2% -3% greater than conventional tillage.

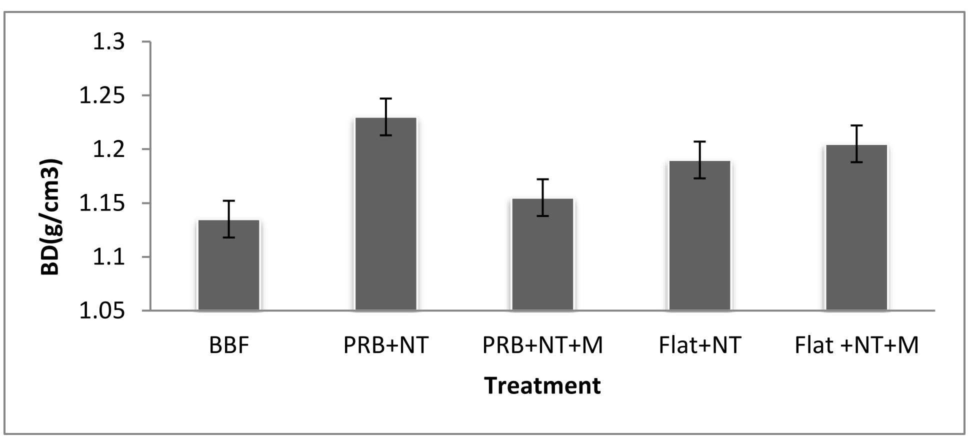

Figure 4. Effect of conservation agriculture on soil bulk density

The Economic Viability of Conservation Agriculture: Furthermore, this experimenthas not only seen the effect of conservation agriculture on crop yield and soil properties but also on the reduction of energy, labor, and inputs. As shown in Table 4, the result of the partial budget analysis Flat bed with no tillage could have maximum MRR (1147.6 %) and the Net benefit (64460.2 ETB) was also highest than the other treatments. This revealed that the Flat bed with no tillage treatment was economically feasible and the MRR could dominate the other treatments. Zero tillage offers farmers of a great opportunity to reduce energy inputs in crop production.

Table 4. The partial budget analysis of the experiment

Treatments	TVC ($ETBha^{-1}$)	Revenue ($ETBha^{-1}$)	Net benefit ($ETBha^{-1}$)	MC	MB	MRR (%)
PRB+NT+M	2800.9	62246.4	59445.5			
FLAT+NT+M	3339.1	65940.3	62601.2	538.2	3155.7	586.3
PRB+NT	4490.7	67888.2	63397.5	1151.6	796.4	69.2
FLAT+NT	4583.3	69043.5	64460.2	92.6	1062.7	1147.6
BBF	8257.2	70675.2	62418.0	3673.9	-2042.2	-55.6

Conclusion and Recommendation

Effects of conservation agriculture practices on crop yield were analyzed using seven-year field experimental data. The effect of land management practices on the growth parameter (plant height); grain yield and straw yield depend on the crop type and year. The statistically highest wheat grain yield was obtained from Flat+NT+M and Flat +NT for the experimental year 2015/16 and 2017/18 due to a small amount of rainfall rained during the cropping season but in the experimental year, 2019/20 and 2021/22 wheat yield high in BBF compared to Flat+NT+M and Flat+NT due to excess amount of rainfall rained on cropping season than the previous experimental year. The result of this study indicated conservation agriculture for wheat yield showed a positive result on Vertisols for dry years. But for normal years BBF gave high yield advantages compared to conservation agriculture practice. Additionally, BBF provided the statistically highest Faba bean yield and plant height. Flat+ NT+M and Flat+NT have a lower impact on the environment and can better preserve soil organic matter, soil organic carbon, and extractable Potassium and especially Flat+NT is a feasible and energy-saving strategy. The findings of this study led us to the conclusion that while conservation agricultural approaches were not preferable for the production of Faba beans, they would be more beneficial for the production of wheat during years with little rainfall. We found through a long-year trial that Flat+NT+M and Flat +NT were effective in many dimensions and that they should be employed widely.

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3. Evaluation of Biological Measures and Multipurpose Adaptive Grass on Soil Bund in Lasta District, Ethiopia

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Abstract

The use of biological measures, such as grasses combined with soil bunds, has numerous benefits, including reducing soil nutrient loss, increasing soil moisture conservation, securing animal fodder in areas with low grass potential, enhancing land productivity, and boosting green biomass. However, adoption of these practices has been limited in the study area. This study explored the effects of grasses combined with soil bunds using seven treatments in a randomized complete block design. Data on moisture content and bulk density were collected and analyzed using the gravimetric method. Additional data on survival rate, tiller number, plant height, and biomass were also collected. Data analysis was conducted using R-Software, with mean separation performed using LSD at a 5% significance level. The grasses positively impacted moisture content and bulk density, improving water retention and bund stabilization. In 2020, moisture content differences were 22.2% for vetiver, 17.56% for Sudan grass, and 12.3% for elephant grass and panicum. In 2021, Sudan grass showed a 13% improvement (1.36) compared to the control (1.57). Sudan grass and panicum had survival rates of 100% and 80%, respectively, supporting bund stabilization and runoff protection. Panicum averaged 77.2 tillers per 0.15m², affecting biomass and runoff. In 2021, Sudan grass reached 98.7 cm, elephant grass 85.4 cm, and panicum 81 cm in height. In 2020, Sudan grass reached 136.4 cm, elephant grass 91 cm, and panicum 78.3 cm. Biomass yields in 2020 were 20.8 tons per hectare for Sudan grass, 12.7 tons for elephant grass, and 10.6 tons for panicum. Overall, Sudan grass, Panicum Coloratum, and elephant grass demonstrated better adaptability and survival, increased farmland productivity, and provided multipurpose fodder production.

Keywords: biological measures, green biomass, land productivity, moisture content, soil bund, survival rate.

Introduction

Ethiopia is one of the most bio-diverse countries in the world, with 79% of the population working in agriculture. In contrary, one of the countries with increasing degradation of soil fertility and water quality, biodiversity loss, deforestation, and mainly by soil erosion (Cheever & Howell, 2011).

Lack of adequate soil protection measures and poor land use management plays a major role in the country's severe soil erosion problem, with an average annual soil loss rate of 30.2 $tha^{-1}yr^{-1}$ recorded,

Those problems are product estimated minimum soil loss become 12.1 $tha^{-1}yr^{-1}$ around the Kogagawa estuary, which is larger than the minimum allowable soil loss (2 $tha^{-1}yr^{-1}$) (Molla & Sisheber, 2016). To tackle from Sevier erosion and soil loss by soil embankments of farmlands is one method, complemented by biological and agronomic measures help improve production, in order to improve adaptability to local conditions. is needed (Herweg & Ludi, 1999).

The grass is one of the biological countermeasures among those Panicum coloratum grass one of provides excellent forage for livestock. It is commonly use as forage or hay for animals. The plant produces an abundance of high quality forage has many other conservation benefits including : soil stabilization and re-vegetation on depleted soils or range condition.it can also be used to prevent soil erosion on embankment, ditches, farm lands, and other highly erodible sites(Panicum, 1994). The species seem promising as forage species to be introduced in temperate, lowland areas prone to soil flooding (A *et al.*, 2015).

Sudan grass is essential for the dry-steppe zone and most productive and drought-resistant, as well as promising culture (Nasiyev *et al.*, 2020).

Elephant grasses, an important tropical grass and one of the highest-yielding tropical grasses and a versatile species that can be grown in a wide diversity of conditions and systems. Nowadays, an increasing interest in producing feeds is imperative to achieving economic and sustainable goals dry or wet conditions, small or large scale farming (El Ghobashy *et al.*, 2023). It is a valuable fodder and very popular in the tropics, especially in cut-and-carry systems (Journal *et al.*, 2018). *Panicum coloratum* originates from Africa and is now found in many tropical and subtropical regions (Armando *et al.*, 2013), between 30°N and 33°S, from sea level to an altitude of 2100 m(Armando *et al.,* 2013). *Panicum coloratum* grows best during the warm season, with temperatures ranging from 18°C to 36°C, with an annual mean temperature around 22°C, and annual rainfall ranging from 400 to 2000 mm (depending on the variety), on fertile sandy to clay soils. *Panicum coloratum* is drought tolerant and moderately tolerant of flooding and waterlogged conditions. Var. *makarikariense* is particularly suitable for flooding conditions (Banks, 2018). *Panicum coloratum* can withstand significant levels of salinity. It is susceptible to frost but can recover after it. It also recovers from fire (Banks, 2018).

Use soil and water conservation with biological measures are one of the most important practices for conserving soil and water structures, biodiversity and increase agricultural land productivity through soil conservation measures (grasslands, erosion ditches, dikes, hedges, and terraces). It's one refinement of research promotion of the feed market and feed research is desired (Studies, 1997). The importance of bund stabilization with Desho grass and others is not well known until recent time (EthioCAT, 2010). And there is a loss of nutrient, soil and water from cultivated land in soil bund without supporting by biological measures as (Adimassu *et al.,* 2012) conclude and the importance of stabilizers in the mandate area are not supported by research and the agro ecology of the study area are also not well addressed.

The aim of the experiment was to evaluate and adopt the Contribution of biological measures grasses that are not practiced in the study area, conservation structure stabilizer demonstration, availability of choice of different grass and increase stability of the soil with integration of soil and water conservation practices (SWC),

Forage availability for animals, to convince the perception of farmers on SWC practices is minimizing the farm size rather than minimizing soil erosion, mitigation of degraded rangelands, fodder and other ornamental importance. There for this study was be offered to evaluate different adaptive biological grass on soil bund and its multipurpose uses.

Materials and Methods

Area Description: The experiment conducted as figure 1 expresses were in North Wollo administrative zone the specific area of Genete Maryam 17 km from Lalibela and found in Lasta district. The location is $11^{0}56^{'}58.11^{''}$N latitude, $39^{0}06'35.81''$E longitude and the Elevation is 2326 m m.a.sl. Annual rainfall, maximum and minimum temperature in 2020 was 979.2 mm, 24.5 °C and 13.5 °C respectively and in 2021 was 1027.2 mm, 24.3^{0}c and 13.6^{0}c respectively. The trial field soil characteristics are 7.5 soil pH, 0.067% organic matter and 26.97 ppm available Phosphorous.

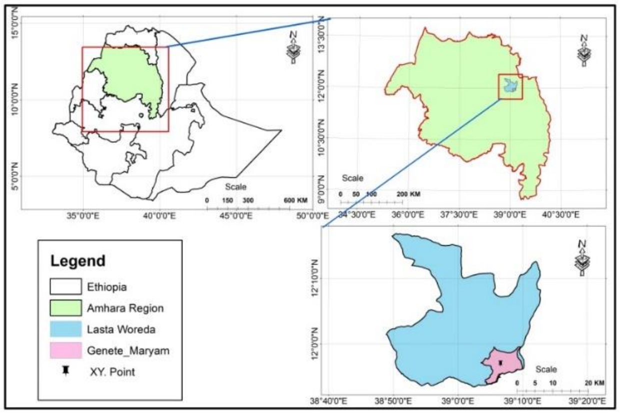

Figure 1. Map of study area

The trial site slope was recorded 12% gentle slope where soil bund is recommended in the area. The growing periods mostly from beginning of July until end of October. As the rainfall usually stops early, particularly at flowering stages of local grass of the area and major crops, the availability of low soil moisture content at this stage and low soil fertility status of most agricultural lands are the major limiting factors for most grass and shrubs production in the study areas.

The study was conducted in Lasta district for two years from 2020-2021. The study area was select by using purposive sampling method for stable trial establishment. The trial was done on soil bund with grass. Six grasses selected based on their adaptability and multipurpose use. The design for the experiment was arrange in randomized complete block design (RCBD) with three replications.

1.Vetiver (*Vetiverial zizanioides*) spacing of vetiver between rows are 1-2 m areas which is appropriate for soil bund and the space between plants are 50 cm(Sanguankaeo *et al.*, 2003),

2. Elephant (*Pennisetum purpureum*) Elephant grass produces very few seeds and is mostly propagated vegetative through stem cuttings consisting of at least 3 nodes, 2 of which are buried in rows. Row width ranges from 50 to 200 cm and distance within rows is between 50 and 100 cm(Armando *et al.*, 2013).

3.Desho (*Pennisetum pedicelluatum*) the spacing between rows to be 50 cm and between plants are 50cm (Asmare *et al.*, 2017), 4.*Sudan grass* (Sorghum sudanense) the spacing between rows is 25 cm and drilling (Belete *et al.*, 2018),

5.Rhodes (*Chloris gayana*) the spacing of Rhodes grass between row is 30 cm and root splitting its seed rate is 15Kgha^{-1} (Abera, 2017) and will put on constructed soil bund found on each field. Each grass will plant on strip of soil bund with recommended planting pattern (Table 1). Grasses plant in 5 m length and the standard width of soil bund, 1m interval between treatments

6. Panicum (*Panicum coloratum*) the spacing of panicum grass between row is 30 cm and root splitting its seed rate is 10Kgha-1

Treatment Design

1. Soil bund with Desho grass (*P. pedicelluatum*) (*SB + Dg*)

2. Soil bund with Elephant grass (*Pnnisetumpurpureum*) (*SB + Eg*)

3. Soil bund with *Vetiver* (*V. zizanioides*) (*SB + Vs*)

4. Soil bund with Sudan grass (SB+SG)

5. Soil bund with Rhodes (*Chlorisgayana) (SB+RO) and*

6. Panicum *coloratum* (SB+PC)

7. Soil bund only (SB)

Soil Bund Design and Construction: Soil bunds in the study area construct based on the soil and water conservation guideline of the Ministry of Agriculture (Yakob *et al.*, 2015) uses for control erosion, increases soil moisture, reduce slop length their by improve land productivity and there will be maintenance of soil bunds to make appropriate for the trial. The horizontal distance between two successive soil bunds determine based on the vertical interval between bunds (usually 1 m for Ethiopia) and the slope angle (Yakob *et al.*, 2015). The base width and top width of the bund (embankment) from 1 m to 1.2 m and 0.30 m to 0.50 m respectively, the channel 0.3 m deep and 15cm berm will have. Besides, the height of the bund will 0.60 m after compaction as described in table 1.

Table 1. Planting pattern of grass and bund size

Grass stabilize/	Planting method	Space between row	Space between plant	Bund size in meter
Vetiveria zizanioides	Root split	1-2m	0.5m	3*(0.5-0.75m)
Pennisetum purpureum	Root split	0.5-2m	o.5-1m	3*(0.5-0.75m)
Pennisetum pedicellatum	Root split	0.5m	0.5m	3*(0.5-0.75m)
Sorghum sudanens	Seed dressing	0.5m	0.5m	3*(0.5-0.75m)
Chloris gayana	Root split	0.5m	0.5m	3*(0.5-0.75m)
Panicum coloratum	Root split	0.5m	0.5m	3*(0.5-0.75m)

Data Collection

Agronomic Data: Data on biological performance of grass, Morphological parameters as such plant height and tillers was measured from five (5) plants randomly selected from rows of each soil bund after planting then compute as mean counts. To determine biomass yield, the forage frequency of harvest done by hand using a leaving sickle a stubble height of 8 cm according to recommended practice. The fresh herbage yield measured immediately after each harvest using a portable balance with a sensitivity of 0.01g. Survival data of the adaptable multipurpose grass was done by available plant count per total planted plant of the grass.

Soil Data: A soil composite sample collected from 0 - 20 cm on representative points in the trial sites to examine in the laboratory for major physiochemical properties and soil moisture characteristics. The USDA textural classification triangle was used to define the textural class for each composite soil samples taken *(Groenendyk et al., 2015)***.**

Besides, additional soil samples was taken from each treatment every 2–3 week intervals after heavy rainfall by core sampler for monitoring the soil moisture content during the growing season, and a gravimetric field technique was used to determine the soil moisture content in this experiment.

Data Analysis: The data obtained was subjected to analysis of variance using R-studio-1.1.463.0 and treatment effects were compared using the Fisher's Least Significant Differences test at 5% of significance level.

Results and Discussion

Effect of Different Multipurpose Grass on Moisture Content and Bulk Density of the Soil Bund

There is no significant difference among treatments at $p<0.01$ level of significance on moisture content and bulk density discussed in table 2 both in 2020 and 2021 experimental period. However; this may not be there is no positive impact according to the authors grass biological measures with soil bund may increase the moisture content and bulk density of the soil (Sinore & Doboch, 2021). Likewise, vetiver and Sudan grass intervention have considerable impact in moisture content compare to the control (without grass stabilizer) treatment and stabilizer grasses increase the moisture content and ideal soil bulk density than constructed soil bund structures only.

Moisture content and bulk density of the soil with comparison of the experiment control treatment without intervened grasses; in 2020, there was 22.2%, 17.56%, and 12.3% of percentage difference on moisture content soil in vetiver, Sudan grass, elephant and multipurpose grass respectively on soil bund structure. The bulk density of 2020 experiment period has no marked difference to prioritize among treatments which is the grass stabilizers have no impact on bulk density of the soil bund during the experiment period.

Table 2. Moisture content and bulk density on 2020 and 2021

Treatment	Moisture (%) (2020)	*Bd (gcm^{-3}) (2020)	Moisture (%) (2021)	Bd (gcm^{-3}) (2021)
Desho with soil bund	6 [a]	1.26 [a]	8.5[a]	1.52 [a]
Elephant with soil bund	6.11 [a]	1.31 [a]	9 [a]	1.51 [a]
Vetiver with soil bund	6.75 [a]	1.44 [a]	9.1 [a]	1.44 [a]
Sudan grass with soil bund	6.44 [a]	1.48 [a]	9.2 [a]	1.36 [a]
Rhodes with soil bund	5.58 [a]	1.27 [a]	8.4 [a]	1.54 [a]
Panicum with soil bund	5.6 [a]	1.41 [a]	8.4 [a]	1.53 [a]
Control	5.4 [a]	1.29 [a]	9.1 [a]	1.56 [a]
LSD	Ns	Ns	Ns	Ns
CV	16.42	13.24	10.98	8.87

**Bd= bulk density, LSD=list significant difference, Ns = non-significance, CV= coefficient of variation and same letters in the column indicate no significant difference.*

In 2021, no significant difference on moisture content and there is 13% ideal bulk density of Sudan grass with comparison of the control treatment (1.57) in the soil bund.

Effect of Different Multipurpose Grass on Adaptability and Survival Rate of Soil Bund

There was different survival rate of multipurpose grass in the experiment site to adapt and support the soil bund structure. In the trial treatments was have significant different on survival rate among the treatment of Sudan grass, Panicum and Rhodes grass have advanced survival rate which is more than 60% that are contribute biomass for fodder consumption rather than the control treatment constructing soil bund without multipurpose use grasses.

Based on statistical mean square value analyses discussed in table 3 and figure 2 the effect of different multipurpose grass on soil bund has highly significance difference in $p<0.01$ level of significance on survival rate in 2021, whereas there is no significant difference in 2020 at ($P\leq0.05$) in survival rate

Table 3. First year (2020) and second year (2021) mean square value on survival rate of trial site

Treatment	Survival rate (2020)	Survival rate (2021)
Desho with soil bud	9.66 [a]	3 [c]
Elephant with soil bud	8.33 [a]	7.33 [b]
Vetiver with soil bud	9 [a]	7.66 [b]
Sudan grass with soil bud	10 [a]	10 [a]
Rhodes with soil bud	9.33 [a]	7.66 [b]
Panicum with soil bud	9 [a]	8 [b]
L.S.D*	Ns	2.24**
CV	10	10.54

**L.S.D:least significant difference, Ns is non-significance, CVis coefficient of variation, ** is indicate highly significance difference and the latter is indicate difference at p* is 0.05 (at 5 % significance level).

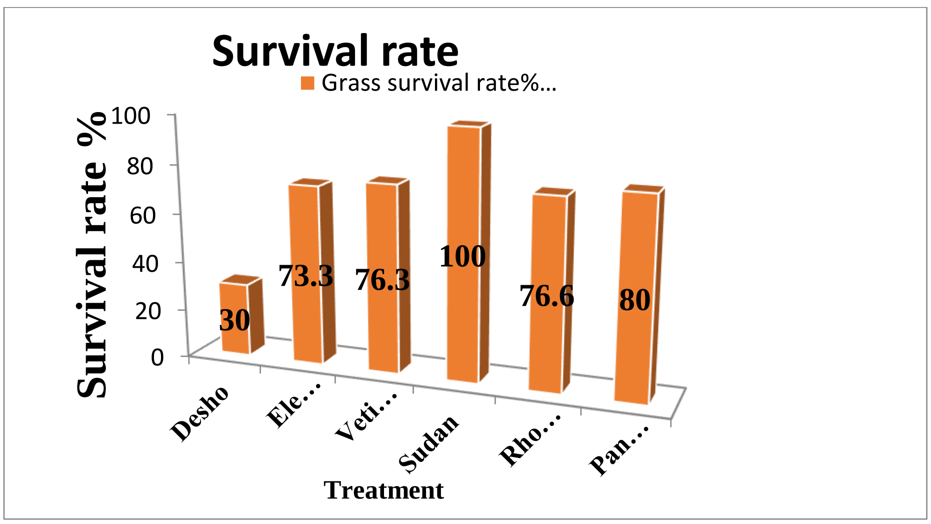

Figure 2. Percentage survival rate of different multipurpose grass correspondence

Percentage Survival Rate of Grass Stabilizers: The higher mean survival rate is (100%) at Sudan grass (annual grass) with soil bund according to authors the grass highly drought tolerant and can give good green fodder biomass up and around to mid altitude, and the altitude of experimental site is 2326 m from average above mean see level that tells Sudan grass well perform across the area *(Nasiyev et al., 2020).* (80%) at panicum (perennial grass) with soil bund had rigorous abundance in the experiment period as (González Marcillo *et al.*, 2021) finding was around (70.2%) percentage of plant coverage and amazon region partaken yearly average precipitation and temperature in rainy season is 1969 ±81 mm and 26.48 *°C and in* dry season 945 ± 50 mm and 27.03°C respectively whereas the grass most probably need medium rainfall and considerable temperature can be established as the author suggested where mean maximum daily summer temperature are above 30 ^{o}C, mean daily winter temperature rarely fall below 00 ^{o}C, summer growing season rainfall ranges from 400 to 999 mm (Cox *et al*., 1988) and in the experiment period the rainfall, maximum and minimum temperature in 2020 were 979.2 mm, 24.5 °C and 13.5 °C respectively and in 2021 were 1027.2 mm, 24.3^{0}c and 13.6^{0}c, respectively, (76.6%) at Rhodes (perennial grass) with soil bund as compared the lowest survival rate (30%) of Desho grass which is effective in much more moisture area than other grasses (Yakob *et al.*, 2015) that was ideal survival rate of perennial grass range (60%) except Desho grass. In 2020 there is no significance difference among treatments *at p* = 0.05 level of significance and the result show that effective means of preventing sediment transport and off-site sedimentation (Stabilization, n.d.).

Effect of Different Multipurpose Grass on Tiller, Plant Height and Biomass in Soil Bund

In the trial grass have highly significance effect at $p<0.01$ level of significance in tiller, plant height and biomass parameter recording but in 2020 there was no significant difference in tiller parameter *at* $p<0.05$ level of significance in 2020 and 2021 as discussed below in table 4.

Table 4. Mean square value of tiller, plant height, and biomass during the period of 2020 and 2021at trial site

	2020			2021		
Treatment	Tiller (No)	Plant height(m)	Biomass (t/ha)	*Tiller (No)*	*Plant height(m)*	*Biomass (t/ha)*
Elephant with SB	26.34 ^{a}	91.3^{b}	6.7^{b}	45.8^{b}	85.4^{b}	12.7^{a}
Sudan with SB	24.60 ^{a}	136.4^{a}	20.8^{a}	17.5^{c}	98.7^{a}	4.0^{c}
Rhodes with SB	24.4 ^{a}	69.7^{c}	6.2^{b}	35.4^{bc}	69.5^{c}	7.9^{b}
Panicum with SB	27.00 ^{a}	78.3^{bc}	5.3^{b}	77.2^{a}	81.0^{b}	10.6^{ab}
LSD (5%)	Ns*	16.43**	5.43**	*23.8185***	*8.1285***	*2.945***
CV (%)	13.52	8.75	27.87	*27.11*	*4.86*	*16.74*

** Ns=non significance, No= count per single plantation, **= highly significance difference, B=soil bund and t*he same letter are not significantly different at $p = 0.05$ (5 % level of significance).

Figure 3. Field Performance of different multipurpose grass, where; A is panicum Grass, B is Sudan Grass, C is Elephant Grass, D is all treatment on soil bund.

Different grass with soil bund were had significant effect on number of tiller 27 or 77.2 (as Onyeonagu & Asiegbu, 2013 used to calculated per plantation tiller number) counts was recorded in 0.15m^2 area per plantation of Panicum. In 2021 which is greater tiller advantage (77.3%) as compared the lowest tiller Sudan grass, the finding is closely related with the conclusion of (Onyeonagu & Asiegbu, 2013) is around 74 counts of tillers per plantation. There were no significant difference at p = 0.05 (5 % level of significance) in 2020. However, Panicum (11%) percentage number of tiller difference as compared with the lowest tiller of Rhodes with soil bund treatment.

There is highly significant difference among treatments on plant height in 2020 and 2021 at p = 0.01 % level of significance) accounts (98.7cm) Sudan grass is first and followed by elephant and panicum grass 85.4 and 81 cm respectively in 2021. Whereas there is highly significant difference among treatments on plant height in 2020 at p = 0.01 % level of significance) accounts (136.4 cm) Sudan grass is first and followed by Elephant and Panicum grass 91 and 78.3 cm respectively in 2020 and have slightly or no significant difference at p = 0.05 % level of significance between elephant and Panicum grass.

Effect of multipurpose grass with soil bund was highly significance at biomass (green fodder) at p = 0.01 % level of significance) in 2021 was recorded (12.7 t/ha) and (10.6 t/ha) of Elephant grass and Panicum grass respectively. The biomass of Sudan grass much lower, because of the tiller population was lower that mainly affect the biomass, as scholars conclude the green forage yield significantly associated with tiller (Khurd *et al.*, 2018), related finding in Adaptation Study of Improved Elephant Grasses the highest green fodder was (37.46 tha^{-1}) (Gamachu, 2017) with this result there is 24.76 tha^{-1}green fodder deference because of addition of recommended fertilizer and recommended fertilizer was not used in the experiment because the experiment is applied in soil bund which is not well practiced in such structure based intervention in the study area. The value recorded in (2021) at Panicum is closely related to (González Marcillo *et al.*, 2021) record on Assessment of Guinea Grass Panicum coloratum under Silvopastoral Systems is (11.231 tha^{-1}). In 2020 the result was highly significance difference in green biomass (green fodder) at $p = 0.01$ % level of significance) the green biomass was (20.83 tha^{-1}) at Sudan grass with soil bund and the related experiment on development of sorghum-Sudan grass hybrids for high forage yield and quality (Hussain *et al.*, 2012) average results (42.17 tha^{-1}) and this result is half times much because of using fertilizer.

Conclusion and Recommendation

Multipurpose grasses have prodigious roll mainly on farm lands, range land, forest and degraded areas where conservation structure constructed for the use of additional support and or barrier for soil erosion of the structure as well as multi use to increase moisture, to have good bulk density and green fodder production.

The experiment magnify work with different grass stabilizers and soil bund have positive impact on moisture content and bulk density of the soil bund that may help full to get enough moisture for the grass and the structures to have good strength and not easily collapsed by direct runoff. The better survived grasses were Sudan grass, Panicum and Rhodes which could rehabilitate the degraded soils and support the soil bund structure, blocks the direct concentrated runoff and stabilize the soil bund while the grasses will adapt in the mandate area of similar agro ecology.

The biological parameters showed significant different performance on number of tiller and plant height that affect the green forage biomass productivity of the treatments and in the experiment period Soil bund combined with Sudan grass, Elephant and Panicum Coloratum grasses 20.83 tha^{-1}, 12.7 tha^{-1}, 10.6 tha^{-1} respectively have green biomass productivity advantage. Therefore; Adaptive grass with soil bund can use for green fodder production, means of additional farm land productivity trendy to implement soil and water conservation structure that may stabilize the soil bund. Result increase the productivity of physical soil conservation structure (soil bund) that will important aspect for sustainable watershed development whereas there is constraints of using biological measures for conservation, availability of other related grass and lack of technology demonstration so it is advisable to address it.

Author contribution statement: Haymanot Lamesgn Zena: the conception and design of the study, the acquisition of data, or the analysis and interpretation of data; drafting the article or critically revising its important intellectual content; final approval of the version submitted; Yalelet Abie: the acquisition of data, execution of experiments; interpretation of data

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4. Effect of Ridging and Tie-Ridging Time on Yield and Yield Component of Sorghum in Wag- Lasta Area

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Abstract

A field experiment was carried out at Lasta and Sekota districts of the Eastern Amhara Region in Ethiopia to evaluate the effects of Ridging and tie-ridging time on the yield performance of sorghum (Sorghum bicolor). The experiment consisted of eight treatments of ridging time and time of tie (Tie-ridging at planting, ridge at planting tying 2 weeks after planting, ridge at planting tying 4 weeks after planting, tie-ridging 3 weeks after planting, ridging 2 weeks after planting and tying 4 weeks after planting, ridge 3 weeks after planting and tying 6 weeks after planting, tie-ridging 6 weeks after planting), while Shilshalo as a control farmer practice which was arranged in a randomized complete block design (RCBD) with three replication. The experiment revealed that ridging and tie-ridging time has a significant effect on the yield of sorghum. Based on the result tie- ridging at planting increased the yield of sorghum by about 37.9 % at Sekota (Aybira) relative to the control (farmer practice). On the other hand, 'tie ridging 3 weeks after planting' and 'ridging 2 weeks and tying 4 weeks after planting' increased sorghum yield by 30.11% and 21.58% respectively at Lalibela as compared to the control (farmers practice) respectively. The highest yield of 3642 Kgha^{-1} and 1903Kgha^{-1} and 1696 Kgha^{-1} was obtained from tie ridge at planting for Sekota (Aybira) and tie ridging 3 weeks after plant and ridge 2 weeks and tie 4 weeks after planting with recommendation NP fertilizer at Lalibela. Therefore, tie and ridge at planting could be appropriate for sorghum production at Sekota (Aybira) and sorghum growing similar areas. However, tie-ridge 3 weeks after planting and ridge 2 weeks and tie 4 weeks after planting could be appropriate for sorghum production at Lalibela (Kechinabeba).

Keywords: Sorghum, Tie ridge, time, yield, water deficit

Introduction

The dry land regions of Ethiopia account for greater than 66.6% of the overall landmass and are characterized by low annual rainfall (Georgis, K., *et al*., 2004). The common annual rainfall varies from 400mm to 600mm inside the semi-arid sector and levels among two hundred and 1000 mm from the dry semi-arid to the dry sub-humid sector (Kidane *et al*., 2001). In this semi-arid region, the quantity of rainfall is typically inadequate, erratic in distribution, short, and variability in quantity in the course of the crop developing season. The maximum crucial constraint of sorghum production in East Africa is water stress. Particularly in Ethiopia, soil water deficits in the course of crop status quo and grain fill have been identified as essential constraints (Wortman *et al*, 2009; Tesfahunegn *et al*., 2009).

Sorghum (S. bicolor) is the 5th maximum crucial global cereal crop after maize, rice, wheat, and barley (FAOSTAT, 2013). It is the second essential cereal crop after tef (Eragrostistef) in consumption. Sorghum is likewise a primary and one of the main conventional meal's cereals in Ethiopia with about 297,000 ha production vicinity insurance in keeping with annum and in northern Ethiopia (FAOSTAT, 2013). It accounted for 255,000 hayr^{-1} (Wortmann *et al*., 2006) which contains 15-20% of the overall cereal production inside the country and its common yield in keeping with unit vicinity in Wag-Himra is 1.52 tha^{-1} (CSA, 2016/2017). It is the dominant crop inside the semi-arid vicinity of the country and is restrained via way of means of a one-of-a-kind factor. Two essential elements that symbolize agriculture in Ethiopia include (i) The erratic climatic situations with common durations of water shortage (Stroosnijder and Van Rheenen, 2001; Tewodros, Mesfin, *et al.*, 2009) and (ii) The presence of huge regions of low fertile and crust inclined soils (Morin, 1993; Breman *et al.*, 2001). Sorghum production is specifically restrained by soil water and nutrient deficits in northern Ethiopia.

Water required for plant increase and improvement is taken from the soil via way of means of the roots. Leaves and stems do now no longer soak up considerable portions of water. Limited rainwater in dryland regions needs to consequently be made to go into the soil in any such way as to be simply to be had as soil moisture to the roots on the crucial durations of plant increase. All the land and crop control practices, which enhance rainwater garages inside the soil profile, include water conservation (Rana, 2007). In-situ water harvesting method as though tie ridging is one of the practices in sorghum production regions of drylands to enhance sorghum production. The investigation discovered that tie ridging will increase sorghum yield by as much as 46% compared to the farmer's exercise inside the dry regions of Ethiopia (Abebe *et al.*, 2009). The useful results of tillage include tied-ridging on crop yield range because of variations in quantity and distribution of rainfall, soil type, slope, panorama position, crop type, time of ridging, and the circumstance in which rainfall occasions bring about vast runoff. In addition, different studies discovered that tied-ridging improved sorghum grain yield via way of means of greater than 40% and soil water via way of means of greater than 25% in comparison to the conventional tillage exercise in northern Ethiopia (Gebreyesus *et al.*, 2006).

Ridging and tied ridging includes making ridges and furrows, tying or damming furrows with small mounds to grow the flow water and keep away from a runoff. The tie acts as a barrier for the rainwater motion and will increase touch time to be had for infiltration for this reason improving the provision of soil moisture to the vegetation (Rana, 2007). Tie-ridging includes developing ridges that might be 20-30 cm excessive and typically spaced 75 cm apart, both before, in the course of, or after planting. Row vegetation, including sorghum or corn, is perhaps sown at the ridge or inside the furrow. The furrows are tied at durations of 2 or more meters, depending on field conditions, to prevent runoff in the furrows. Tie-ridging effects on water storage and subsequent crop yield vary considerably from year to year and between locations (Brhane *et al*., 2005).

The effectiveness of tie-ridging construction depends on weather conditions, soil properties, slope, crops, and other factors (Gebreyesus, *et al.*, 2005). Research has found that the main constraint to sorghum production in East Africa is water scarcity. Especially in Ethiopia, lack of soil moisture during crop cultivation and cereal filling is considered to be the main obstacle (Wortman *et al*., 2009; Tesfahunegn *et al*., 2009).

(Demlie G. and Shawel A. (2010) suggested that tied ridges at 75 cm intervals yielded significant yield improvements over other water protection practices and those of dry land farmers in Wag Himra area. Effective water protection practices are therefore of paramount importance in areas where soil moisture availability is generally the most limiting factor for crop production. They had significantly improved yields over water conservation practice, especially farmer practices is one of the biggest limiting factors (Tekur *et al*., 2015). On the other hand, in many areas of Ethiopia, including the study area, the type of rainfall is irregular, leading to water stress during the crop growth stage. As the rainfall usually stops early, particularly at the flowering and graining filling stages of major crops, the availability of low soil moisture content at this stage and the low soil fertility status of most agricultural lands are the major limiting factors for crop production in the study areas. All of this requires sufficient time for water management techniques such as furrows and furrows for dryland crop production. This study then evaluates the appropriate timing of tie ridging constraction and improving sorghum productivity in cropland areas under different climatic and soil type conditions, along with adaptive mechanisms to enhance rainfall tethering. This was done to recommend the appropriate timing of tie-ridging for agricultural production in the study area and other similar agro-ecological areas.

Materials and Methods

Study Area Description: The field experiment was conducted in Wag-Himra and north Wollo administrative zone, namely at Kechinabeba and Aybra found in Lasta woreda and Sekota woreda Amhara regional state. The study sites were located at 11º 58' 20.442'' N latitude 039º 03' 00.804'' longitude E and 12º 437.482''N latitude 39º 01'09.594''E longitude and an altitude of 2159 m and 1928 meters above sea level (masl) respectively show in (Figure1). The experimental sites are characterized by gentle slopes (less than 5%) with soils suitable for agriculture.

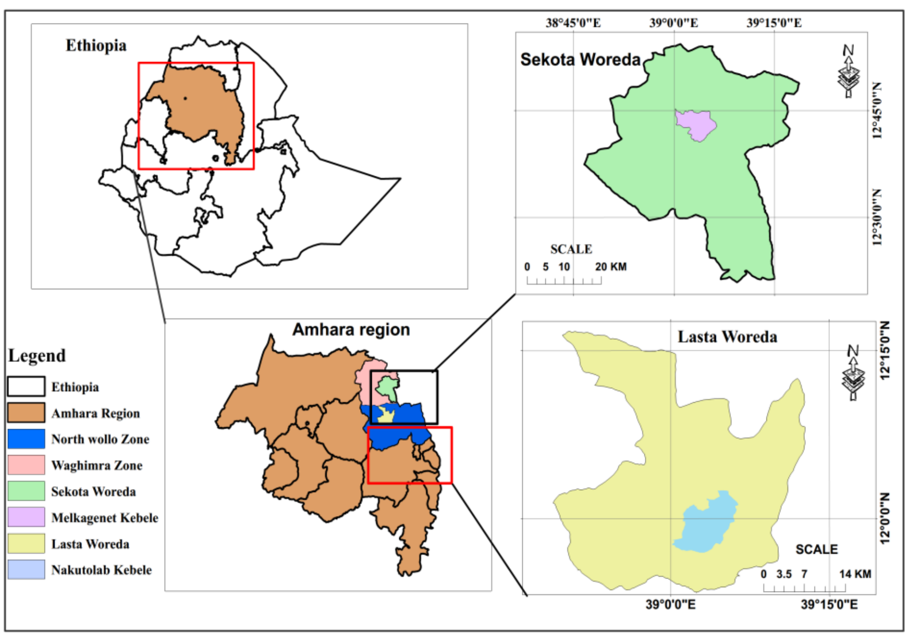


Figure 1: Location map of the study area

The rainfall pattern of the study areas is unimodal and usually occurs between July and August. The rainfall distribution is characterized by short, erratic, and variable across the growing seasons. Based on the 10-year meteorological data collected from the nearby stations, the annual average rainfall and maximum and minimum temperature of Sekota are 660.8mm,26.55ºC and14.97ºc. Similarly, for Lalibela with average annual rainfall and maximum and minimum temperatures are 737mm, 25ºC, and 13.6ºC respectively. The rainfall in the study area usually starts around mid of July extending to the end of August. The growing period annual rainfall and maximum and minimum temperature for Sekota and Lalibela are show in below (Table 1). The growing period of major crops grown in these areas are (sorghum, wheat, Fabian and tef) mostly from the beginning of July to the end of October shown in (Figures 2 and 3). According to (Dejene, A. (2003) the climatic zone classifications of Ethiopia based on altitude, rainfall, average annual temperature, and length of the growing season, Sekota (Melkagenet kebele) belongs to low land and midland for lalibela (Nakutolab kebele).

Table 1. Annual rainfall and maximum and minimum temperature of the study areas in the 2017/2018 cropping season

	Rainfall (mm)		Temperature(ºC)			
Location	2017	2018	2017		2018	
			Max	Min	Max	Min
Lalibela	818.8	886.6	24.7	13.4	23.6	13.08
Sekota	673.7	713.6	24.2	10.02	27.2	12.6

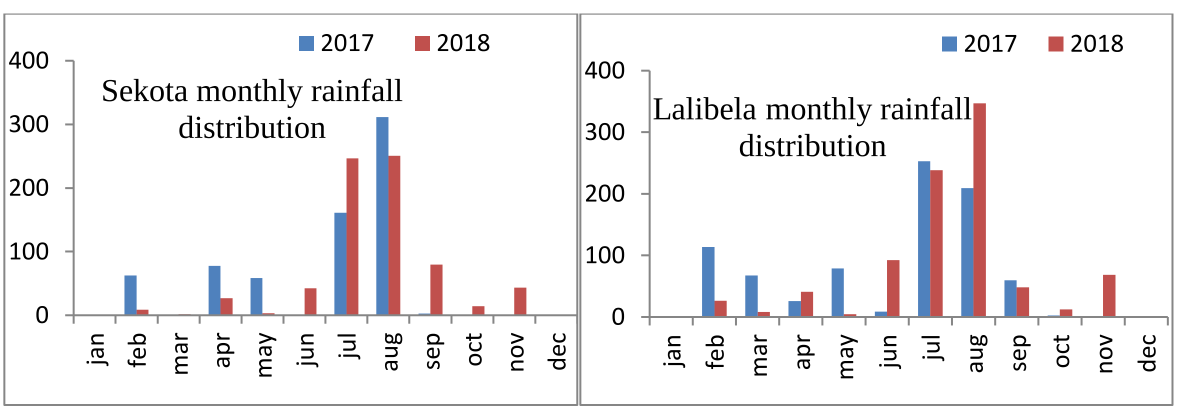
a)  b)

Figure 2: monthly rainfall 2017 and 2018 cropping season (a) Sekota and (b) lalibela

Experimental Design and Treatments: Field experiments were conducted during the summer season of 2017 and 2018 to investigate the effects of ride and tie-riding time on the yield and performance of sorghum under different agroecological conditions. Throughout the study periods, each experiment was laid down in a randomized complete block design with three replications.

The treatments considered were; (1) tie riding at planting; (2) riding at planting and tie 2 week s after planting; (3) riding at planting and tie 4 weeks after planting (4) tied ridge 3 weeks after planting ; (5) riding 2 weeks after planting and tie 4 weeks after planting; (6) riding 3 weeks after planting and 6 weeks after planting ; (7) tie riding 6 weeks after planting (8)control (farmers' practice Shilshalo 6 weeks after planting for sekota and 8 weeks after planting for Lalibela). The plot size of the treatment areas was 5m length by 4.5m width and the distance between plots and blocks was 1 and 1.5 m, respectively.

Diversion ditches were constructed to divert the inflow of runoff. An improved sorghum variety Misker was used as a test crop. The fields were primarily plowed three times and sowing was done in the first week of July. The crop was planted on a plot size of 5 m × 4.5 m in rows with a spacing of 75 by 15 cm. Tie-ridging is developing ridges with 20-30 cm depth and commonly spaced 75 cm apart, ridge and tie-ridge were constructed along with the couture the space between tie was 2m and 1m with staggered zigzag line. The recommended rate of 50 $Kgha^{-1}$ Urea and 100 $Kgha^{-1}$ NPS for Sekota and 50 $Kgha^{-1}$ Urea and 50 $Kgha^{-1}$ NPS for Lalibela were used as a source of Nitrogen and Phosphorus fertilizers respectively for each treatment for sorghum production (Sebnie W and Mengesha M. (2018). Nitrogen fertilizer was applied by split; application method in the form of urea half at planting and the remaining 45 days after planting. Phosphorus was applied once in the form of NPS at the time of planting. Agronomic practices such as weeding, cultivation, and fertilizer were done uniformly for all treatments as per need. Monitoring of weed infestation was regularly carried out, and hand-weeding techniques were applied and done three times to remove weeding

Data Collection

Soil Data: Composite soil samples were taken using an auger at a depth of 0- 20 cm from representative points in the trial sites and analyzed in the laboratory for major physiochemical properties and soil moisture characteristics. The USDA textural classification triangle was used to define the textural class for each composite soil sample taken. Besides, additional soil samples were taken from each treatment every 2-week intervals by a core sampler for monitoring the soil moisture content during the growing season.

A gravimetric field technique was used to determine the soil moisture content in this experiment.

Agronomic Data: Agronomic data including average plant height, length of sorghum head, the average weight of sorghum head, grain yield, and above-ground biomass of sorghum data ***were*** taken in all rows except borders in each plot. Data on plant height and head length were also taken on five randomly selected sorghum plants excluding border rows.

*Data Analysis***:** The agronomic data obtained were subjected to analysis of variance using SAS version 9.0 software and treatment effects were compared using the Fisher's Least Significant Differences (LSD) test at a 5% level of significance.

Soil analysis: The soil was air-dried and sieved through a 2 mm sieve. Soil pH was determined from the filtered suspension of 1:2.5 soil-to-water ratio using a glass electrode attached to a digital pH meter. The organic carbon of the soils was determined following the wet digestion method as described by Walkley and Black (1934) while the percentage of organic matter in the soils was determined by multiplying the percent organic carbon value by 1.724. Total Nitrogen was determined by the micro-Kjeldahl digestion, distillation, and titration method. Available phosphor was determined by the Olsen method (Olsen *et al.*, 1954).

Results and Discussion

Soil Physio-Chemical Characteristics of the Experimental Sites: The major physiochemical characteristics of the soils in the experimental sites are summarized in Table 1. As shown in the table, the soil textural classes were found to be Sandy clay loam and sandy loam for Aybira and sandy loam and sandy clay loam for Lalibela experimental sites. Many agronomic practices require knowledge of the relation between the physical properties of the soil and the amount of soil water contained in a particular soil volume.

Table 2: Physio-chemical properties of soil in the experimental site

Parameter		PH	EC	%OM	%TN	av. P (ppm)	Texture class
Location	Year						
Aybira	1st	6.1	0.14	0.538	0.025	16.1	sand clay loam
	2nd	5.2	0.13	1.076	0.028	3.78	sandy loam
Lalibela	1st	7.6	0.04	0.666	0.045	15.95	sandy loam
	2nd	6.8	0.11	0.37	0.032	4.13	sand clay loam

The soil pH of the trial sites according to (Tekalign, 1991) ranged from moderately alkaline and neutral for Lalibela and strongly acidic and slightly acidic for Sekota, and slightly alkaline and neutral for Lalibela.

Based on the results obtained from soil analysis as shown above in (Table2), the average total Nitrogen (%TN) ranges from 0.025-0.045, according to (Tekalign,1991); was categorized under very low and low, and it needs N fertilizer sources for optimal crop production and productivity. Available Phosphorus (Av. P) ranged from 3.78 -16.1 PPM, according to Cotton. (1980); which grouped under low, medium, and high classes, which need Phosphorous fertilizer sources for optimum crop production and productivity. Soil organic matter (%OM) status of the trial site was ranging from 0.37-1.076, according to (Tekalign, 1991), it was very low and low for both locations.

Effect of Ridging and Tie Ridging Time on Soil Moisture Content and Grain Yield of Sorghum: The results indicated the comparative advantage of the conservation practices in increasing the moisture availability of the soil as compared to the control plot with farmers` practices (Shilshalo). As is seen in (Figure4 and Figure5) below the amount of soil moisture content stored in plots with tie ridging was considerably higher than the farmer's practice (Shilshalo) throughout the growing seasons in both locations, except for the plot treated with tie-ridging 6weeks after planting. It is also clearly seen in the figures that tied ridge practice had the highest soil moisture accumulations on average in both cropping seasons and soil-type conditions.

The gravimetric soil moisture content on plots with a tied ridge at planting was on average 22.22% higher in sandy clay loam soil (at Sekota) and 26.39% higher in sandy loam (at Lalibela) as compared to plots with the Farmer's practice (Shilshalo 6week Sekota 8week Lalibela after planting respectively). Which had the minimum soil moisture content and grain yield throughout the growing season except for the plot with tie-ridging 6 weeks after planting. Plots treated with ridging at planting tie 2 weeks after planting had on average the second-highest level of moisture content accumulated in the soil followed by plots treated with ridging at planting and tie 4 weeks after planting. Plots treated with farmers' practice (Shilshalo) had the minimum soil moisture content next to the plot treated with tie ridging 6 weeks after planting.

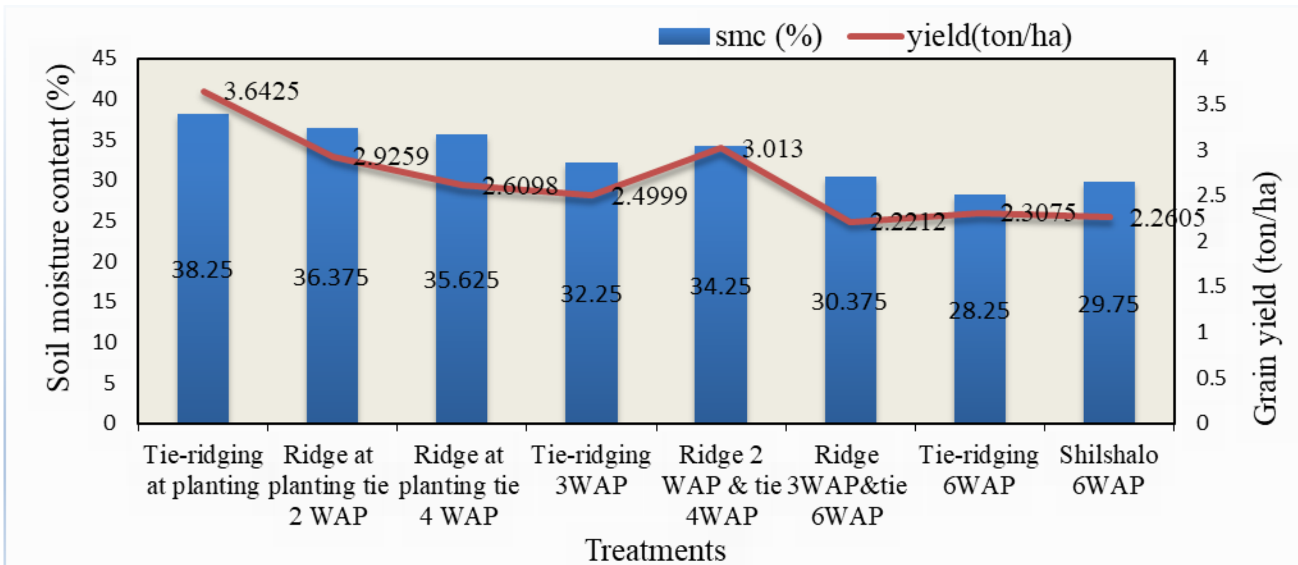


Figure 3. Effect of tie ridging time on soil moisture content and grain yield of sorghum in Sekota (Aybira) site

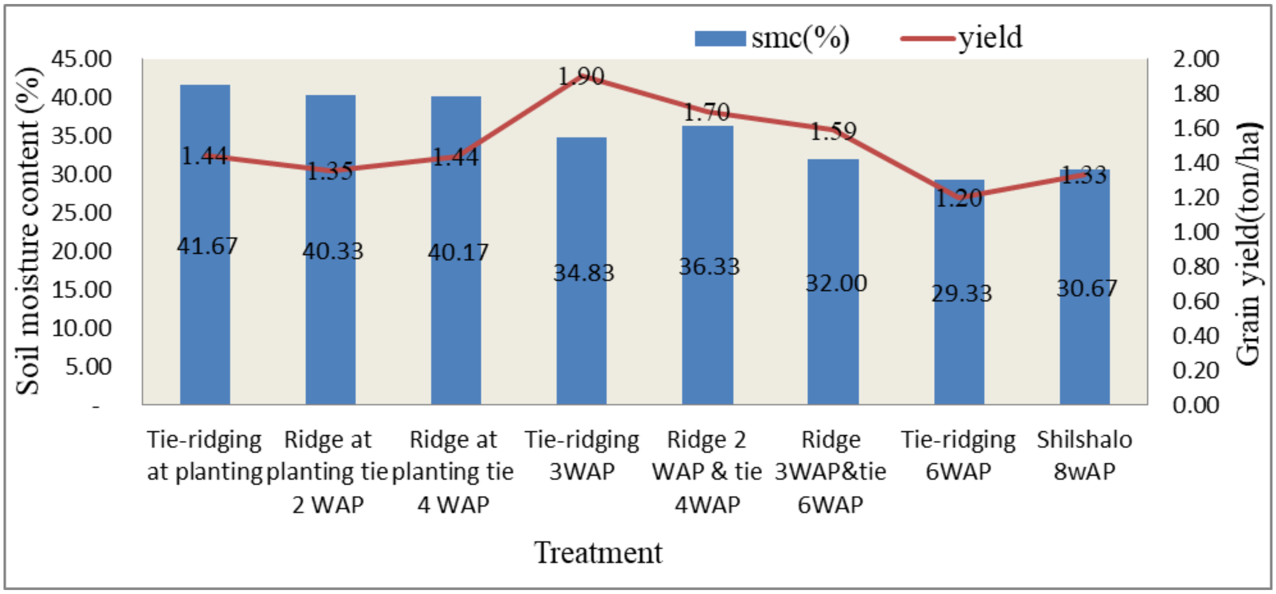


Figure 4: Effect of tie ridging on soil moisture content and grain yield of sorghum in Lalibela (Kechinabeba) site

Effect of Riding and Tie Riding Time on Growth and Yield of Sorghum at Sekota

Plant Height and Head Length: The riding and Tie riding time significantly (P≤0.05) affected the plant height of sorghum (Table 3). The higher Mean plant height of sorghum (175.17cm) at a tie and riding at planting was significantly higher than farmers' practice, The height was increased by 11.6%, compared with farmers' practice and the lower mean plant height (153.4cm) was recorded at the tie and riding 6 weeks after planting. Riding and Tie riding time was not significantly (P≤0.05) affecting the head length of sorghum as shown above in (Table 3). However, the highest mean plant head length (21.6 cm) was recorded at the tie and riding at planting. The current result agrees with the finding of (Legesse and Gobeze, 2015) who report Nitrogen and Phosphorus at a rate of 18 Nitrogen and 46 Phosphorus with tie-ridge had a significant effect on plant growth in areas of southern Ethiopia. Similarly (Brhane, 2012) observed that Nitrogen and Phosphorus at a rate of 18 and 46 $Kgha^{-1}$ with in-situ-moisture conservation had higher plant height.

Table 3: Combined mean square value for the effect of riding and tie riding time on the plant height, sorghum head length at Ayibra

Treatment	Plant height (cm)			Head length (cm)		
	1^{st} year	2^{nd} year	combined	1^{st} year	2^{nd} year	Combined
Tie-ridging at planting	186.47[a]	163.87[a]	175.17[a]	22.4[a]	20.8[a]	21.60[a]
Ridge at planting tie 2 WAP*	179.33[ab]	154.07[ab]	166.7[ab]	22.73[a]	16.88[bc]	19.81[a]
Ridge at planting tie 4 WAP	172.6[abc]	149.87[ab]	161.23[ab]	21.8[a]	16.31[bc]	19.05[a]
Tie-ridging 3WAP	171.07[abc]	145.8[ab]	158.43[ab]	22.46[a]	16.19[bc]	19.33[a]
Ridge 2 WAP & tie 4WAP	179.2[ab]	145.27[b]	162.23[ab]	21.86[a]	14.24[c]	18.05[a]
Ridge 3WAP&tie 6WAP	169.2[bc]	148.13[ab]	158.67[ab]	21.86[a]	16.43[bc]	19.15[a]
Tie-ridging 6WAP	158.33[cd]	148.47[ab]	153.4[b]	21.33[a]	17.53[b]	19.43[a]
Shilshalo 6WAP	151.13[d]	158.47[ab]	154.8[b]	20.26[a]	17.86[b]	19.06[a]
CV (%)	5.61	6.87	9.94	7.9	9.44	16.7
LSD (0.05)	16.78	18.248	18.73	3.02	2.81	Ns

** The same letter is not significantly different at* p *= 0.05 (5 % level of significance) WAP= week after planting*

Grain Yield and Biomass: The grain yield was significantly affected by the ridge and tie-ridge time at ($P \leq 0.05$) shown in (Table 5). The grain yield of sorghum is influenced by the different times of tie and ridge time. Decreasing the time of ridge and tie ridge time increased the yield of the crop from 22.60Qha^{-1} to 36.42 Qha^{-1}. Thus, compared to the farmer's practice, using the recommended rate of N and P_2O_5 (23/46 Kgha^{-1}) with tie-ridge at planting increased sorghum grain yield by 37.9%. This implies that proper management of tie-ridge time can gain the additional grain yield of sorghum. The result of the current study agrees with the finding of, (Gebrekidan, 2003) who observed that fertilizer application 46 P_2O_5 and 18 N with tie-ridge increases the grain yield of sorghum by 15-38% in the moisture stress areas of Eastern Ethiopia.

The biomass yield of sorghum was significantly affected by ridge and tie-ridge time at ($P \leq 0.05$). Biomass yield was increased with proper management of ridge and tie-ridging time. The highest biomass yield (155.15 Qha^{-1}) was recorded at ridge and tie-ridge at planting and the lowest biomass yield (84.53 Qha^{-1}) was recorded at ridging 3 weeks after planting and tied 6 weeks after planting treatment. The result indicates that tie riding at planting with the recommended rate of Nitrogen and Phosphorus (23/46Kgha^{-1}) fertilizer increases the biomass yield by 32.38% over farmers' practice. Biomass yield is very important because the leaves and stems are used for cattle feed during the long dry season.

Table 4: Combined mean square value for the effect of riding and tie riding time on grain yield and biomass of sorghum at Ayibra

Treatment	Total biomass (Q ha^{-1})			Grain yield (Q ha^{-1})		
	1st year	2nd year	Combined	1st year	2nd year	Combined
Tie-ridging at planting	162.28^{a}	148.02^{a}	155.15^{a}	35.94^{a}	36.91^{a}	36.43^{a}
Ridge at planting tie 2 WAP*	121.10^{bc}	113.86^{bc}	117.48^{bc}	29.97^{bc}	28.55^{bc}	29.26^{b}
Ridge at planting tie 4 WAP	103.78^{d}	98.17^{cde}	100.98^{de}	24.69^{cde}	27.50^{c}	26.09^{bc}
Tie-ridging 3WAP	119.32^{bcd}	105.05^{bcd}	112.18^{bcd}	28.76^{cd}	21.23^{d}	24.99^{cd}
Ridge 2 WAP & tie 4WAP	126.61^{b}	114.77^{b}	120.69^{b}	32.82^{ab}	27.44^{b}	30.13^{b}
Ridge 3WAP&tie 6WAP	84.08^{e}	84.98^{e}	84.53^{f}	23.38^{e}	21.04^{d}	22.21^{d}
Tie-ridging 6WAP	106.92^{cd}	89.25^{de}	98.09^{ef}	25.04^{cde}	21.11^{d}	23.07^{cd}
Shilshalo 6WAP	111.43^{bcd}	98.40^{cde}	104.91^{cde}	24.52^{de}	20.69^{d}	22.61^{cd}
CV (%)	8.31	8.56	10.75	10.73	8.9	11.79
LSD (0.05)	17.016	15.97	14.04	4.79	4.075	3.75

** The same letter is not significantly different at* p *= 0.05 (5 % level of significance) WAP= week after planting*

Effect of Riding and Tie Riding Time on Growth and Yield of Sorghum at Lalibela:

Plant Height and Head Length: Riding and Tie riding time did not significantly (P≤0.05) affect the plant height of sorghum. The higher Mean plant height of sorghum (130.63cm) at tie-riding3week after planting was significantly higher than farmers' practice, and the lower mean plant height (119.3cm) was recorded at riding 3 weeks after planting and tied 6 weeks after planting. Riding and Tie riding time significantly (P≤0.05) affected the head length of sorghum as shown the above table8. But the highest mean plant head length (16.06 cm) was recorded at riding two weeks after planting and tie 4 weeks after planting.

Table 5. Combined mean square value for the effect of riding and tie riding time on the plant height and the head length of sorghum at Lalibela

Treatment	Plant height			Head length		
	1st year	2nd year	Combined	1st year	2nd year	Combined
Tie-ridging at planting	110.07	130.60	120.33	15.46	14.2ab	14.83
Ridge at planting tie 2 WAP*	114.4	143.07	128.73	15.53	14.8ab	15.17
Ridge at planting tie 4 WAP	116.13	144.93	130.53	15.40	15.733a	15.57
Tie-ridging 3WAP	116.00	145.27	130.63	16.00	15.80a	15.90
Ridge 2 WAP & tie 4WAP	120.67	135.67	128.17	17.20	14.93ab	16.07
Ridge 3WAP&tie 6WAP	114.13	124.47	119.30	15.45	14.37ab	14.91
Tie-ridging 6WAP	114.67	136.33	125.50	15.33	13.86ab	14.60
Shilshalo 8WAP	117.73	133.60	125.6	16.067	13.13b	14.60
CV (%)	8.41	10.76	13.55	9.84	9.1	10.05
LSD (0.05)	Ns	Ns	Ns	Ns	2.32	NS

**Tthe same letter is not significantly different at* p *= 0.05 (5 % level of significance) WAP= week after planting*

Grain Yield and Biomass: The grain yield was significantly affected by the ridge and tie-ridge time at ($P\leq 0.05$) shown in (Table 9). The grain yield of sorghum is influenced by the different times of tie and ridge time. Decreasing the time of ridge and tie ridge time increased the yield of the crop from (13.309 $Qtha^{-1}$ to 19.03 $Qtha^{-1}$ and 16.96 $Qtha^{-1}$). Thus, compared to the farmer's practice, using a recommended rate of N and P_2O_5 (23/23 $Kgha^{-1}$) with tie-ridge 3week after planting and ridge 2 weeks and tie 3weeks after planting increased sorghum grain yield by 30.11%, 21.58% respectively. This implies that proper management of tie-ridge time can gain the additional grain yield of sorghum. The result of the current study agrees with the finding of, (Gebrekidan, 2003) who observed that fertilizer application 46 P_2O_5 and 18 N with tie-ridge increases the grain yield of sorghum by 15-38% in the moisture stress areas of Eastern Ethiopia.

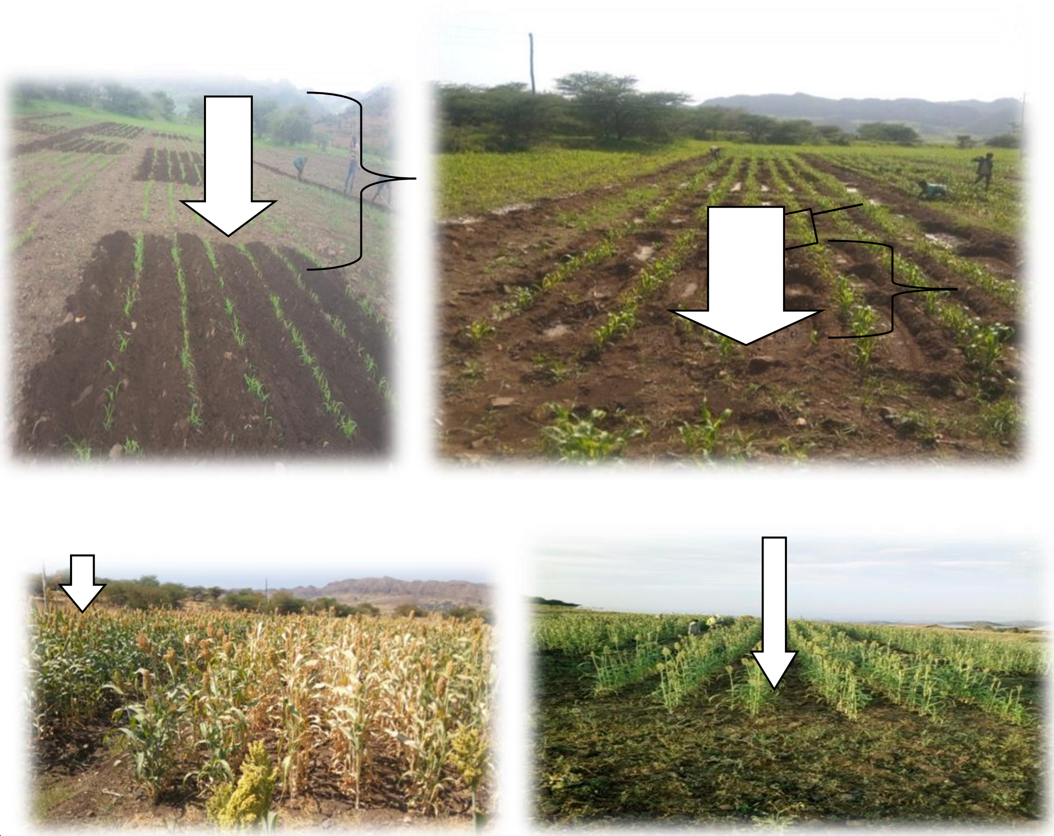
The biomass yield of sorghum was significantly affected by ridge and tie-ridge time at ($P< 0.05$). Biomass yield was increased with proper management of ridge and tie-ridging time. The highest biomass yield (142.99 $Qtha^{-1}$) was recorded at ridge and tie-ridge 3 weeks after planting and the lowest biomass yield (97.75 $Qtha^{-1}$) was recorded at tie-ridge 6 weeks after planting treatment.

The result indicates that tie-riding 3weeks after planting and with the recommended rate of Nitrogen and Phosphorus (23/23Kgha^{-1}) fertilizer increases the biomass yield by 31.6% and 18.07% over tie-ridging 6week after planting and farmers practice (shilshalo) respectively. Biomass yield is very important because the leaves and stems are used for cattle feed during the long dry season.

Table 6. Combined mean square value for the effect of riding and tie riding time on grain yield and biomass of sorghum at Lalibela

Treatment	Total biomass (Qt/ha)			Grain yield (Qt/ha)		
	1st year	2nd year	Combined	1st year	2nd year	Combined
Tie-ridging at planting	104.81^{cd}	117.31^{bc}	109.14^{cd}	15.747^{bc}	13.09^{c}	14.42^{cd}
Ridge at planting tie 2 WAP*	122.31^{b}	122.66^{b}	122.52^{b}	13.277^{cd}	13.75^{bc}	13.52^{de}
Ridge at planting tie 4 WAP	125.06^{ab}	125.38^{b}	125.22^{b}	14.633^{bcd}	14.12^{bc}	14.37^{cd}
Tie-ridging 3WAP	121.28^{bc}	129.53^{ab}	125.41^{b}	20.323^{a}	17.74^{a}	19.03^{a}
Ridge 2 WAP & tie 4WAP	141.27^{a}	144.72^{a}	142.99^{a}	17.947^{ab}	15.98^{ab}	16.96^{ab}
Ridge 3WAP&tie 6WAP	122.57^{b}	119.75^{b}	121.16^{bc}	14.746^{bcd}	17.01^{a}	15.88^{bc}
Tie-ridging 6WAP	95.1^{d}	100.4^{c}	97.75^{d}	11.681^{d}	12.36^{c}	12.02^{e}
Shilshalo 8WAP	113.82^{bc}	120.48^{b}	117.15^{bc}	14.612^{bcd}	12.01^{c}	13.31^{de}
CV (%)	8.06	8.3	9.01	13.11	9.16	12.87
LSD (0.05)	16.7	17.8	12.65	3.53	2.33	2.25

**The same letter is not significantly different at* p *= 0.05 (5 % level of significance) WAP= week after planting*



a b

Figure 5: Field performance of sorghum at (a) Sekota and (b) Lalibela

Conclusion and Recommendation

Overall, it is found that the efficiency of in situ moisture conservation practices for sorghum production in dry-land areas like in Wag-lasta areas has varied based on climatic and soil conditions. The result shows that appropriate timing of ridge and tie-ridge with recommended rate of Nitrogen and Phosphorous fertilizer for sorghum production could make an important contribution to soil moisture improvement and increase production and productivity in the areas. Further research should be carried out on soil moisture content and fertilizer to put the recommendation on a strong basis and also to come up with increased yield and improved sorghum production in the area.

The mean grain yield of sorghum was significantly affected by the treatment of ridge and tie ridge time. Tie ridging at planting with the recommended rate of N and P_2O_5 (23/46Kgha^{-1}) fertilizer is found to be the appropriate timing for optimum productivity of sorghum in sekota (Aybira). Tie ridging at planting is recommended for Sekota (Aybira) and similar agroecology areas. Whereas tie ridging 3 weeks after planting with the recommended rate of N and P_2O_5 (23/23Kgha^{-1}) fertilizer is found to be the appropriate timing for optimum productivity of sorghum in lalibela (Kechinabeba) and ridge 2 weeks and tie 4 weeks after planting recommended as the second option in Lalibella (*Kechinabeba*) and the similar agro ecology areas.

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5. Characterization of Biophysical and Socio-economic Aspects of Agewmariam Experimental Watershed, Northern Ethiopia

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Abstract

Watershed characterization is required to measure the changes due to intervention and it is important in the planning, monitoring, and utilization of resources in a sustainable way. This paper provides a detailed insight into the biophysical and socio-economic conditions of the Agewmariam watershed and the land capability and suitability maps including the management options. The study collected biophysical data such as land slope, soil properties, erosion severity, stoniness/ rockiness cover, and vegetation cover parameters from field surveys. Socio-economic data such as population demography, income, and expenditure were collected from individual interviews, complete census, and focus group discussions. The study found that there are 259 households inside and around the watershed, with an average family size of 4 people per household and a demographic dependency ratio of 96.6%. The major sources of income are crop production and livestock rearing, while working as casual labor and receiving food aid also contribute to their livelihood. The average farmland holding size in the watershed is 0.5 ha while sorghum, barley, tef, and wheat are the most dominantly grown crops. The study also revealed that the watershed is characterized by six land capability classes; which are classes II, III, IV, VI, VII, and VIII. The suitability analysis shows that the watershed is not currently suitable for wheat and tef crops unless it is managed and improved physically, chemically, and biologically. The major limiting factors were slope, erosion severity, and stoniness for the land capability and soil organic matter and soil texture for the suitability analysis in the watershed. The socioeconomic characterization increased awareness about the local socio-economic condition for appropriate planning and implementation of available management activities. The study suggests that an intensive soil and water conservation intervention, afforestation on hillsides, changing the land use system, and organic matter & fertilizer addition on farmlands could be considered the best alternative management options to improve the land capability and suitability.

Keywords: Land Capability, Land Suitability, Limiting Factor, Soil Properties.

Introduction

A watershed or catchment is commonly defined as an area in which all water drains to a common point (Desta *et al.,* 2005a; Kerr and Chung, 2005; Raghunath, 2006), On the other hand, watershed management is defined as the process of organizing land and resource use in a watershed to provide desired goods and services while preserving natural resources (DENR, 2015) It is recognized as the ideal approach for integrated natural resources management (Desta *et al.,* 2005a; Wani *et al.,* 2003) It is also a principal approach that fits community level planning and that can optimize the use of natural resources and untapped potential in degraded and potential areas (Desta *et al.,* 2005a). The hydrological perspective of a watershed makes it a useful unit of operation and analysis for a systems approach to land and water use in interconnected upstream and downstream areas (Kerr and Chung, 2005).

The Ethiopian Ministry of Agriculture and Rural Development employs a community-based participatory watershed development guideline to enhance productivity, generate income opportunities, and improve livelihood support systems while building resilience to shocks. It is designed to involve community members from the beginning of the idea up to its implementation and impact assessment (Desta *et al.,* 2005a). The partnership and participation of the local community, including farmers, state and local agencies, and community leaders, based on strong commitment, is essential for successful watershed management (Wani *et al.,* 2003).

The Ethiopian governmenthas been long implementing a watershed approach for soil conservation, water harvesting, afforestation, and land rehabilitation activities (Desta *et al.,* 2005a). Baseline assessments also have been conducted in Ethiopia to establish a reference point to monitor changes, and project impacts, and inform other stakeholders and restoration initiatives (Desta *et al.,* 2005a; Sacande *et al.,* 2018). Baseline data facilitates management tasks, research process policy, and planning decisions (Wani and Shiferaw, 2005).

Watershed Characterization is the process of describing the biophysical and socio-economic characteristics and features of a watershed to have an understanding of the various processes therein (DENR, 2015). It involves assessment, quantification, mapping, and understanding of the biophysical resources of a watershed. This process aids in land capability classification, targeting restoration interventions, and monitoring their effects on the environment and people (Desta *et al.,* 2005a; Sacande *et al.,* 2018; Sheng, 1990). Furthermore, Anantha *et al.,* (2009) suggested that characterizing economic variables before and after development can facilitate measuring the impact of watershed development programs on people's economic conditions.

Biophysical characterization involves identifying and characterizing various factors such as slope steepness, surface cover, vegetation type and coverage, soil texture, soil depth, and size of land holdings (Desta *et al.,* 2005a; Sheng, 1990; Ziadat *et al.,* 2006). General data should include agroecology, name and location, boundaries, size, elevation, streams, rivers, tributaries, and others (Desta *et al.,* 2005a).

According to the FAO (1976), the term "Land" encompasses the physical environment, including climate, relief, soils, hydrology, and vegetation, to the extent that they influence the potential for land use. On the other hand, "land evaluation" is the process of assessing land performance for specific purposes by analyzing the relationships between land use and resources, including physical and socio-economic resources(FAO, 1976; SYS C. *et al.,* 1991).

The approach and methods employed in land evaluation are based on fundamental principles such as assessing and classifying land suitability for specific uses, comparing the benefits obtained and inputs needed on different types of land, using a multidisciplinary approach, evaluating in terms relevant to the physical, economic, and social context of the area, evaluating for sustained use, and comparing more than one kind of use (FAO, 1976).

The two most commonly used methods for land evaluation are the USDA land capability classification developed by Klingebiel and Montgomery in 1961 and the FAO land suitability classification developed in 1976. Recently developed classification systems are more quantitative as there is an increased understanding of the relationships among the different factors that influence soil productivity and stability (Cruz, 1990).

The terms "capability" and "suitability" are sometimes viewed as interchangeable, while others consider capability as the inherent capacity of land to perform at a given level for general use and suitability as the adaptability of a given area for a specific kind of land use (FAO, 1976). Land capability classification involves describing and classifying lands based on their biophysical features and ability to sustain various kinds of uses (Cruz, 1990).

The USDA land capability classification system (Klingebiel and Montgomery, 1961) categorizes land into three major groups based on their capability to respond to management systems, conservation problems, and relative degree of hazard or limitation. These groups are capability units, capability subclasses, and capability classes. Accordingly, land suited for cultivation and other uses falls under Class I, Class II, Class III, and Class IV. Meanwhile, land limited in use and generally not suited for cultivation is categorized as grazing, woodland/wildlife, recreation/wildlife/water supply, or esthetic and falls under Class V, Class VI, and Class VII. Class VIII is considered the most limited in use.

The FAO, (1976), land suitability classification method for crops involves four levels: Land Suitability Orders, Land Suitability Classes, Land Suitability Subclasses, and Land Suitability Units. The method helps identify the types and degrees of suitability, as well as any limitations or improvement measures required for successful crop growth.

The FAO, (1976)Framework for Land Evaluation presents principles and procedures that can be applied worldwide. The watershed management guideline used in Ethiopia (Desta *et al.,* 2005a), is considered adaptable and practical for different types of areas. However, Hurni *et al.,* (2016) suggested that conservation technologies should be selected based on the area's characteristics where they will be implemented. Therefore, before implementing soil and water conservation measures, it is crucial to understand the characteristics of a specific region, given Ethiopia's diverse climatic conditions and altitudes (Hurni *et al.,* 2016). An assessment of the population, environment, agriculture, people's economic situation, their needs, characteristics, and professional bacKgrounds is necessary to plan any project or program (Wani and Shiferaw, 2005). The greatest weakness of the study area and the surrounding environment is the high variability in land characteristics inconsequence the difficulty to characterize and document the available data of justified accuracy. Hence, the research aimed to evaluate and describe the biophysical and socio-economic characteristics of the Agewmariam watershed, identify technological requirements, create land capability and suitability maps, and verify the local applicability of evaluation methods and techniques considering the variability in the biophysical and socioeconomic characteristics.

Material and Methods

Description of the Study Area

Location and Topography: The Agewmariam watershed was established in 2016 as an experimental area for soil and water conservation research on a watershed scale to represent the surrounding ecological, biophysical, and socioeconomic conditions accurately. The experimental area is situated in Sayda kebele, which is 23 km southwest of Sekota town in the Waghimra administrative zone of Amhara regional state, Ethiopia (figure 1). The area is part of the Tekeze River basin and covers 147 ha, with coordinates ranging from 12° 31' 40" to 12° 32'33" N Latitude and 38° 55' 14" to 38° 56' 15" E Longitude. The watershed's altitude varies from 2109 to 2381 meters above sea level, and the land slope ranges from nearly flat (<3%) to extremely steep slope (>50%).

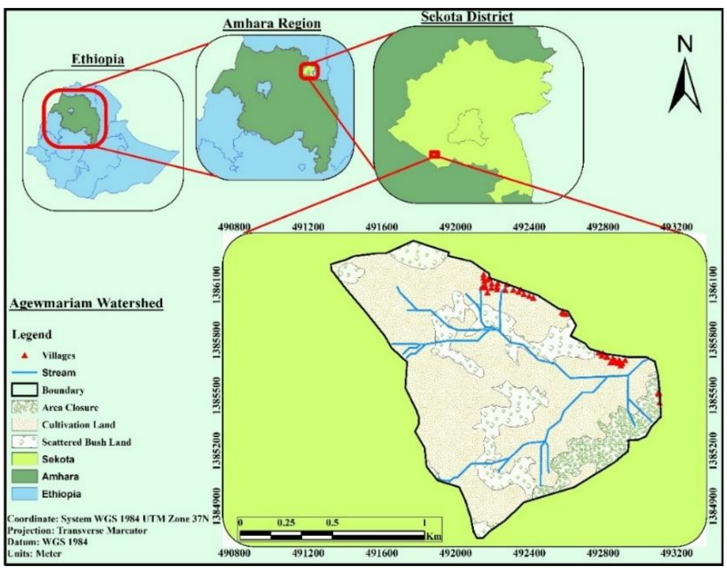


Figure 1 Location map of the watershed.

Climate: According to Hurni *et al.,* (2016), the experimental area is categorized as a Dry-Weyna-Dega agroecological zone. The region experiences a unimodal rainfall pattern, with low and inconsistent rainfall distribution. The rainy season lasts from late June to early September, and the average annual rainfall is 570.3 mm. The National Meteorology Agency (NMA) reported that the mean minimum and maximum annual temperatures in the area are 12.5 °C and 26.5 °C, respectively (NMA, 2019).

Methodological Procedures and Techniques: The study utilized a four-phase methodology which involved the selection and establishment of an experimental watershed, biophysical and socio-economic characterization, land capability mapping, and land suitability mapping for tef and wheat crops of the watershed.

The establishment process followed a Community Based Participatory Watershed Development Guideline approach (Desta *et al.,* 2005a) and included the selection of a representative watershed based on predefined criteria, the formation of a multi-disciplinary technical team, and the creation of a community watershed team from elected representatives of different social classes.

The watershed was selected based on various factors including geographical characteristics, agricultural productivity, natural resources degradation, socioeconomic factors, agroecological characters, land use type, and existing status of the watershed. The first activity conducted after the decision was made on the selection process was the delineation of the watershed using GPS tools and Arc GIS software.

Data collection

Socio-Economic Data Collection: The socioeconomic data were obtained through complete census and household surveys conducted on sample sets of households and villages. The questionnaire used in the survey focused on demographic data, economic profile, agricultural technology and experience, and access to extension service and training.

A representative sample of respondents were selected from the population using Systematic sampling. In such a system the selection process was started by picking some random point in the list of households and then every 4^{th} household was selected aiming for more than 25% of the population and the probability of each household to be included in the sample was ensured (Babbie and Rubin, 2015; Kothari, 2004).

In addition to the household surveys, secondary socioeconomic data such as beneficiaries of governmental and non-governmental food aid programs were collected from documents in the Bureau of Agriculture. A focus group discussion was also held with selected farmers to identify the problems in the watershed and develop solutions for the identified issues.

Biophysical Data Collection: According to Sheng, (1990), it is important to gather and study all available reference material and aerial photographs before going out to the field. In addition, sometimes a general observation in the field is required. To study the land use, land cover, and land characteristics of the watershed, a transect walk was conducted across the watershed, and observations were made to create a rough map. Biophysical data such as slope, stoniness, past erosion severity, land use type, and soil depth were collected using a 100m*100m fixed grid, and some points were sampled based on the variability of land use, slope, and soil.

Soil depth was determined using a soil auger (Desta, *et al.,* 2005b) and by looking at stream banks and gullies for deep soils (Desta *et al.,* 2005b; Sheng, 1990). Soil depths were taken across the watershed to obtain an average soil depth, as cited in (Sheng, 1990)and the soil depth to a contrasting layer significant for soil conservation requirements was recorded as soil depth, as cited in (Desta *et al.,* 2005a).

The extent of stoniness cover and vegetation cover was assessed through visual estimates of cover in randomly established sample plot quadrants, as described in studies by (Blanco and Lal, 2008; Elzinga and Salzer, 1998). In order to assess the extent of erosion, (Lal, 2001) and his previous works suggested examining various indicators including gullies, rills, exposed roots, and rocks.

For the land suitability classification, further information on soil nutrients was collected (Sheng, 1990). In general, the data gathered from field surveys was complemented by data obtained from Google Earth Pro.

*Data Analysis**:*** Descriptive statistics, such as total count of the population, average land holding size, average household head age, average number of people per household, and percentage of students in the community, were used to summarize the collected socio-economic data. These statistics were used to describe the basic features of the dataset, including total count, average, and percentage. The total count provided an overview of the population size, while the average was calculated by adding up all the values and dividing by the number of observations. The percentage was calculated by dividing the number of observations in a particular category by the total number of observations and multiplying by 100 (Gravetter and Wallnau, 2014).

The collected soil samples were sent to the soil laboratory for the determination of texture and soil chemical properties. Soil samples were analyzed for soil pH, soil EC, soil organic matter, and organic carbon using standard laboratory procedures. Particle size distribution (texture) was determined using the hydrometer method, whereas organic carbon was determined by the wet combustion method.

The soil depth, soil texture, stoniness data, and erosion severity point data were mapped on ArcGIS into a raster form using the IDW interpolation technique. The elevation data was generated from Google Earth and DEM & slope maps were generated by using the elevation data on the topo to raster interpolation tool on ArcGIS environment. In line with Cruz, (1990); For the entire watershed, different data, such as slope, soil, Stoniness, past erosion severity, and land use maps, were used for overlay analysis to generate the land capability class map and land suitability class map. From the data overlays, the features and parameters needed in the capability classification, and land use suitability assessment for each cell were extracted. In overlaying several maps, format considerations, such as map resolution and projection, were appropriately defined to keep the joint probability of coincidence the same at all locations (Cruz, 1990).

For the suitability analysis tef and wheat were selected as major crops in the watershed. Land characteristics like slope, soil depth, soil texture, soil pH, and soil organic matter were used as a criterion for land suitability analysis. The limitation approach was employed as a procedure of land evaluation (Belayneh and Desta, 2014; Klingebiel and Montgomery, 1961; SYS C. *et al.*, 1991).

In summary, Determining the evaluation objectives and data requirements, a description of the types of land use to be considered and their requirements, a description of land mapping units and derivation of land qualities, a comparison of land use types with the types of land present, economic and social analysis, classification of land suitability (either qualitative or quantitative), and presentation of the results of the evaluation were the activities involved in land capability and suitability classification (FAO, 1976; Klingebiel and Montgomery, 1961).

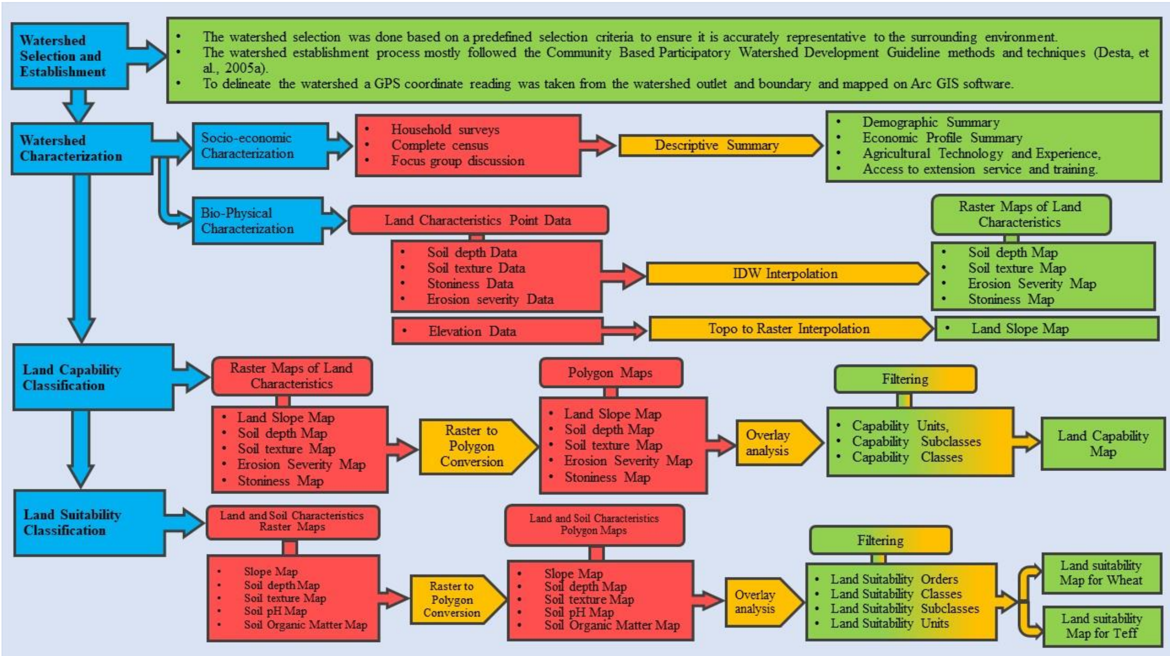


Figure 2: Research methodology flow chart.

Results and Discussion

Selection and Establishment of Model Watershed: The Agewmariam watershed was selected as the appropriate watershed based on several factors including its representativeness of the site, geographical characteristics, agricultural productivity, extent of natural resource degradation, socioeconomic factors, agroecological characters, land use type, and existing status of the watershed. The watershed was established on a 147-hectare area of land as an experimental watershed to represent the surrounding dry land areas of Waghimra which is characterized by a variable environmental condition.

The multi-disciplinary technical team consisting of 11 members organized from soil and water, crop, livestock, land use, and forestry experts was formed to oversee the project. Additionally, a community watershed team of 13 members was formed from elected representatives of the community who are from different social classes in the community to ensure community participation. An agreement on responsibility sharing was also reached between the partner sectors.

Socio-economic Characterization

Population: The watershed community consists of five villages with a total population of 1113 inhabitants and 259 households. The average family size in the community is 4.3 people per household, which is lower than the rural community average of 5 persons per household in Ethiopia (Sisha, 2020). The household heads in the watershed community have an average age of 49 years, and they are the most active participants in farming practices and decision-making (Mansoor, 2008).

The dependency ratio in the watershed community is 96.6%, which is lower than the national average of the rural population in Ethiopia as reported by Sisha, (2020). The demographic dependency ratio is the most commonly used measure of dependency, which shows that young ages (0-15 years) and old ages (more than 65 years) are dependent groups that rely on the workforce or Middle Ages (15-64 years) (Bekele and Lakew, 2014; Habtamu, 2011; Harasty and Ostermeier, 2020). A higher dependency ratio puts a burden on active members of the family to feed the household, leading to a higher probability of being food-insecure (Sisha, 2020).

Income Status and Occupation of the Watershed Community: According to the research, the majority of households in the watershed community rely on crop production, livestock rearing, labor, and food aid as their main sources of income. Food crop production and animal rearing are the dominant sources of economic income for all households. However, the average land holding size is only 0.5 ha, and only 8.4% of household heads own irrigable land which are very small in size (< 0.0625 ha). As a result, 36.7% of the respondents' resort to land tenancy to solve the shortage of land for landless youths and to get additional arable land for more food grain production.

The farmers in the community have no strong experience in recording their annual expenditures for health, shelter maintenance, children's clothing, books, and other expenses. They produce food grain for their family's consumption throughout the year and take some part of the grain to the market to substitute with other commodities. They also work as laborers for others and take animals to market to supplement their economic gap or in case of emergency. Additionally, they earn food aid from the government and non-governmental organizations.

Although Ethiopia has been successful in poverty reduction, the poorest segment of the population is mainly concentrated in remote rural areas, including the watershed community (Tom, 2020). However, more than 10.4% of members of the community in the watershed were food insecure and dependent on food aid programs of the government, which is a common issue in Ethiopia (Sisha, 2020).

Crop Production and Livestock Rearing in the Watershed: The farming system in the watershed is a mixed crop-livestock production system with a cereal-dominant cropping system. This practice is common in different parts of Ethiopia for example in the Bale highlands (Abate *et al.,* 2012), Adama and Arsi Negelle Districts (Addisu *et al.,* 2012). Sorghum, barley, tef, and wheat are the most dominantly grown crops. Even though cereals are dominant, farmers also grow pulse crops such as fabba bean, and field pea and all farmers allocate all of their farmland for food crop production for its high yield in grain and straw simultaneously.

The watershed is known for the production of common domestic farm animals like sheep, goats, cattle, donkeys, chickens, and honeybees. A large number of livestock populations exist in the watershed and follow a free grazing system. The livestock production system is extensive and completely local breeds. The main source of feed for animals is crop residue and some hey collected from farm boundaries. This is in line with (Abate *et al.,* 2012).

Draft cattle are the most important animals because of their use for cropland cultivation and crop threshing. In line with (Abate *et al.,* 2012)Animals are also kept for manure, meat, milk, and cash income.

Education and Capacity Building in the Community: Education and continuous training are crucial for ensuring the employability of all workers (Harasty and Ostermeier, 2020). In Ethiopia, there have been slight improvements in educational outcomes over time (Sisha, 2020). However, the high number of old-aged students in the watershed community indicates that children go to school too late or stop early due to social and economic limitations. About 27.2% of children between the ages of 6 and 15 still do nothave the chance to go to school. To address these issues, it is recommended to invest in education and capacity-building programs that cater to the needs of different age groups. Countries with young populations need to invest more in schools, while countries with older populations need to invest more in the health sector (EASD, 2018).

The Ethiopia Land Policy and Administration Assessment Final Report (ARD, 2004), has teachings of different management responsibilities to rural landholders to take care of their land. For example, if a person's holdings happen to border river banks and slopes, the landholder has the responsibility of cultivating his land at a distance away from the banks or slopes and taking care of them by planting trees and other plants, as shall be specified by the relevant body.

Since rural land cultivation is the major life support source of income in the watershed; they have a lifetime experience of traditional farming and taking care of their farmland. Almost all of the farmers have more than 10 years of experience in soil and water conservation. Moreover, awareness creation and capacity building of rural communities on integrating crops, livestock, and natural resource management technologies for effective soil and water conservation measures should be enhanced through a participatory integrated watershed management approach (Desta *et al.,* 2005a; Jilo *et al.,* 2020).

Biophysical Characterization

Land Characteristics: The Agewmariam watershed is composed of four major land use types: settlement, area closure, scattered bushland, and cultivation land, with an area coverage distribution of 1.1, 12, 29, and 104.9 hectares, respectively (Figure 3). The largest area is covered by cultivation land use type, which is the largest contributor to soil erosion.

Jilo *et al.,* (2020) suggest that knowledge of the distribution and slopes on which trees exist in the watershed can be useful in preparing an intervention plan for massive tree planting. The vegetation cover in the watershed is dominated by acacia tree species, shrubs, and grass species. The estimated vegetation cover percentage was 30% and 60% for the scattered bushland and area closure, respectively, during the dry period, while it was 70% and 85% during the rainy season.

According to Raghunath, (2006), the drainage system of a watershed can be characterized by stream density and drainage density. The Agewmariam watershed had two major streamlines and 25 tributaries, with a total length of 7.5 Km. The stream channels in this watershed had an irregular shape, and the stream density was 0.2 ha^{-1} while the drainage density was 0.0051 m/m^2.

A watershed's physical characteristics were assessed using several parameters, such as slope, soil depth, soil texture, stoniness, and erosion severity classes (Table 2). According to ratings in(Belayneh and Desta, 2014; Desta *et al.,* 2005b; Girmay *et al.,* 2018) the watershed is mainly characterized by a soil depth ranging from 0.5 to 1m (Figure 3c), sandy loam texture (Figure 3d), 15 to 30% stoniness (Figure 3f), and slight to moderate erosion severity (Figure 3e) and the watershed has an undulating topography that encompasses all land slope levels, ranging from flat to very steep slope (Figure 3b).

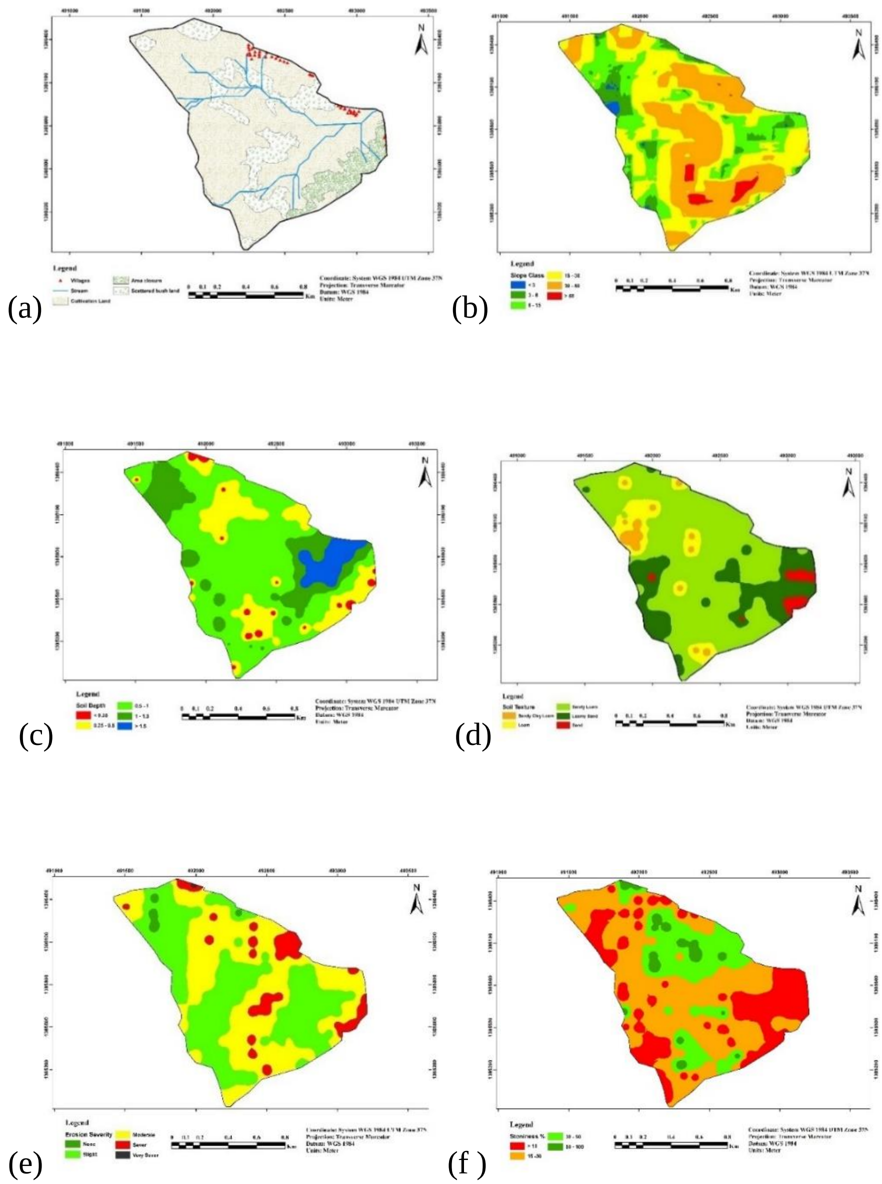


Figure 3: (a) Land use map, (b) Slopemap, (c) Soil depth map, (d) Soil texture map, (e) Erosion severity map, and (f) Stoniness map of the watershed.

In line with Ziadat *et al.*, (2006) the sampling procedure during the biophysical characterization was a compromise between free sampling and grid sampling. A 100*100 m grid sampling used in this study will be the highest resolution ever used in the study area and its surroundings. The accuracy of the results obtained from this method is largely dependent on the accuracy of the different input or source maps (Cruz, 1990). The greatest weakness of the surrounding environment is the high variability in land characteristics and the difficulty of having input data with these kind of resolutions to secure accuracy of input data. Since the watershed is established aiming to represent the surrounding environment the findings from this study watershed can be extrapolated by projects demanding threshold initial data for the use in the planning and management of the surrounding environment. The evaluation techniques used in this study also can be considered as they are verified to be used in the surrounding similar environments except the demanded flexibility of operation according to the variability in the local condition.

Table 1: Vegetation species identified in the Agewmariam watershed

Trees Spp.		Shrubs Spp.		Trees and Shrubs Spp.	
Local Name	Scientific Name	Local Name	Scientific Name	Local Name	Scientific Name
Sirwa	*Acacia sayal* Del.	Bubusha	Senna didymobotrya	Tikur Girar	*Acacia etbaica*Schweinf
Qulqual (Beles)	*Opuntia ficus-indica* (L.) Miller	Gorgoro	*Dichrostachys cinerea* (L.) Wight & Arn	Egula/Gemero	*Capparis tomentosa* Lam.
				Talo	*Rhus vulgaris*
Feteqa	*Combretum molle* R. Br. ex G. Don.	Anquwa	*Commiphoraafricana* (A. Rich) Engl	Kokoba	*Maytenus senegalensis* (Lam.) Exell
				Qulqwal	*Euphorbia abyssinica*Gmel.
Qulqwal	*Euphorbia abyssinica*	Duduna	*Cussoniaholsti*Harms ex Engl.	Gulo	*Ricinus communis* L.
Woyra	*Olea europaea* L. subsp.cuspidata (Wall.exG.Don) Cif.	Dediho	*Euclearacemosa subsp. schimperi*(A.Dc.) Dandy		
Wanza	*Cordia africana* lam.	Limurna	*Ormocarpumtrachycarpum* (Taub.) Harms	Grass Spp.	
Bamba/Shola	*Ficus sycomorus* L.	Mentese	Becium grandiflorum (Lam.)		
Grfatsa	*Acacia albida* Del.	Eret	*Aloe vera* (L.) Burm.f.	Serdo	---
Giba	*Ziziphus spina*-christi L.	Qentafa	Pterolobiumstellatum (Forssk.)	Sembelet	Hyparrheniarufa
Qnchib	*Euphorbia tirucalli* L.	Damakase	*Ocimumlamiifolium*Hochst. ex. Benth.	Berbera	---
Bisana	*Croton macrostachyus* Del.	Qetetina	*Verbascum sinaiticum* Benth.	Chubasar	---

Table 2. Land characteristics for land capability classification in the Agewmariam watershed

class	Land Slope %			Soil depth (m)			Textural class			Stoniness			Erosion Severity		
	Slope Range	Area (ha)	Coverage %	Depth Range	Area (ha)	coverage %	Texture Class	Area (ha)	Coverage %	Stoniness Range	Area (ha)	Coverage %	Severity Class	Area (ha)	Coverage %
1	< 3	1.2	1	< 0.25	2.4	1.6	Sandy Clay Loam	3.9	2.7	< 15	36.8	25	No	1.6	1.1
2	3 – 8	11	7	0.25-05	28.8	19.6	Loam	12.7	8.6	15-30	72.9	49.6	Low	66.5	45.2
3	8 – 15	30	20	0.5-1	82	55.8	Sandy Loam	96.8	65.9	30-50	31.5	21.4	Moderate	67.2	45.7
4	15-30	52.5	36	1-1.5	25	17.0	Loamy Sand	30	20.4	50-90	5.8	3.9	High	11.7	8
5	30-50	49	33	> 1.5	8.8	6.0	Sand	3.6	2.4	> 90	0	0	V. high	0.1	0.1
6	>50	3.3	2												
	Total	*147*	*100*	*Total*	*147*	*100*	*Total*	*147*	*100*	*Total*	*147*	*100*	*Total*	*147*	*100*

**The table is based on the ratings and classes of the USDA land capability classification method as used in (Belayneh and Desta, 2014; Desta et al., 2005b; Girmay et al., 2018).*

Land Capability Classes in Agewmariam Watershed: Land capability is a measure of the potential and limitations of agricultural land use, ranging from ample to limited uses. It serves as a nationwide indicator of land quality. The overlay analysis of soil depth, slope, soil texture, stoniness, and erosion severity maps of the watershed revealed six classes of land capability, namely Class II, Class III, Class IV, Class VI, Class VII, and Class VIII, covering an area of 2.5, 15.1, 61.6, 32.8, 29.9, and 5.1 hectares, respectively.

Class III, class IV, and Class VI are the dominant capability classes in the watershed. This could be caused by being the slope, soil depth, and erosion severity were the major capability limiting factors in the area. This is confirmed by(Girmay *et al.*, 2018) reported that slope and stoniness were the primary limiting factors for land capability classes VI and VII in a similar neighboring watershed, while erosion severity and slope were the primary limiting factors for land capability class VIII in the watershed.

Moreover, land capability classes II, III, and IV in the watershed are found suitable for crop cultivation with slight limitations due to slope, soil depth, erosion severity, and stoniness. This is in line with (Girmay *et al.*, 2018; Klingebiel and Montgomery, 1961).

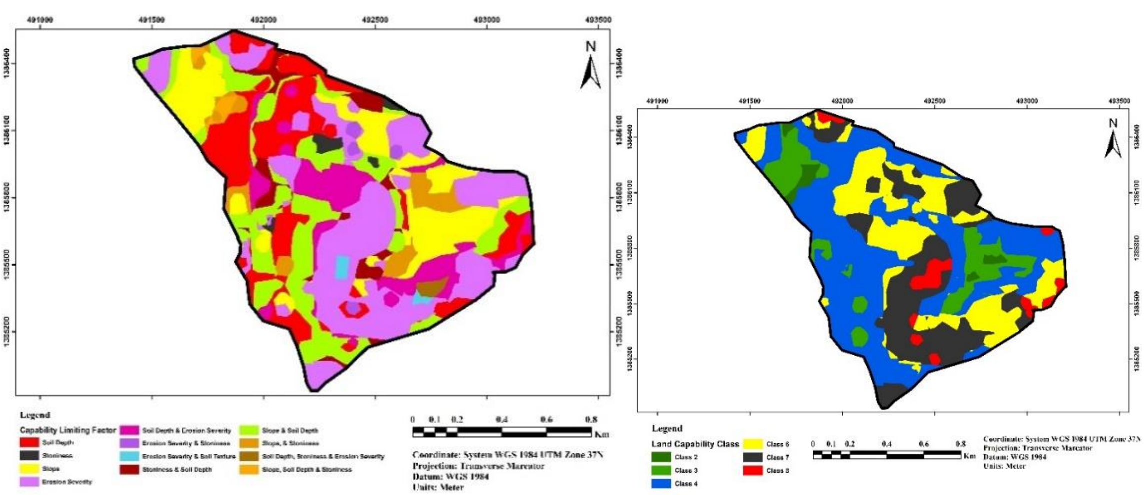


Figure 4: (a) Land Capability limiting factor and (b) Land capability maps of Agewmariam watershed.

The Federal Democratic Republic of Ethiopia Rural Land Administration and Land Use Proclamation (Federal NegaritGazcta, 2005), declares that rural lands, with a slope of more than 60 percent; shall not be used for farming and free grazing; they shall be used for the development of trees, perennial plants and forage production. It also states that rural land of any slope that is highly degraded shall be closed from human and animal interference for a given period to let it recover. In contrast a large area in the Agewmariam watershed with a slope, the major limiting factor is, unfortunately, under cultivation. This study is in line with (Jilo *et al.,* 2020) reported that the communities are not utilizing the resources potential wisely due to resource misuse and inadequate resource management.

However, Jilo *et al.,* (2020) concluded that land degradation was a serious concern, and watershed management programs could be enhanced. Girmay *et al.,* (2018); also recommended soil and water conservation interventions. Therefore, based on the land capability analysis in the watershed, soil and water conservation interventions, changes in land use patterns, and afforestation could be recommended as the best available management options to improve the capability of the land units in the watershed. The watershed also has to be closed from human and animal interference and be rehabilitated for a certain period.

Land Suitability for Wheat and Tef Crops in the Agewmariam Watershed: Land suitability refers to the fitness of a particular type of land for a defined use (FAO, 1976). The process of land suitability classification involves evaluating and grouping specific areas of land based on their suitability for defined uses. Suitability has been used to determine the degree of agroecological and socioeconomic adequacy of a specific use or land utilization type for each land unit (Comerma, 2010).

The limiting condition principle, in which the most unfavorable quality determines the suitability class (FAO, 1976), was used withLupia's, (2014) land characteristics and crop requirement rating for the specified tef and wheat crops (Table 3). Accordingly, 87.6% of the watershed area is permanently not suitable (N2) and 12.4% is currently not suitable (N1) for tef cultivation. Similarly, 47.1% is classified as N2 and 48.5% as N1 for wheat cultivation. Overall, the watershed is not suitable for wheat and tef cultivation, except for 4.5% which is marginally suitable (S3) for wheat. In line with Moshago *et al.,* (2022) there is no topographic position in the watershed that was classified as highly suitable (S1) for either crop.

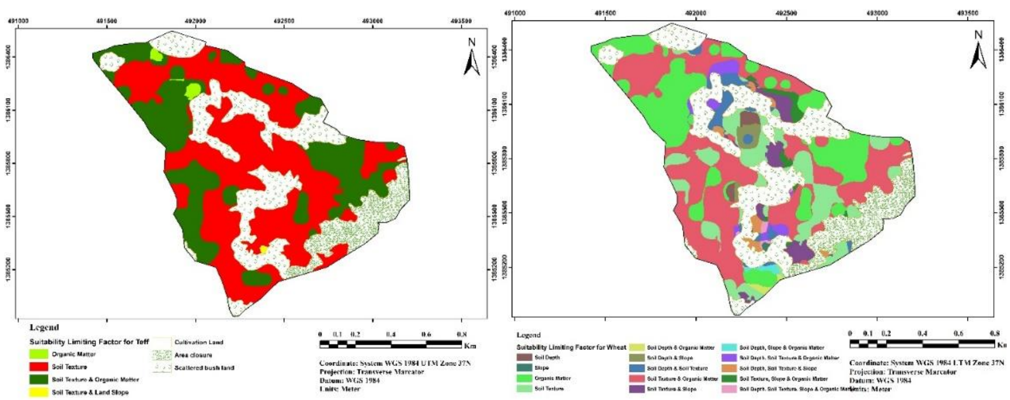
Table 3. Physiochemical land characteristics and land suitability in the Agewmariam watershed

Crop type	Suitability Class	Land characteristics & area coverage in the watershed										Overall suitability	
		Soil Depth		Slope		Soil Texture		pH		OM			
		Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Tef	S1	94.7	89.3	30.2	28.5	0.0	0.0	105.9	99.9	5.4	5.1	0.0	0.0
	S2	10.8	10.2	42.2	39.8	0.0	0.0	0.1	0.1	5.2	4.9	0.0	0.0
	S3	0.5	0.4	21.9	20.7	0.0	0.0	0.0	0.0	9.5	8.9	0.0	0.0
	N1	0.1	0.1	11.4	10.8	16.0	15.1	0.0	0.0	52.5	49.5	13.1	12.4
	N2	0.0	0.0	0.3	0.2	90.0	84.9	0.0	0.0	33.5	31.6	92.9	87.6
	Total	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*
Wheat	S1	32.4	30.6	30.2	28.5	0	0	101.8	96.1	5.4	5.1	0	0
	S2	29.3	27.7	42.2	39.8	12.1	8.6	4.2	3.9	5.2	4.9	0	0
	S3	32.9	31.0	21.9	20.7	3.9	2.7	0	0	9.5	8.9	4.8	4.5
	N1	11.1	10.5	11.4	10.8	66.1	65.9	0	0	52.5	49.5	51.4	48.5
	N2	0.2	0.2	0.3	0.2	23.9	22.8	0	0	33.5	31.6	49.9	47.1
	Total	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*

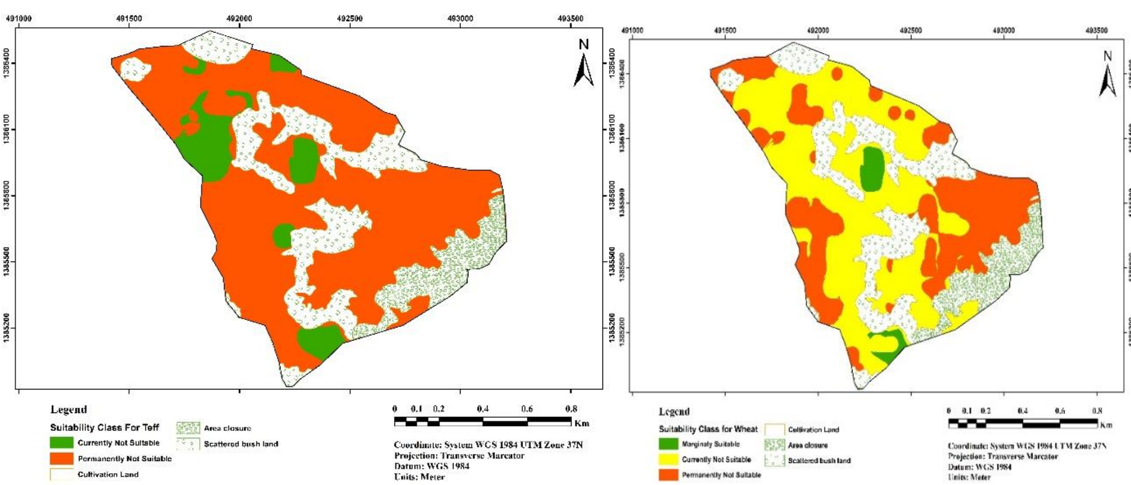
***Note:** *S1 = Highly Suitable, S2 = Moderately Suitable, S3 = Marginally Suitable, N1= Currently Not Suitable, andN2 = Permanently Not Suitable.*

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. A classification of current suitability refers to the suitability for a defined use of land in its present condition, without major improvements (FAO 1981).

In line with Girmay *et al.*, (2018) erosion, climate, and soil fertility are considered as common limiting factors for land suitability in general. The measured soil pH value in the watershed, ranging between 5.6 and 7.9, was not a limiting factor for wheat and tef cultivation. The major limiting factors were organic matter and soil texture for tef production, while organic matter, soil texture, and slope were the dominant limiting factors for wheat production. Girmay *et al.,* (2018) confirmed that soil organic matter was the major suitability limiting factor. Therefore, in line with Bahir *et al.,* (2015) integrated soil fertility management practices to increase soil organic matter levels and enhance soil fertility, such as increasing usage of readily available organic amendments and implementing fertilization programs based on published guidelines and correct diagnostics of soil nutrient status are recommended.



(a) *(b)*



(c) *(d)*

Figure 5: (a)Land suitability limiting factor for tef, (b) Land suitability limiting factor for wheat, (c) Land suitability map for tef, and (d) Land suitability map for wheat.

Conclusion and Recommendation

The study provides insights into the biophysical and socioeconomic aspects of the watershed. These insights can be used to propose appropriate policy directions and management plans to enhance productivity and sustainability. Additionally, the information generated from this research can serve as a baseline to evaluate future management intervention effectiveness.

The study reveals that the watershed is incapable of serving general and specific uses under the current biophysical and socioeconomic characteristics, leading to a reduction in overall production potential. To address this issue, it is recommended to plan and set a management option among different alternatives. Capacity building and enforcement bylaws are also recommended as a social aspect improvement to facilitate the implementation of rehabilitation and development plans.

The study identifies slope, stoniness, and erosion severity as the major land capability limiting factors in the watershed. To improve land capability and make it capable of multiple uses, intensive soil and water conservation intervention and re-vegetation, including changing the land use pattern, can be implemented.

For both tef and wheat, the major limiting factors were organic matter and soil texture. To improve organic matter and soil texture, management practices involving measures that increase soil organic matter levels and enhance soil fertility are recommended. Increasing usage of readily available organic amendments and implementing fertilization programs are also recommended.

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6. Evaluations of Grass Pea (*Lathyrus sativus*) Relay Inter-Cropping and Its Mulching Effect on Vertisols in Eastern Amhara Region, Ethiopia

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Abstract

Studies on the management of Vertisols have mainly concentrated on waterlogged soil drainage systems rather than on diversifying agricultural productivity. Inter cropping is one of the diversification techniques used in agricultural practice. Ethiopia has historically grown grass pea for food and livestock feed, and huge portions of the nation also produce wheat. The land's ability to produce crops was boosted in order to aid in the improvement of Vertisols productivities. Nine field experiments were carried out, two grass pea planting time integrated with two wheat row spacing and two soil drainage planting techniques. Each treatment was set up with randomized complete block design in three replications. The analysis result show that at tillering stage of wheat planting grass pea on furrow and between rows with in 30cm spacing is more effective than others. It contributes a significant value to soil fertility status and soil moisture contents. Grass pea is a legume crops it incorporates Nitrogen and it also used as a cover crop which retain soil moisture. This type of planting technique also efficient in case of land utilizations. A total of 1.9 ha of sole cropping area would be required to produce the same yields as 1 ha of the intercropped system. Planting of grass pea during the tillering stage of wheat crop with 30 cm spacing is recommended while farther studies in case of economic impact is needed.

Keywords: Grass pea, land equivalent ratio, planting time, Vertisols, Wheat

Introduction

The origin of grass pea cultivation is around 6000 Before Christ (De Ron, 2015). *Lathyrus sativus* L. or grass pea (Guaya in Ethiopia) has been cultivated in South Asia and Ethiopia for over 2500 years and is used as food and feed. Its tolerance to drought, not affected by excessive rainfall and can be grown on land subjected to flooding, including very poor soils and heavy clays (Jiang *et al.*, 2013). The world's population is increasing rapidly, and in order to feed it, one of the most attractive strategies is to increase productivity per unit area of available land or to increase the land area under production, which seems shrinking day by day (Snapp *et al.*, 2005). Therefore, to maximize land use and production, the ultimate goal of agriculture, namely yield, intercropping is an advanced agronomic technique that allows two or more crops to yield from the same area of land. Better utilization of resources and reduced weed competition minimize the risk of food shortages by enhancing yield stability (Aziz *et al.*, 2015).

In Ethiopia, Vertisols cover about 12.6 million ha of land, or about 10% of the total area of the country (Asamenew *et al.,* 1993). These soils have great potential for crop production since they have relatively good inherent fertility and are located mainly in the highlands where rainfall is sufficient. Grass pea has been an important crop both for human consumption and for animal feed or fodder since ancient times.

Food shortages are common in many parts of the world, particularly in Asia and Africa, due to population growth. One possible solution to this dilemma is to boost productivity per unit area of available land by maximizing the use of limited agricultural land through multiple cropping (Seran and Brintha, 2010). Intercropping is a crop management strategy that involves cultivating two or more dissimilar crop species or kinds in separate row combinations on the same piece of land at the same time (Yildirim and Guvenc, 2005).Intercropping has been demonstrated in numerous studies to be more productive than monoculture, yet it can also result in resource rivalry (Aziz *et al.,* 2015). One of the many competing resources in crop production systems is light, and soil moisture is another one that could be a competitor (Harper and Glyde 2010).

It is a legume crop grown in arid and semi-arid regions that is well known for being extremely drought tolerant (Campbell, 1997). This crop is a high protein content and remarkable resistance to extreme environmental conditions, such as flooding, drought, salinity, and low soil fertility, as well as a significant amount of resistance to biotic stress agents (Jiang *et al.*, 2013).

In Ethiopia, it is the third most important pulse crop after Fababean (*Vicia faba*) and chick pea. Mostly planted in September / October on residual moisture in the cambisol and vertisol**.** It can withstand heavy rains in the early growth stages and prolonged drought during grain filling (Girma and Korbu, 2012; Hillocks and Maruthi, 2012). Before the first crop is harvested, growing one crop and then planting another one in the same field helps with computation and extends the usage of the field (Debele Berhanu, 1985; Snapp *et al.*, 2005).

In this study, the experiment was carried out using a relay inter cropping system using wheat and grass pea crops. Wheat yields and grain protein content are lower and more variable in organic conditions than in conventional agriculture, mainly due to Nitrogen (N) deficiency and weed competition. The under sowing of legume cover crops in growing winter wheat, also known as relay intercropping, is assumed to be a proficient way of enriching the soil-crop system with Nitrogen and improving weed control *(Amossé et al., 2013)*.

Relay inter cropping systems have the advantages of being affordable and simple to grow without requiring much work. Grass pea offers a variety of distinctive qualities that appeal to both growers and customers. Which are: Withstanding adverse environmental circumstances including drought and high moisture, it can be grown with very little input. It enhanced food security in harsh environments, low input livestock feed and as a cover crop for soil conservation. In relay intercropping, wherein late-season crops are planted in rows whereas early-season crops are still growing (Gao *et al.*, 2014). Therefore, the ultimate goal of this study is in order to evaluate the effectiveness of grass pea relay inter cropping with wheat for better productivity and to evaluate its effect on soil moisture and soil fertility improvement.

Materials and Methods

Experimental Site Description: The study was conducted in main cropping season during 2019 and 2020 in Jama district, that lies 10^{o} 23'to10^{o}27'N latitudes and 39^{o}07' to 39^{o}24'E longitudes. The dominant soil type of the study districts Vertisols, the area is characterized by poor drainage or water logging, difficulty to work (Belete *et al.,* 2013). The area receives an average annual rainfall of 1012.0 mm of which 74.6% is received during the main rain season (June to September) and the highland plateau of Jama has a very cold temperature which ranges from 0 to 20^{o}c. The nature of its soil type is gray clay with high swelling and shrinking character. It is poorly drained when wet and cracking when dry. The land use is mostly cultivated field crops: wheat (*Triticum aestivum*), tef (*eragrostis tef*), and fabba bean (*Vicia faba*) in rotation, while the marginal lands along the roadsides and communal pasture lands purposely left for feed sources are the major grazing grounds (Lebay *et al.*, 2021).

Experimental Design: Nine field experiments were carried out, two grass pea planting time integrated with two wheat raw spacing and two drainage planting techniques. Each treatment was set up with randomized complete block design in three replications. The plot size was adjusted 4.8mx3m and the spacing between plot and replication is 1m by1.5m respectively. The land preparation and agronomic practices have been adopted the farmers practice of the study area.

The planting time of wheat was in the second week of July. After a month or at tillering stage of wheat (mid-August) grass pea was planted as inter cropping. The conventional planting time of grass pea was starting from September first week.

The locally recommended Nitrogen and Phosphorus fertilizers (69 $Kgha^{-1}$ Nitrogen and 46 $Kgha^{-1}$ Phosphorous) was applied in splithalf at planting and half at knee height. The agronomic results were analyzed statistically and tested using F-test to estimate the least significant difference at % level of significant.

Table 1. Experimental treatments

Treatments	Grass pea Planting time	Grass pea Planting practiceand wheat planting spacing
1	Tillering stage of wheat	Planting on furrows only (20cm)
2	Tillering stage of wheat	Planting on furrow and between row (30 cm)
3	Tillering stage of wheat	Planting between rows (30 cm)
4	Conventional planting time of grass pea	Planting on furrows only (20cm)
5	Conventional planting time of grass pea	Planting on furrow and between row (30 cm)
6	Conventional planting time of grass pea	Planting between rows (30 cm)
7		Sole cropping of wheat (20 cm)
8		Sole cropping of wheat (30 cm)
9		Sole cropping of grass pea

Soil Sampling Technique and Methods of Analysis: Soil moisture content was taken after the last grass pea planting time (in dry season); 15 day late after the rainfall. For soil moisture and bulk density, the sample was taken from the surface 0 up to 20 cm. For soil moisture analysis, soil data from 0-20cm was taken during wheatharvesting time (Funakawa *et al*., 2012). Then the soil moisture content was analyzed by the gravimetric method and soil bulk density (Blake, 1965), soil organic matter and soil pH also done by volumetric, wet digestion and water and Potassium chloride suspension method respectively in addition total Nitrogen and available Phosphorous was analyzed by Kjeldahl and Olsen procedure respectively (Walkley, 1934).

Methods of Agronomic Data Analysis: The agronomic data was analyzed statistically and tested using the F-test to estimate least significant difference at 5% level of significance. In addition land equivalent ratio also calculated based on in the following formula for both sole and inter cropping area coverage with the proportional yield productions (Yilmaz *et al*., 2008).

$$LER = \frac{\text{YG in mixed stand}}{\text{YG in pure stand}} + \frac{\text{YW in mixed stand}}{\text{YW in pure stand}}$$ LER=Land equivalent ratio (FAO 1976)

YG= Yield of grass pea and YW = Yield of wheat

Results

Effect of intercrops on crop yield and biomass production: In this trial, relay intercropping had no impact on wheat grain production, independent of the chance to grow a grass pea crop. Wheat biomass and yield did not significantly differ from one another in terms of production potential, however grass pea production potential varied according on the treatments (Table 1 and Table 2).

Table 2. Grain Yield (GY) and Biomass Weight (BWT) of grass pea and wheat in 2019

Treatments		Gy Wheat Kgha^{-1}	Bwt Wheat Kgha^{-1}	Gy Grass pea Kgha^{-1}	Bwt Grass pea Kgha^{-1}
Tillering stage of wheat	• Planting on furrows only (20cm)	2432a	6632a	602c	1818b
	• Planting on furrow and between row (30 cm)	2501a	6458a	1436bc	4747a
	• B/n rows (30 cm)	2218a	6250a	1331bc	3939ab
Conventional planting time of grass pea	• Planting on furrows only (20cm)	2254a	6562a	872bc	2449b
	• Planting on furrow and between row (30 cm)	2491a	6181a	1637b	5101a
	• Planting between rows (30 cm)	2501a	6944a	922bc	2424b
Sole cropping of wheat (20 cm)		3224a	7917a	-	-
Sole cropping of wheat (30 cm)		2266a	6181a	-	-
Sole cropping of grass pea		-	-	2625a	6086a
CV		21.1	17.3	36.90	31.45
LSD		ns	ns	884.0*	1717.2*

**= significant. ns= non-significant. a, b and c= level of similarity*

The second-year result also in lined with the previous yield and biomass of wheat and grass pea production. Since planting of grass pea at tillering stage of wheat with 30cm of wheat is more productive from the other treatments (Table 3).

Table 3. Grain Yield (GY) and Biomass Weight (BWT) of grass pea and wheat in 2020

Treatments		Gy Wheat $Kgha^{-1}$	Bwt Wheat $Kgha^{-1}$	Gy Grass pea $Kgha^{-1}$	Bwt Grasspea $Kgha^{-1}$
Tillering stage of wheat	• Planting on furrows only (20cm)	1667a	5595a	976.9ab	2803a
	• Planting on furrow and between row (30 cm)	1906a	6823a	1508.5a	3535a
	• B/n rows (30 cm)	1752a	7083a	1064.2ab	2210ab
Conventional planting time of grass pea	• Planting on furrows only (20cm)	1687a	5387a	369.1b	1193 b
	• Planting on furrow and between row (30 cm)	1805a	6042a	882.9ab	2247ab
	• Planting between rows (30 cm)	2005a	5469a	271.4b	1136b
Sole cropping of wheat (20 cm)		2014a	6518 a	-	-
Sole cropping of wheat (30 cm)		1545a	5208a	-	-
Sole cropping of grass pea		-	-	1524.8a	3580a
CV (%)		24.5	20.3	43.3	34.6
LSD(0.05)		772.402	2138.27	725.3	1469.98

Figure 1. Grass pea planting on furrow and row of wheat space

The above illustration depicts a wheat and grass pea crop covering the entire land. Even though the ground's surface was cracked from the dryness, the grass pea covers the entire plot, helping to reduce soil surface evaporation. The grass pea used to cover the land used to alleviate the surface cracking (Figure 1).

Table 4. Combined result over years

Treatments		Gy Wheat $Kgha^{-1}$	Bwt Wheat $Kgha^{-1}$	Gy Grasspea $Kgha^{-1}$	Bwt Grasspea $Kgha^{-1}$
Tillering stage of wheat	• Planting on furrows only (20cm)	2049ab	6114	790bc	2311cd
	• Planting on furrow and between row (30 cm)	2204ab	6641	1472ab	4141ab
	• B/n rows (30 cm)	1985ab	6667	1198bc	3074bcd
Conventional planting time of grass pea	• Planting on furrows only (20cm)	1971ab	5975	620c	1821d
	• Planting on furrow and between row (30 cm)	2148ab	6111	1260bc	3674abc
	• Planting between rows (30 cm)	2253ab	6207	597c	1780d
Sole cropping of wheat (20 cm)		2619 a	7217	-	-
Sole cropping of wheat (30 cm)		1905 b	5694	-	-
Sole cropping of grass pea		-	-	2075a	4833a
CV		16.5	14.8	31.2	23.9
LSD		618.3	ns	635.5	1316.02

Intercropping for Effective Utilization of Land Resource: Intercropping results in increased yields because environmental resources are utilized effectively. Combinations, especially cereal/legumes blends, can help with sustainable agriculture and effective land use.

An interpretation of this result would be that a total of 1.9 ha of sole cropping area would be required to produce the same yields as 1 ha of the intercropped system. This result was recorded from the treatment of tillering stage of wheat with planting on furrows and between row spacing of 30cm (Table 5).

Table 5. Land equivalent ratio (LER)

Treatments		LER
Tillering stage of wheat	Planting on furrows only (20cm)	1.2
	Planting on furrows and b/n row (30cm)	1.9
	Planting on rows (30cm spacing)	1.6
Conventional planting time of grass pea	planting on furrows only (20cm)	1.1
	Planting on furrow and b/n row (30 cm)	1.4
	Planting on rows (30cm spacing)	1.5
Sole cropping of wheat (20 cm)		1
Sole cropping of wheat (30 cm)		1

Impact of Intercropping on Soil Fertility and Conservation Status: The soil moisture content was obtained after the rainfall decreased in August since the first soil moisture sample was taken in September, the second in December, and the third in January, respectively. The findings revealed that while there was no significant variation between the first two samples, there was a difference during the final measuring period (Table 6). In case of soil health status, it could improve the soil productivity with improving soil moisture content and enhancing basic soil macro nutrients (Table 6, 7 and 8).

Table 6. Soil moisture content (SMC) and bulk density (BD) in 2019

Treatments		SMC% 07-02-2019	SMC% 11-03-2019	SMC% 10-04-2019	BD(g/cm3)
Tillering stageof wheat	• Planting on furrows only (20cm)	26.8	15.2	6.5ab	1.4
	• Planting on furrow and between row (30 cm)	24.3	15.9	7.2b	1.3
	• Planting between rows (30 cm)	22.4	14.8	5.1ab	1.29
Conventional planting time of grass pea	• Planting on furrows only (20cm)	28.0	16.2	6.8b	1.6
	• Planting on furrow and between row (30 cm)	25.0	17.8	3.5ab	1.28
	• Planting between rows (30 cm)	22.3	14.5	4.2ab	1.4
Sole cropping of wheat (20 cm)		23.7	19.4	2.5c	1.5
Sole cropping of wheat (30 cm)		26.2	18.1	2.9c	1.4
Sole cropping of grass pea		23.0	16.0	14.7a	1.3
Cv		15.5	15.53	14.28	9.77
LSD		ns	ns	3.5*	0.24*

The bulk density or soil compaction indicator of the results showed that the treatments differed significantly from one another. This showed that the principal crops should be spaced 30 cm apart from the row and furrow planted with grass peas (Table 6).

Table 7. Soil moisture content (SMC) and bulk density (BD) in 2020

Treatments		SMC% 05-01-2020	SMC% 10-04-2020	SMC% 20-05-2020	BD (g/cm3)
Tillering stage of wheat	• Planting on furrows only (20cm)	26.8	9.5	8.5	1.2ab
	• Planting on furrow and between row (30 cm)	26.2	10.4	8.7	1.1a
	• Planting between rows (30 cm)	25.5	9.8	7.6	1.1a
Conventional planting time of grass pea	• Planting on furrows only (20cm)	29.1	9.4	9.2	1.1a
	• Planting on furrow and between row (30 cm)	26.6	10.2	7.6	1.3ab
	• Planting between rows (30 cm)	27.3	8.9	8.1	1.3ab
Sole cropping of wheat (20 cm)		27.7	10.5	7.3	1.4b
Sole cropping of wheat (30 cm)		24.5	5.2	7.8	1.4ab
Sole cropping of grass pea		31.7	11.3	9.4	1.2ab
Cv		9.5	20.6	17.0	8.8
LSD		ns	ns	ns	*

Table 8. Soil chemical property status of the soil

Treatments		%OM	%Tot.N	Avi.P (ppm)	PH
Tillering stage of wheat	• Planting on furrows only (20 cm)	1.36[ab]	0.187	7.4ab	6.5
	• Planting on furrow and between row (30 cm)	1.43[ab]	0.163	9.0a	6.4
	• Planting between rows (30 cm)	1.30[ab]	0.150	7.2ab	6.4
Conventional planting time of grass pea	• Planting on furrows only (20cm)	1.41[ab]	0.187	6.7ab	6.4
	• Planting on furrow and between row (30 cm)	1.34[ab]	0.160	5.3b	6.2
	• Planting between rows (30 cm)	1.58[a]	0.150	7.1ab	6.5
Sole cropping of wheat (20 cm)		1.10[b]	0.173	6.6ab	6.4
Sole cropping of wheat (30 cm)		1.26[ab]	0.187	7.8ab	6.4
Sole cropping of grass pea		1.29[ab]	0.150	6.7ab	6.3
Cv (%)		19.26	14.02	15.05	1.77
LSD (0.05)		*	ns	*	ns

Discussion

Intercropping of cereal and pulse crops have been maximized the productivity potential of the land and increased the land use efficiency. While it does contribute to maximizing the efficiencies of the cultivated field, this sort of cropping system has little impact on the output potential (Amossé *et al.*, 2013). According to many authors, it makes an argument based on all of its implications. When main crop and inter crop have separate growing seasons such that their principal resource demands are met at different times, the yield advantage have be at its highest (Aziz *et al.*, 2015). The component crops in intercropping are concurrent throughout a sizable amount of their production cycle or growing period, even though they may not be planted or harvested at precisely the same time (Srivastava *et al.,* 2008). Contrary to single crop systems, intercropping systems often result in higher yields *(Lithourgidis et al.,* 2007).

Utilizing plant growth factors effectively is important for assessing the benefits of intercropping in sustainable agriculture to fulfill the growing demand for food caused by population growth. That is if LER >1 is used to indicate that intercropping is superior to solo crops in terms of light, water, and Nitrogen use (Corre-Hellou et al., 2009; Liu *et al.,* 2018). The intercrops' land equivalent ratios (LER) values ranged from 1.08 to 1.21 at both harvest stages (Hauggaard-Nielsen et al., 2006). According to some studies, different intercrops use plant growth elements up to 50% more effectively than a single crop (Hauggaard-Nielsen *et al., 2001)*. Under conditions of low Nitrogen fertilization, pea and barley intercropping also utilized environmental resources for plant growth more effectively than a single crop (Cowell, L. and Bremer, Eric and Kesel, 1989). Thus crops are similar in most characteristics of wheat and grass pea.

Because intercropping uses resources like light, water, and nutrients more effectively than a single crop, it generally results in higher yields (Mousavi and Eskandari, 2011). With the use of the Land Equivalent Ratio, it is possible to precisely evaluate the competitiveness of the intercropping system's component crops, effective land use, and total production (Maitra, 2019). A popular index used in intercropping is the land equivalent ratio, which is used to gauge the productivity of the land (Seran and Brintha, 2009). A land equivalent ratio larger than one indicates that the land is being used more effectively in an intercropping system. The benefits of cereal-legume intercropping were demonstrated by LER due to more effectively using resources in intercropping by increasing plant density (Osiru and Willey, 1972; Fisher, 1977).

Various literatures indicated that, if the land and furrow should be covered by the crop was possible to sustain the surrounding moisture (Shaxson, Barber and Food and Agriculture Organization of the United Nations, 2003). The main crop raised on the bed was grown well with substantial amount of yield could be harvested on the furrows without affecting the main crop on the bed (Kathuli and Itabari, 2014).

In Italy, cultivation of grass pea almost stopped but there is renewed interest in the crop to provide an efficient alternative to wheat on land degraded by excessive cereal cultivation (Grandgirard *et al.,* 2002).

Due to its very strong and deep-reaching root system, grass pea is tolerant to different soil pHs, and is capable of growing and developing on different soil types, which makes it unique among legumes (Campbell, 1997).

Conclusion and Recommendation

The influence of relay intercropping of what and grass pea on productivity and soil property status has been assessed. As a result, the time and planting technique of grass pea were taken into account in order to assess the effectiveness of grass pea relay intercropping with wheat for increased productivity as well as its impact on soil moisture and fertility. As a result, the findings indicate that planting grass pea alongside wheat did nothave a substantial impact on wheat production potential, but it did contribute to additional output in the specific parcel of land. Since grass pea planting during the wheat tillering stage is more effective in every way. Wheat planting, on the other hand, should be spaced 30 cm apart.

The covering of grass pea, which is employed for Nitrogen fixation and soil surface covering, has had an impact on the soil moisture and fertility status of the land. As a result, the grass pea furrow was covered, indicating a higher soil moisture content and fertility quality. While some qualities did not indicate a significant difference, the majority of soil chemical and physical parameters show a greater differential improvement in the covering of the land's bed and furrow.

To increase output potential and soil fertility, farmers should be instructed to employ release intercropping on vertisoil with grass pea planting at the tillering stage of wheat. The cropping technique also should be prepared the broad bed and furrow based on its recommendation and sowing of wheat at 30 cm spacing. The grass pea should be sowing with in the wheat row and entire the furrow. Cropping techniques should also include preparing the broad bed and furrow according to the manufacturer's recommendations, as well as sowing wheat at 30 cm spacing. In the wheat row and throughout the furrow, the grass pea should be sown.

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