Amhara Regional Agricultural Research Institute (ARARI)

Proceedings of the 11th Annual Regional Conference on Completed Research Activities on Soil and Water Management, April 30 –May 05, 2018, Bahir Dar, Ethiopia

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Comparative evaluation and validation of soil fertility map based fertilizer recommendation for bread wheat and food barley

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Abstract

Site-specific fertilizer rate recommendation is mainly projected for N and P in Ethiopia. In recent times, the Ministry of Agriculture and Natural Resources (MoANR) in coordination with the Agricultural Transformation Agency (ATA) recommended eight new fertilizer types for Amhara National Regional State (ANRS). As a result, in the region, seven soil nutrients (N, P, K, S, Zn, B, and Cu) are found to be deficient in the developed soil fertility map. However, the comparative advantages of recommended fertilizer types were not examined and understood under various production environments. Then this trial was conducted to validate the response of wheat and barley to soil fertility map based on various balanced fertilizer recommendations under Debark district. Four and six fertilizer formulations on barley (recommended NP, NPSB, NPSZnB and modified NPSZnB) and wheat respectively (recommended NP, NPSB, NPSZnB, modified NPSZnB, NPKSZnB, and modified NPKSZnB) were used for validation of soil fertility map based fertilizer recommendation at Debark district. The result of this experiment revealed that addition of S, K, Zn and B to wheat; and addition of S, Zn and B to barley did not show significant difference in above-ground biomass and grain yield over the application of recommended NP alone. Hence, application of additional plant nutrients (K, Zn and B) besides the current fertilizer recommendations (NP) for wheat and barley is not recommended in the study areas and similar agroecologies.

Keywords: Boron, Nitrogen, Phosphorus, Potassium, Sulfur, Zinc

Introduction

The need for site-specific NP fertilizer recommendations is familiar in Ethiopia; however, fertilizer trials involving multi-nutrient blends that include micronutrients are rare. The Ministry of Agriculture and Natural Resources (MoANR) in coordination with the Agricultural Transformation Agency (ATA) launched a new national fertilizer blending program on February 12, 2013. It aims to popularize new high-yield blended fertilizers and to create Ethiopia's first in-country blended fertilizer production facilities (Ethio SIS, 2014). Accordingly, ATA and MoANR (2016) have been developed eight fertilizer types: NPS, NPSB, NPSZn, NPSZnB, NPSBCu, NPSZnBCu, Muriate of Potash (MoP) and urea to solve site-specific nutrient deficiencies of nitrogen, phosphorus, potassium, sulfur, zinc, boron and copper in the Amhara National Regional State (ANRS).

In the past field experimentations, nitrogen is deficient in almost all soils and phosphorus is also deficient in about 70% of the Ethiopia soils (Tekalign *et al*., 2001). These low availabilities of nitrogen and phosphorus have been demonstrated to be a major constraint to cereal production. This is due to soil erosion, continuous crop cultivation without fallow, unbalanced nutrient supply during crop cultivation, low organic matter and absence of nutrient recycling. On the other hand, most of the area used for grain production, especially tef, wheat and barley fall under the low fertility soils (Hailu *et al*., 2015). Although there is a general perception that the new fertilizer blends provide better crop production than the traditional fertilizer recommendations (urea and DAP), their comparative advantages are not yet clearly examined and understood under various production environments.

Then, soil fertility research teams drawn from Ethiopian Institute of Agricultural Research, Amhara Regional Agricultural Research Institute (ARARI), Oromia Regional Agricultural Research Institute (ORARI), Tigray Regional Agricultural Research Institute (TRARI) and Southern Regional Agricultural Research Institute (SARI)were designed experiments to validate blended fertilizer formulas that were recommended based on soil fertility maps. The validation of new recommended blended fertilizer types by field experiments on the response of different crops therefore, avoids unnecessary use of fertilizers by smallholder farmers or confirm the recommendations by Ministry of Agriculture and Natural Resources (MoANR) in coordination with the Agricultural Transformation Agency (ATA)

Objectives

- ✓ To validate the response of wheat and barley to different soil fertility map based blended fertilizer recommendations under Debark district
- ✓ To quantify their comparative advantage over the traditional fertilizer recommendation

Materials and methods

This study was conducted on farmers' fields for two consecutive years (2015 and 2016) at Debark woreda; 5 sites for wheat (Digalu variety) and 5 sites for barley (HB1307 variety) in each year. The selected physico-chemical properties of soil of the experimental sites in 20 cm depth indicated that textural classes are dominated by loam and clay loam. The soil pH of the experimental sites ranged 5.58-5.74, which is moderately acidic (Hazelton and Murphy, 2016). The range of organic carbon percentage is 1.43-2.53, percentage of total nitrogen is 0.21-0.28, available (olsen) P is ranged 14.37-56.24 ppm, and Cation Exchange Capacity (CEC) is ranged 35.82-45.30 cmol (+) kg^{-1} of soil.

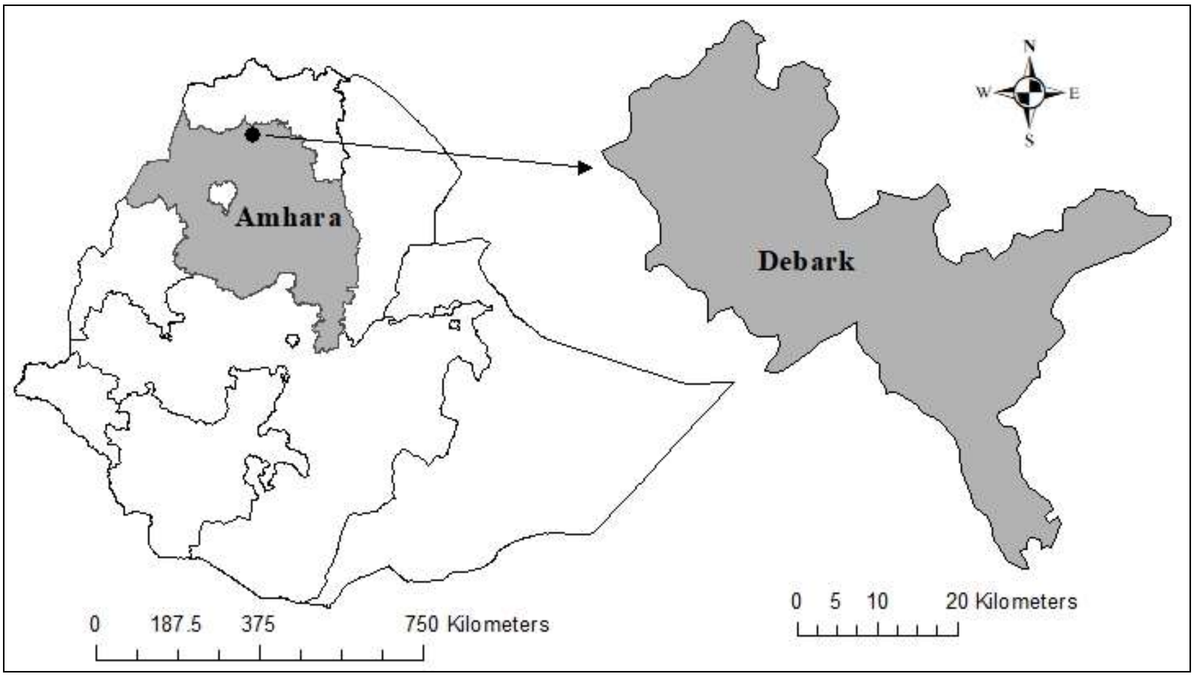

Figure 1: Location map of Debark district

The area was received an annual rainfall of 1152.63 mm, a minimum temperature of 16.01° C and a maximum temperature of 28.64° C during the year 2015. It was also received an annual rainfall of 1814.2 mm, a minimum temperature of 15.34° C and a maximum temperature of

27.54° C in 2016. The area received the highest rainfall in August 2015 (416.81 mm) and July 2016 (656.31 mm) cropping seasons (Figure 2).

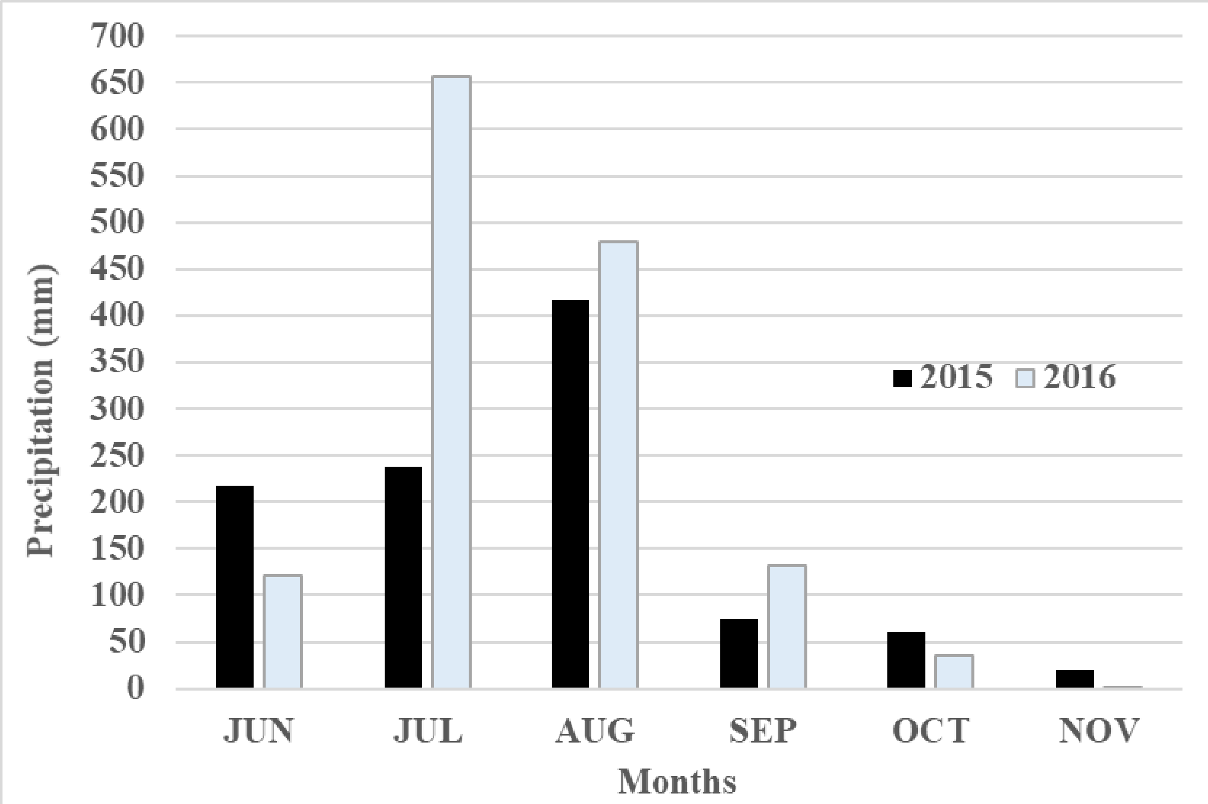

Figure 2. Rainfall in 2014 and 2015 cropping season at Debark district (Source: https://power.larc.nasa.gov)

Based on the soil information data of EthioSIS (2014), critical values for each limiting nutrients identified were compared among each other and against the blanket recommended N and P from DAP and Urea fertilizers. Blended fertilizers and DAP were basal applied at planting for wheat and barley. Urea was top-dressed 30 to 45 days after planting. The test crops were planted in rows. The plot size was 4m*3m for both barley and wheat. It was planted with 20 cm between rows. The seed rate was 125 kg/ha and 100 kg/ha for wheat and barley respectively.The other crop management practices were applied as per the recommendation for each crop. The detailed treatment set-up for each location and crop type is indicated in Table 1 and 2.

Table 1. Fertlilizer formulations tested on food barley

Treatments for barley	N	P_2O_5	K	S	Zn	B
T1= Recommended NP (50 kg/ha Urea + 100 kg/ha DAP)	41	46	0	0	0	0
T2= Formula 2: 100 kg/ha + 50 kg/ha urea top dressed	41	36	0	6.7	0	0.71
T3= Formula 4: 100 kg/ha + 50 kg/ha urea top dressed	41	34	0	6.3	2.23	0.67
T4= formula 4 modified: 150 kg /ha + 35 kg/ha urea top dressed	42	51	0	10.95	3.36	1.01

Table 2. Fertilizer formulations tested on bread wheat.

Treatments for wheat	N	P_2O_5	K	S	Zn	B
T1= Recommended NP (140 kg/ha Urea + 150 kg/ha DAP)	91	69	0	0	0	0
T2= Formula 2: 150 kg/ha + 140 kg/ha urea top dressed	92	54	0	10.1	0	1.07
T3= Formula 4: 150 kg/ha + 150 kg/ha urea top dressed	94	51	0	11	3.35	1.01
T4 =formula 4 modified: 200 kg/ha + 124 kg /ha urea top dressed	92	70	0	15.2	4.46	0.5
T5 = formula 5: 150 kg/ ha + 156 kg/ha urea top dressed	91	39	21	8.4	2.58	0.77
T6 = Formula 5 modified: 250 kg/ha + 128 kg /ha urea top dressed	90	65	37	14	4.3	0.63

Results and Discussion

Both food barley and bread wheat crops were grown well in the area as shown in figure 3, but there is no treatment difference across the study sites in both growing seasons. But, the productivity of the crops was highly varied on the experimental sites.

Figure 3: Pictures for barley and wheat trials at early and maturity stages

The second year crop performance was better than the first year in most locations. Growing seasons and experimental sites did not change the response of those crops to fertilizer formulations. Above-ground biomass and grain yield of bread wheat and food barley were none significantly responded to fertilizer formulations or treatments (Table 3). The result showed that the application of recommended NP compared to the additional nutrients such as S, K, Zn and B did not show significant difference in the above-ground biomass and grain yield of bread wheat; likewise, application of recommended NP fertilizer compared to addition of S, Zn and B did not show significant difference in the above-ground biomass and grain yield of barley.

As a result, it is possible to prove that there is no need to apply new plant nutrients (K, S, B and Zn) other than nitrogen and phosphorus for both crops in the district. Similar findings by Tadele *et al.* (2018) reported that the addition of fertilizers including potassium, zinc and boron under different districts for maize, wheat and tef did not show any significant yield advantage over NPS alone. Hence from this finding, it can be justified that the recommendations made by MOA in collaboration with ATA might not be feasible and an aproparaite site specific NP nutrient recommendations has to be strengthend.

Table 3. Effect of different fertilizer formulations on yield of barley and wheat at Debark

Types of fertilizer applied	BW(kg/ha)	GY(kg/ha)	Types of fertilizer applied	BW(kg/ha)	GY(kg/ha)
Wheat			Barley		
T1=Recommended NP	11087	4812	T1=Recommended NP	9661	4383
T2= NPSB	11381	4857	T2= NPSB	10424	4755
T3= NPSZnB	11656	5049	T3= NPSZnB	10625	4852
T4= Modified NPSZnB	12179	5333	T4= Modified NPSZnB	10474	4812
T5= NPKSZnB	10836	4679			
T6= Modified NPKSZnB	10214	4487			
LSD (0.05)	NS	NS		NS	NS
CV (%)	14.3	14.6		23.9	19.7
Location	**	**		**	**
Year	NS	**		**	**
Fertilizer*Location	NS	NS		NS	NS
Fertilizer*Year	NS	NS		NS	NS

*BW; above-ground biomass , GY; grain yield **= Significant at 0.01 and NS=Not Significantly Different at 0.05.*

The present result proved that the importance of each new blended fertilizer to increase the yield of wheat and barley was insignificant as compared to the two major nutrients (N and P) in the district (Table 3). The present finding was harmony with the study of fertilizer rate determination on late-maturing local food barley cultivar, which is evaluated at Wogera in the highlands of North Gondar. According to this result, the most profitable fertilizer rates for food barley production were 69 kg ha^{-1} N and 20 kg ha^{-1} P (Mulatu and Grando, 2011).

Conclusion and Recommendation

This study disproved that the general perception suggesting new blend fertilizers may provide better wheat and barley grain and biomass yield than the traditional fertilizer recommendations (urea and DAP) at Debark and similar agro-ecologies and soil types. At Debark and similar environments, the application of various blend fertilizers that included sulfur, potassium, boron and zinc did not showed significant yield and biomass advantage as compared to recommended NP fertilizer. Therefore, it is recommended that the application of NP fertilizers will be beneficial until further studies in the future provide evidence-based wheat and barley yield advantage as compared to recommended NP fertilizers.

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Evaluation of blended fertilizers and validation of soil fertility map-based fertilizer recommendations in Jamma and Werreillu Districts of South Wollo Zone, Amhara Region

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Abstract

Recently acquired soil inventory data from EthioSIS indicated multi-nutrient deficiencies including nitrogen (N), phosphorus (P), sulfur (S), potassium (K), boron (B) and zinc (Zn) in most Ethiopian cultivated soils. Thus, a field study was conducted in Jamma and Wereillu districts in 2014 and 2015 to evaluate the comparative advantage of the recommended blended fertilizers for the districts over the recommended NP fertilizers and validate the soil fertility map-based fertilizer recommendations. The study comprised five blended fertilizer formulations (F): F1: NPS (100 kg ha^{-1}), F2: NPSB (100 kg ha^{-1}), F4: NPSBZn (100 kg ha^{-1}), F6: modified F4 (150 kg ha^{-1}), F7: modified F5 (NPKSZnB) (150 kg ha^{-1}) and the recommended NP fertilizers (69/46 kg ha^{-1} N/P_2O_5). Nitrogen was applied as urea in split; half at planting and half at tillering. In the first year, K, S and P were applied all at basal as muriete of potash (KCl), calcium sulfate (CaSO4) and triple superphosphate (TSP), respectively, while, Zn ($ZnSO_4$) and B (Borax) were sprayed as foliar application at 45 and 60 days after planting, respectively. While, in the second year, all fertilizers were band applied at basal as blended fertilizer except N and K, which were applied as urea and KCl forms, respectively. The results indicated that there was no significant ($p>0.05$) yield difference due to the application of the blended fertilizers over the recommended NP fertilizers in both districts and in both years. However, there were some limitations in the study; 1. The rates of K and S fertilizers (21 kg K_2O ha^{-1} and 14 kg S ha^{-1}) used in the study were too low to meet wheat requirements, 2. Zinc and B application methods followed in the study might lead to low nutrient recovery efficiency and subsequently insignificant effect of the nutrients on the yield. Therefore, further comprehensive study with adequate rates of K and S, with the right application method for the micronutrients and with soil analysis and plant nutrient uptake data should be done.

Keywords*:* blend, formulation, uptake, validation, yield

Introduction

The use of chemical fertilizers, particularly nitrogen (N) and phosphorus (P), in Ethiopia has made a contribution to crop yield growth to date (Asnakew *et. al.*, 1991; Tekalign *et. al.,* 2001) although there is a potential for further improvement. Nitrogen (N) and phosphorus (P) based location-specific fertilizer recommendation (69/46 N/P_2O_5 kg ha^{-1}) for wheat crop was made so far for Jamma and Wereillu districts of South Wollo Zone of Amhara Region (Yared *et. al.,* 2003 unpublished). However, recently acquired soil inventory data from EthioSIS (Ethiopian Soil Information System) revealed that sulfur (S), potassium (K), born (B) and zinc (Zn) deficiencies are widespread in the country which all potentially limit crop productivity despite the continued use of high analysis N and P fertilizers (EthiosSIS, 2014). Different research findings also showed that nutrients like K, S, calcium (Ca), magnesium (Mg) and all micro-nutrients except iron (Fe) are becoming depleted and deficiency symptoms are observed on major crops grown in different areas of the country (Wassie and Shiferaw, 2011; Asgelil *et al.,* 2009; Abyie *et. al.,* 2003).

Based to the EthioSIS soil fertility maps for Jamma and Wreillu districts, in addition to N and P, S, Zn and B are deficient in major areas of the districts and K is deficient in some pocket areas of the districts (Figure 1 and 2). Accordingly, EthioSIS has made site-specific blended fertilizer recommendations which is Kebele-based balanced-nutrient recommendations. Six fertilizer blends have been recommended in the country that when targeted to deficient soils can dramatically improve fertilizer-use efficiency and crop profitability. Hence, NPSB and NPSZnB blended fertilizers were recommended for the entire area of the two study districts except for some pocket areas where NPKSB and NPKSZnB blends were recommended (Figure 1 and 2).

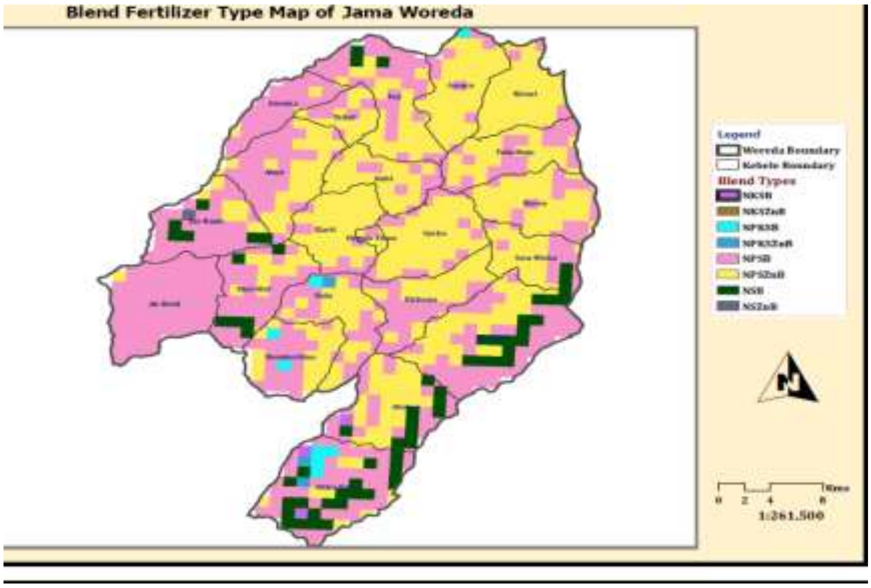

Figure 1: Recommended fertilizer blend types for Jamma district

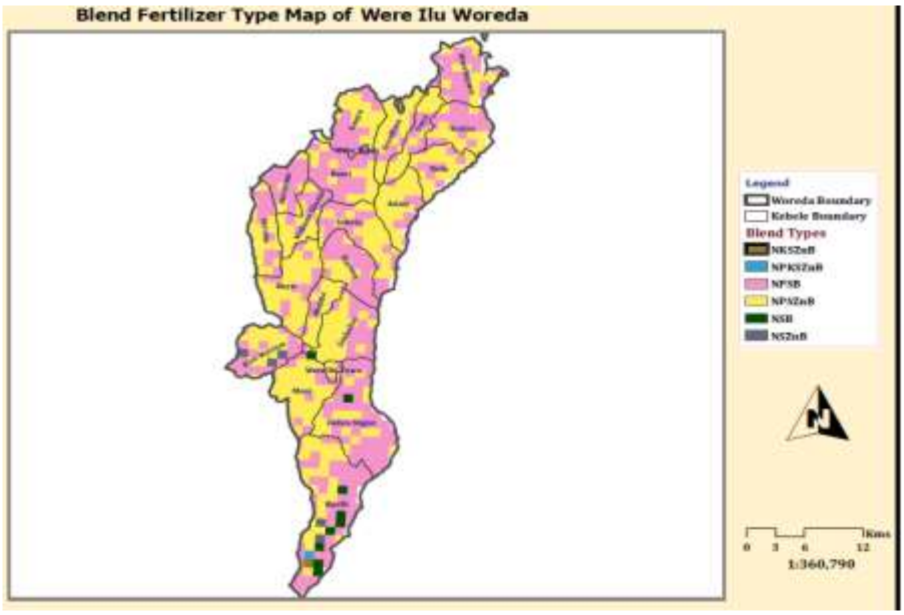

Figure 2. Recommended fertilizer blend types for Wereillu district

However, the new fertilizer blends have not been explicitly examined and understood under various production environments and nutrient response studies involving multi-nutrient blends that include micronutrients were rare in the present study areas. This research was therefore initiated to evaluate the comparative advantage of the recommended blended fertilizers for the two study districts over the recommended NP fertilizers and validate the new soil fertility map-based fertilizer recommendations made by EthioSIS (EthioSIS, 2014).

Materials and methods

Study site description

The study was carried out in 2014 and 2015 main cropping seasons in Jamma and Wereillu Districts of South Wollo Zone of Amhara Region. Jamma district is situated within the geographical boundaries of 10^o 06' 24'' - 10^{o}35' 45'' N latitudes and 39^{o}04' 04'' - 39^{o}23' 03'' E longitudes and altitudinal ranges of 1428 - 2752 meters above sea level. It receives a mean annual rainfall of 1130 mm, while the mean minimum and maximum temperatures of the district are 9 and 21 ^{o}C, respectively. Wereillu district is located within the geographical coordinates of 10^{o}50' N - 10^{o}33' N latitudes and 39^{o}10'E - 39^{o}16'E longitudes and with altitudinal ranges of 1700 to 3200 m.a.s.l. The dominant soil type in both Districts is Pellic Vertisols with physico-chemical characteristics as described in Table 1 and the cropping lands of the districts are characterized by poor drainage and intense water-logging (Getachew, 1991).

Table 1. Range of physico-chemical properties of surface soil (0-30 cm) of the study sites

Soil Properties	Values	Rating*
pH (H_2O)	6.5-6.8	Slightly acidic to neutral
Organic matter (OM) (%)	1.36-1.75	Low
Total N (TN) (%)	0.10-0.11	Low
Available P (mg kg^{-1} soil)	3.08-5.20	Low
Exchangeable Ca (cmol$_C$ kg^{-1})	30.6-46.3	Very high
Exchangeable Mg (cmol$_C$ kg^{-1})	9.9-12.9	Very high
Exchangeable K (cmol$_C$ kg^{-1})	0.6-0.7	High
Cation exchange capacity (CEC) (cmol$_C$ kg^{-1})	52.0-61.7	Very high
Percent acid saturation (PAS) %	82.5-97.6	Very weakly leached
Sand %	16.3-17.5	
Silt %	20.0-21.3	
Clay %	62.5	
Textural class	Clayey	

***Source**: Abebe et. al,. 2013. *Ratings are based on pH (Jones, 2003), OM and TN (Tekalign, 1991), Available P (Cottenie,1980), Exchangeable Ca, Mg and K (FAO, 2006), CEC and PAS (Hazelton, Murphy, 2007)*

Experimental procedures

Table 2 below shows the description and formulations used to prepare each blended fertilizer formulas. Six treatments composed of five different blended fertilizers and the recommended NP fertilizer were used in the study (Table 3).

Table 2. Blended fertilizer descriptions, formulations and their source

Formula	Blended fertilizer formulations	Source of each nutrient for blending
1:NPS	19 N + 38 P_2O_5 + 0.0 k_2O + 7 S + 0.0 Zn + 0.0 B	19 kg N + 38 kg P_2O_5 +7 kg S
2:NPSB	18. 1 N + 36.1 P_2O_5 + 6.7 S + 0.71 B	95 kg NPS + 4.9 kg Borax
3:NPSKB	13.7 N + 27.4 P_2O_5 + 14.4 k_2O + 5.1 S + 0.54 B	72.2 kg NPS + 24.1 kg KCl + 3.7 kg Borax
4:NPSZnB	16.9 N + 33.8 P_2O_5 + 7.3 S + 2.23 Zn + 0.67 B	86 kg NPS + 6.4 kg ZnSO4 + 4.6 Kg Borax
5:NPKSZnB	13.0 N + 26.1 P_2O_5 + 13.7 K_2O + 5.6 S+ 1.72 Zn + 0.51 B	68.7 kg NPS + 22.9 kg KCl + 4.9 kg ZnSO4 + 3.56 kg Borax
6:FORMULA 4 MODIFIED	17.5 N + 34.9 P_2O_5 + 0.0 k_2O + 7.6 S + 2.23 Zn + 0.25 B	+1.22 kg Borax
7:FORMULA 5 MODIFIED	13 N + 26.1 P_2O_5 + 14.8 k_2O + 5.6 S + 1.72 Zn + 0.25 B	68.7 kg NPS + 24.7 kg KCl + 4.9 kg ZnSO4 + 1.75 kg Borax

Table 3. Treatments used at both Jamma and Wereillu Districts

Treatments	N	P_2O_5	K_2O	S	Zn	B
T1= Rec. NP (111 kg ha^{-1} urea + 100 kg ha^{-1} DAP)	69	46	0	0	0	0
T2= 100 kg ha^{-1} F1 + 109 kg ha^{-1} urea top dressed	69	38	0	7	0	0
T3= 100 kg ha^{-1} F2 + 111 kg/ha urea top dressed	69	36	0	6.7	0	0.71
T4= 100 kg ha^{-1} F4 + 115 kg/ha urea top dressed	69	34	0	7.3	2.23	0.67
T5= 150 kg ha^{-1} F6 + 109 kg/ha urea top dressed	69	52	0	11.4	3.34	0.38
T6= 150 kg ha^{-1} F7 + 108 kg/ha urea top dressed	69	39	21	7.5	2.23	0.38

Five representative farmers' fields in each district were randomly selected for the study. The farmers' fields were divided into six experimental plots each of which had an area of 4.8 m x 4.0 m. Four raised beds with a width of 0.80 m and length of 4.00 m and furrow width of 0.40 m, as shown in Fig 3 below, were prepared in each plot to drain excess water, as the soil type of the sites is Vertisols with heavy clay texture. The treatments were randomly assigned to the six experimental plots in a randomized complete block design (RCBD) using the five farmers' fields as replications.

Figure 3. Raised bed preparation to drain excess water and reduce waterlogging problem

Planting and fertilizer applications

Bread wheat, improved variety - *Dinknesh,* was planted in rows with 20 cm spacing and seed rate of 150 kg ha^{-1} on the raised beds. In the first experimental year, P and S fertilizers were applied at basal by drilling as triple superphosphate (TSP) and calcium sulfate ($CaSO_4$), respectively. Potassium was applied as muriate of potash (KCl) in a row 5 cm away from the seeding rows to avoid possible solute-stress effect during germination, while N was applied as urea in split, half at planting and half side dressed 45 days after planting. Zinc sulfate ($ZnSO_4$) and borax, which were used as a source of Zn and B, respectively, were dissolved in water separately and sprayed as foliar application at 45 and 60 days after planting, respectively (Figure 4). In the second experimental year, different formulas of blended fertilizers containing N, P, S, Zn and B were used and K was applied as a straight fertilizer in KCl form. The blended fertilizer and KCl were applied all at planting, while, N was applied in split at half planting and half side-dressed 45 days after planting.

Figure 4. Foliar applications of Zn and B micronutrients in the first experimental year

Data collection and statistical analysis

Grain yield was measured at maturity from the innermost 2 rows in the four raised beds in each plot and was adjusted to a moisture content of 12.5%. Fresh biomass weight was measured by weighing the fresh total above-ground biomass of the harvested rows. The dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105^oC for 12 hours and adjusting the fresh biomass weight on to dry basis by using the moisture content measured after drying.

All recorded relevant agronomic data were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS Institute, 2004). The LSD method at 5% probability level was used to separate the significant treatment mean differences.

Results and Discussion

Effect of blended fertilizers on the yields of wheat

There was no statistically significant (P>0.05) influence of the blended fertilizers both on the grain and dry biomass yields of wheat as compared to the recommended NP fertilizers in both experimental years and at both districts (Table 4 and 5). Application of S, Zn, B and K fertilizers were not found to significantly affect the yield of wheat as compared to the recommended NP fertilizers. At Jamma district, the maximum grain (2.7 t ha^{-1}) and dry biomass (7.5 t ha^{-1}) yields in 2014 were obtained from F6 (Modified NPSBZn) but with insignificant difference with the recommended NP and other treatments. While, in 2015, the maximum grain (3.4 t ha^{-1}) and dry biomass (10.6 t ha^{-1}) yields were recorded from F7 (modified NPSBZnK) treatment and F6 (Modified NPSBZn), respectively with non-significant difference from the yields recorded from recommended NP treatment (Table 4).

Table 4. Effect of the blended and recommended NP on the grain and dry biomass yields (kg ha^{-1}) of wheat at Jamma district

Treatment/Formula*	2014		2015		Combined	
	Grain Yield	Dry Biomass	Grain Yield	Dry biomass	Grain yield	Dry biomass
Rec. NP	2583.8	7250.0	3082.1	9570.3	2774.6	8281.3^{ab}
F1: NPS	2371.3	6625.0	3017.2	8945.3	2632.2	7656.3^{b}
F2: NPSB	2316.6	6562.5	3342.3	9453.1	2806.6	7847.2^{b}
F4: NPSBZn	2358.4	6718.8	3299.7	9531.3	2798.3	7968.8^{b}
F6: Modified NPSBZn	2734.2	7531.3	3387.1	10625.0	2982.5	8906.3^{a}
F7: Modified NPSBZnK	2612.8	7281.3	3473.1	9687.5	2974.5	8350.7^{ab}
LSD (5%)	Ns	Ns	Ns	Ns	Ns	700.4
CV (%)	8.7	8.3	11.5	9.9	10.6	9.0
Treatment*Year	-	-	-	-	Ns	Ns

Means within a column followed by the same letter are not significantly different at p = 0.05; **Ns - non significant at p = 0.05.*

At Wereillu district, in 2014, the maximum grain (2.7 t ha^{-1}) and dry biomass (7.6 t ha^{-1}) yields were recorded from F6 (modified NPSBZn) statistically at par with the recommended NP fertilizers. While, in 2015, the maximum grain (2.1 t ha^{-1}) and dry biomass (7.7 t ha^{-1}) yields were obtained from F4 (NPSBZn) and recommended NP, respectively (Table 5).

Table 5. Effect of the blended and recommended N and P on the grain and dry biomass yields (kg ha^{-1}) of wheat at Wereillu district

Treatment/Formula*	2014		2015		Combined	
	Grain Yield	Dry biomass	Grain Yield	Dry biomass	Grain Yield	Dry Biomass
Rec. NP	2320.4^{c}	6687.5	2059.6	7734.4	2204.5	7152.8
F1: NPS	2559.4^{ab}	7093.8	2130.2	7656.3	2368.7	7343.8
F2: NPSB	2523.1^{abc}	7406.3	1801.3	6679.7	2202.3	7083.3
F4: NPSBZn	2415.4^{bc}	7000.0	2130.5	7187.5	2308.6	7083.3
F6: Modified NPSBZn	2737.6^{a}	7656.3	1751.4	7695.3	2299.3	7673.6
F7: Modified NPSBZnK	2565.8^{ab}	7468.8	2043.3	7656.3	2333.6	7552.1
LSD (5%)	237.1	Ns	Ns	Ns	Ns	Ns
CV (%)	7.1	8.8	11.0	9.0	9.9	9.3
Treatment*Year	-	-	-	-	Ns	Ns

Means within a column followed by the same letter are not significantly different at p = 0.05. **Ns - non significant at p = 0.05.*

However, in contrast to the results from this study, different studies indicated Zn deficiency in the central highland Vertisols of Ethiopia (Amsal *et. al.*, 2000; Asgelil *et. al.*, 2007; Hailu *et. al.*, 2015). Though the present study showed insignificant yield response to the application of Zn and B, Abera and Kebede (2013) reported deficiency of Zn in 98% of the soil samples collected from central highland Vertisols of Ethiopia. A finding by Bereket *et. al.* (2011) also indicated Zn deficiency on Ethiopian Vertisols. In contrary to this finding, Fayera *et. al.* (2014) carried out a study on tef crop on clay loam soil of Didessa District, Southwestern Ethiopia and revealed that application of blended fertilizer at a rate of 200 kg ha^{-1} of Zn + B blended (14N $21P_2O_5$ $15K_2O$ 6.5S 1.3Zn 0.5B) + 23 kg N ha^{-1} gave a statistically significant and higher yield than the recommended NP fertilizer. Moreover, Graham and Welch (1995) reported that Zn deficiency is one major micronutrient deficiency in humans particularly in developing countries where cereals contain very low levels of Zn are the primary staple foods for human consumption.

According to Ranjbar and Bahmaniar (2007), soil or foliar applications of Zn fertilizer alone were not found as effective as soil + foliar applications to increase yield. Thus, the insignificant yield response of wheat to Zn and B micro-nutrients in the present study might be attributed to the low recovery efficiencies of Zn and B fertilizers applied. In the first year, Zn and B fertilizer were applied on foliage, while in the second year they were applied at basal with the blended fertilizer. It could have been effective if the fertilizers were applied as basal + foliar application in both experimental years as this is supported by Ranjbar and Bahmaniar (2007).

Concerning S, in contrast to the finding in this study, available sulfur (SO_4^{2-}-S) in the Vertisols of the central highlands of Ethiopia ranged from 1.2 to 2.1 mg $kg^{-1}$and it was found to be deficient assuming 5 mg kg^{-1} S as critical level (Hailu *et. al.*, 2015). In line with this, a study conducted at six sites in Arsi, East Shewa and Oromia *Liyuu* zones indicated that about 50% of the studied fields showed highly significant response and 22% showed marginal-response to S (Assefa, 2016). Habitegebriel and Singh (2009) conducted research on Cambisols and Andosols and also indicated that the application of S fertilizer along with N fertilizer significantly increased the yield and nitrogen use efficiency (NUE) of bread wheat. The insignificant ($P>0.05$) yield response to S in the present study districts might be due to the optimum level of available S (SO_4^{2-}-S) in the surface soil or due to the low level of S used in the study which might be insufficient to meet the crop's S requirement.

The insignificant yield response to K in the present study might be attributed to the K-fixing characteristics of the pellic Vertisols in the study districts due to the expanding nature of the minerals that make up these soils (Getachew, 1991; Abunyewa *et. al.*, 2004). The other reason might be accounted for the low level of K (21 kg K_2O ha^{-1}) used in the study, which might not be sufficient to satisfy the K hunger of the soil let alone to be available for the crop. This is supported by Hagos *et. al.* (2017) who concluded that the level of K in the blended fertilizers was not sufficient to meet the yield requirement of wheat. Application of K did not receive due attention, as most Ethiopian soils were believed to be adequate in native supply. However, according to Stoorvogel and Smaling (1990) and Scoones and Toulmin (1999), the neglect of K application in Ethiopia and the continuous crop removal from the soil without additions has resulted in continuous depletion and negative balance (-26 to -33.2 kg K ha^{-1} $year^{-1}$) of the nutrient reserve. Moreover, the K: Mg ion ratio, 0.05 to 0.06, in the present study sites was in the range leading to Mg-induced K deficiency according to the rating by Loide (2004). Thus, a sufficiently higher dose of K than the rate used in the present study should have been tested on Vertisols with a high tendency of K-fixation. This is supported by Astatke *et. al.,* (2004) who conducted a study in the highland Vertisols of central Ethiopia and revealed that application of potassium sulfate resulted in about 1 t $ha^{-1}$of wheat yield advantage compared to untreated plots. Hailu *et. al.* (2017) also revealed the yield response of wheat to K and P fertilization in the central highland Vertisols of Ethiopia. In agreement with the result in this study, a study in the Sinana District of Bale Zone of Oromiya Region by Mulugeta *et. al.,* (2018) revealed that wheat yield response to K fertilizer was not significant.

Conclusion and Recommendation

The result revealed that the use of blended fertilizers with micro and macro-nutrients did no provide a significant yield difference over the recommended NP fertilizers. However, there were some limitations in this study; 1. The rates of K and S fertilizers (21 kg K_2O ha^{-1} and 14 kg S ha^{-1}) used in the study were too low to meet wheat nutrient requirements. Besides, the insignificant effect of Zn and B on the yield of wheat might be attributable to the low recovery efficiency of these nutrients. Therefore, further comprehensive study with sufficient rates K and S, with the right application method of micro-nutrients and with the support of soil analysis and plant nutrient uptake data should be done.

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Refining Fertilizer Rate Recommendation for Teff (*Eragrotis tef (Zucc.) Trotter*) in Different Agro-Ecological Zones of Ethiopia: the case for Jamma District, South Wollo Zone, Amhara Region

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Abstract

A field study was conducted for two years to determine the yield response of tef to application of nitrogen (N), phosphorous (P) and sulfur (S) fertilizers under balanced fertilization. The study comprised of three separate studies: 1. Seven levels of N (0, 23, 46, 69, 92, 115, 138 kg ha^{-1}), 2. Six levels of P (0, 23, 46, 69, 92, 115 kg P_2O_5 ha^{-1}) and 3. Six levels of S (0, 10, 20, 30, 40, 50 kg ha^{-1}). One negative (-Ve;0,0,0 kg ha^{-1}, N, P and S) and one positive (+Ve) control treatments (recommended NP i.e 69/46 N/P_2O_5 kg ha^{-1}) were included in all studies. Balanced nutrients of 69/80/30/2/1 P_2O_5/K_2O/S/Zn/B for N; 92/90/30/2/1 N/K_2O/S/Zn/B for P; and 92/69/90/2/1 N/P_2O_5/K_2O/Zn/B for S response studies were applied to all treatments except to the –Ve and +Ve control treatments. The treatments were laid in a randomized complete block design with three replications. Each study was conducted on three representative farmers' fields. The result revealed that there was a significant ($P \leq 0.01$) yield response to the application of N fertilizer. A quadratic response curve (R^2=0.988) was found the best fitting curve to explain the relationship between the grain yield and the N levels applied. The yield response curve showed that the grain yield increased significantly up to 92 kg N ha^{-1} and declined beyond this rate. Tef yield response study to P fertilizer showed a significant response to P at 50% of the testing sites. Although there was a significant treatment by site interaction effect on the yield, the average effect across all the testing sites and the yield response curve indicated that application of 23 kg P_2O_5 ha^{-1} was the agronomic optimum rate to maximize yield of tef. Application of S, however, was not found to have a significant effect on the yield of tef at all testing sites. Therefore, the application of S cannot be recommended for tef production in the district.

Keywords: Balanced nutrients, Fertilization, Nitrogen, Phosphorous, Sulfur

Introduction

Tef [*Eragrostis tef (Zucc*.)] is the most important cereal crop in Ethiopia covering 29.7% of the area and 19.5% of the total cereal production (CSA, 2019). It is rich in minerals, especially iron and it is also an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods (Abebe *et. al.* 2007; Berhane *et.al.* 2011). It has also recently been receiving global attention particularly as a 'health food' due to the absence of gluten and gluten-like proteins in its grains (Spaenij *et. al.* 2005). In addition to its importance as a staple food, tef straw is important for fodder and use in house construction (Teklu and Tefera, 2005). However, the productivity of tef is very low as the country's national average yield is in the order of 1.76 t ha^{-1} (CSA, 2019).

One of the factors responsible for the low yield is soil fertility depletion (Stoorvogel and Smaling, 1990; Tulema, 2005). Ethiopia is one of the sub-Saharan African countries with the highest rates of nutrient depletion due to erosion, leaching, limited return of organic residues and manure and high biomass removal. Amare *et. al.* (2006) pointed out that management-related N and K fluxes in the tef-based cropping system were -28 kg N $ha^{-1}yr^{-1}$ and -34 kg K ha^{-1} yr^{-1}. As a result, replenishment of the soil nutrient reserve through fertilization with organic or inorganic sources is essential. Studies show that N and P are the most critical growth-limiting nutrients impeding crop production (Asnakew *et. al.,* 1991; Fassil and Charles, 2009) although recent studies indicated a deficiency of K, S, Zn and B (Habtegebrial and Singh, 2006; Bereket *et. al.* 2011; EthioSIS, 2014).

Current fertilizer recommendation for tef in the study area is very old and was based only on nitrogen and phosphorus fertilizers (50 kg DAP and 81 kg Urea ha^{-1}) (Yared *et. al.* 2003, unpublished). Therefore, refinement of the previous site-specific fertilizer recommendations under balanced fertilization is essential from the basis of the dynamic property of soils as a result environmental changes such as climate change and repeated cultivation without replenish ment. Fertilizer recommendations are usually generated based on field crop-nutrient-response studies under balanced fertilization, which was lacking for tef production in the present study District. Therefore, this research was conducted to develop the yield response curve of tef to N, P and S fertilizers under optimum supply of major micro nutrients.

Materials and method

Study site description

The study was conducted in 2014 and 2015 in Jamma District of South Wollo Zone of the Amhara Region. The district is situated within the geographical boundaries of 10^o 06’ 24’’ - 10^o 35’ 45’’ N latitudes and 39^o 04’ 04’’ - 39^o 23’ 03’’ E longitudes and altitudinal ranges of 1428 - 2752 meters above sea level (m.a.s.l). The district receives a mean annual rainfall of 1130 mm. The mean minimum and maximum temperatures of the district are 9 and 21 ^oC, respectively. The monthly rainfall distribution of the district in 2014 and 2015 is described in Figure 1 below. The dominant soil type for the District is Pellic Vertisols and some chemical properties of surface soil (0-30 cm) of the study sites are given below (Table 1).

Table 1. Some chemical properties of surface soil (0-30 cm) of the study sites

	2014			2015		
Soil parameters	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Organic matter (%)	1.15	1.15	1.90	1.49	2.04	1.72
Total N (%)	0.08	0.06	0.10	0.31	0.22	0.25
Available P (mg kg^{-1})	26.4	20.8	28.5	25.1	27.2	21.4

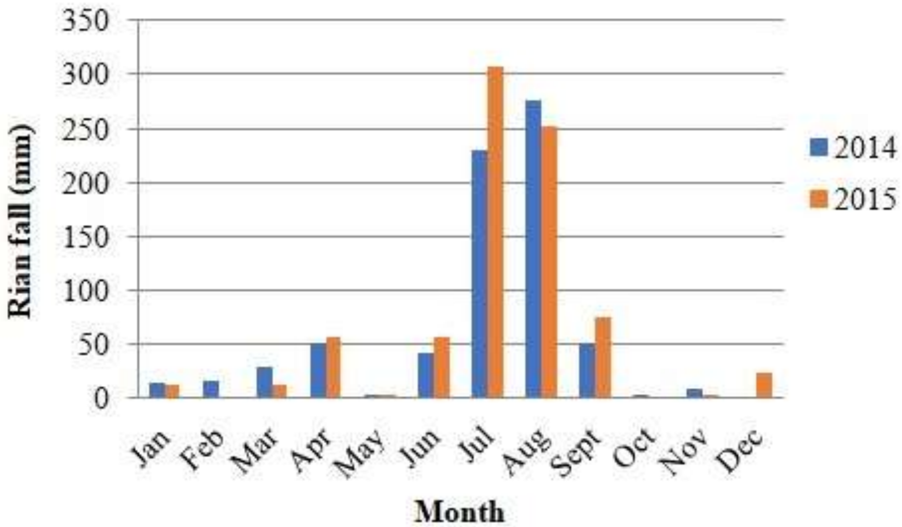

Figure 1. Monthly rainfall distribution of Jamma District in 2014 and 2015

Treatments and experimental design

The research comprised three separate studies; determination of yield responses of tef to N, P and S nutrients under balanced fertilization. Each of the nutrient response studies were conducted on three representatives randomly selected testing sites. Different levels of each nutrient, as described in Table 2 below, were evaluated separately under balanced fertilization. Seven rates of N (0, 23, 46, 69, 92, 115 and 138 kg ha^{-1}), six rates of P (0, 10, 20, 30, 40 and 50 kg P ha^{-1}) and six rates of S (0, 10, 20, 30, 40 and 50 kg ha^{-1}) were evaluated separately with application of sufficient balanced fertilizers (Table 2). In all nutrient response studies, absolute control (negative control; 0,0, 0 kg ha-1 N, P and S) and recommended NP (69/46 N/P_2O_5 kg ha^{-1}) as a positive control both without balanced fertilizer were included. The treatments were laid in a randomized complete block design (RCBD) with three replications.

Table 2. Treatments for the yield response studies of the three nutrients (NPS)

Nutrient levels	Balanced nutrients (kg ha^{-1})				
1. Nitrogen treatments (N kg ha^{-1})	P_2O_5	K_2O	S	Zn	B
0, 23,46, 69, 92,115 and 138	69	80	30	2	1
2. Phosphorus treatments (P kg ha^{-1})	N	K_2O	S	Zn	B
0, 10, 20, 30, 40 and 50	92	90	30	2	1
3. Sulfur treatments (S kg ha^{-1})	N	P_2O_5	K_2O	Zn	B
0, 10, 20, 30, 40 and 50	92	69	90	2	1

Nutrient sources: N=urea, P=Triple Super Phosphate (TSP), K= Muriate of Potash (KCl), S= $CaSO_4$, Zn=$ZnSO_4$, B = Borax

Experimental materials and procedures

In the first experimental year, the test crop was planted in a row with a 20 cm spacing and seeding rate of 10 kg ha^{-1} on the flat fine seedbeds. In the second year, it was planted by broadcasting with a seeding rate of 25 kg ha^{-1}. The variety *dega tef - DZ675* was used as a test crop. Phosphorus, K and S fertilizers were applied as Triple Super Phosphate (TSP), muriate of potash (KCl) and calcium sulfate ($CaSO_4$) straight fertilizers, respectively, in a row all at planting in the first year and broadcasted in the second year. While, N was applied as urea in split, at planting and top dressed at 45 days after planting. The micronutrients Zn ($ZnSO_4$) and B (Borax) were applied as foliar application 45 and 60 days after planting, respectively (Figure 2).

Figure 2. Foliar application of Zn and B micronutrients 45 and 60 days after planting, respectively

Data collection

Grain yield was measured by taking the weight of the grains threshed from the harvestable area of each plot and converted to kilograms per hectare. While, straw yield was obtained as the difference between dry biomass and grain yield. The dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105 ^{o}C for 12 hours and adjusting the fresh biomass weight on to dry basis by using the moisture content measured after an oven-dry.

Data analysis

Analysis of variance (GLM procedure) using SAS software version 9.00 (SAS Institute, 2004) was used to test the significance of the treatment's effect on the yield of tef. The mixed model procedure was used for the combined analysis over the testing sites in which each nutrients N, P and S were considered as a fixed variable while site and replication were considered as random variables. Significant differences between treatment means were delineated by Duncan's Multiple Range Test (DMRT) method at $P \leq 0.05$. Simple regression analysis was run using SAS to determine the significance of the relationship between yield response and nutrients.

Results and discussion

Yield Response of Tef to Nitrogen Fertilizer

In the first year (2014), there was a significant ($P \leq 0.01$) yield response to N at all testing sites (Table 3). The maximum grain yields were recorded from application of 138 kg N ha^{-1} and 115 kg N ha^{-1} which were statistically at par with the grain yields obtained from application of 23, 46 and 69 kg N ha^{-1} at testing sites 1, 2 and 3, respectively. The significant yield response of tef to N in all testing sites was attributed to the low indigenous total N ($\leq$0.1%) of surface soil of the study site (Table 1), while the significant yield response variation to N at the three testing sites was attributed to the difference in the total N status of surface soil of the sites (Table 1).

However, in the second year (2015), it was only on one testing (Site 1) that the application of N was found to have a significant ($P \leq 0.01$) effect on the yield of tef. Application of 69 kg N ha^{-1} was found to give statistically equivalent grain yield with the grain yields obtained from 115 and 138 kg N ha^{-1} (Table 3). At testing sites 2 and 3, however, the yield of tef was not significantly ($P>0.05$) affected by the application of N. This was due to the relatively better N nutrient existed in these sites as the sites were newly cultivated fields which were range lands previously. This was also confirmed from the high yields obtained from the –Ve control treatments from these sites.

The pooled analysis over the two experimental years and four testing sites (excluding those two sites in the second experimental year where there was no yield response to application of N) revealed that though the maximum grain yield was obtained from application of 138 kg N ha^{-1}, statistically ($P>0.05$) equivalent grain yield were recorded from application of 92 kg N ha^{-1} (Table 3). Significant ($P \leq 0.05$) grain yield advantages of 31.5, 71.8, 81.2, 94.3 and 107.6% over the zero N-treated plot were obtained from application of 23, 46, 69, 92 and 115 kg N ha^{-1}, respectively. The significant yield difference recorded in the 2014 and 2015 cropping years was due to the higher amount of rainfall and its better distribution in the growing period in 2015 which favored the yield in 2015 (See rainfall pattern on Figure 1).

Table 3. Teff grain yield (kg ha^{-1}) affected by N rates at Jamma (2014, 2015 and combined over years)

Treatment* (N kg ha^{-1})	2014			2015			Combined
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	642.8b	603.7c	827.0d	683.3d	2152.5	1765.0ab	721.6e
0	633.9b	708.8bc	898.6cd	725.0d	2243.3	1858.3ab	741.6e
23	960.1ab	704.3bc	1041.6bcd	1318.3c	2015.0	1881.7ab	975.1d
46	1050.3ab	948.2ab	1063.1bc	1841.7b	1935.0	2066.7a	1273.9c
69	1087.5ab	920.3ab	1163.4ab	2203.3ab	2189.9	1531.7bc	1343.7bc
92	1397.7a	1004.8a	1133.9ab	2228.3ab	2053.3	1546.7bc	1441.2ab
115	1390.8a	1049.1a	1309.8a	2346.7a	2038.3	1686.7ab	1539.4a
138	1497.6a	1062.2a	1186.3ab	2356.7a	1970.0	1260.0c	1544.0a
+Ve control	1235.5a	878.0abc	1145.3ab	1861.7b	2495.0	1826.7ab	1290.4bc
CV (%)	26.5	17.3	11.3	14.1	17.6	12.1	14.8
SEM	292.0	151.5	122.5	243.9	372.4	207.4	179.5
Trt*Site	-	-	-	-	-	-	**

**Treatments means within a column followed by the same letter are not significantly different at p = 0.05. ** = significant at p=0.01.*

Many nutrient response studies in Ethiopia also revealed that tef responds significantly to N fertilization especially in the highland Vertisols (Temesgen, 2001; Tulema et al., 2005; Alemayehu et. al., 2007; Habtegebrial et. al., 2007; Wakene and Yifru., 2013). Research conducted at Sirinka by Legesse (2004) also indicated that as applied N rates increased the grain uptake also increased which also reflected in the yield and yield components of tef like panicle length, grain yield, straw yield and biomass yield. Earlier studies by Tekalign *et. al*. (2002) confirmed that 60 kg N ha^{-1} is the optimum rate of N fertilizer. In a research report by Fissehaye *et. al.*, 2009, it is stated that maximum grain yield was recorded from the application of 69 kg N ha^{-1} on Vertisols. However, a study by Kumela and Thomas (2016) showed that a higher rate of N at 80 kg N ha^{-1} along with P (80 P_2O_5 kg ha^{-1}) with tef row planting spacing of 10 cm was found to give the highest yield.

Yield response trend to application of N

When each yield data collected (excluding those sites where there was no significant yield response to N) is plotted against the N level applied, the yield response trend to N looks like as shown in Figure 3. It showed an increasing and predictable pattern with a quadratic curve (R^2 =

0.3122**) found to be the best fitting curve. Similarly, the response curve of the average grain yield data pooled over the four testing sites indicated that the grain yield was increased with a predictable trend as the level of N was increased (Figure 4). The quadratic response curve was found the best fitting curve with R^2=0.988 to explain the relationship between the grain yield and the N level applied (Figure 4).

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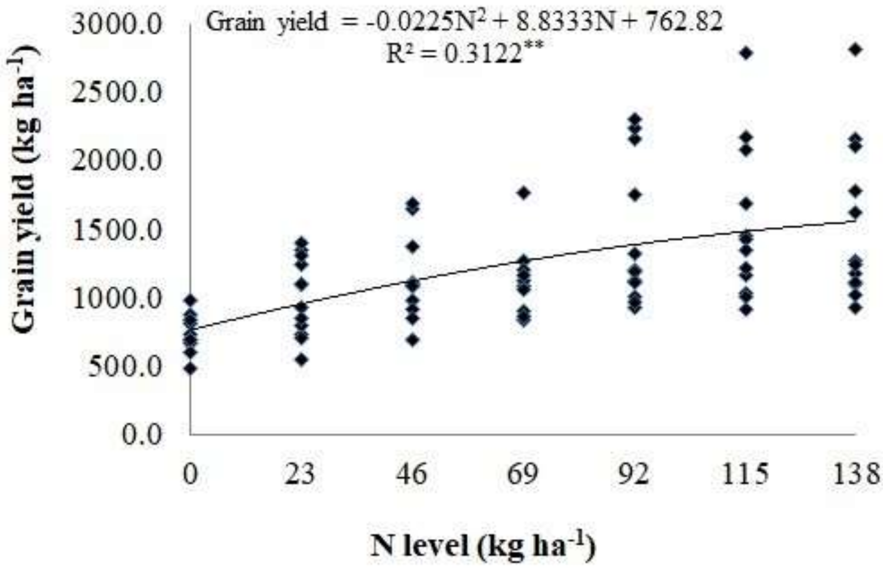

Figure 3. Grain yield data in response to N from all testing sites; GY = Grain yield in kg ha^{-1} and N = nitrogen rate in kg ha^{-1}

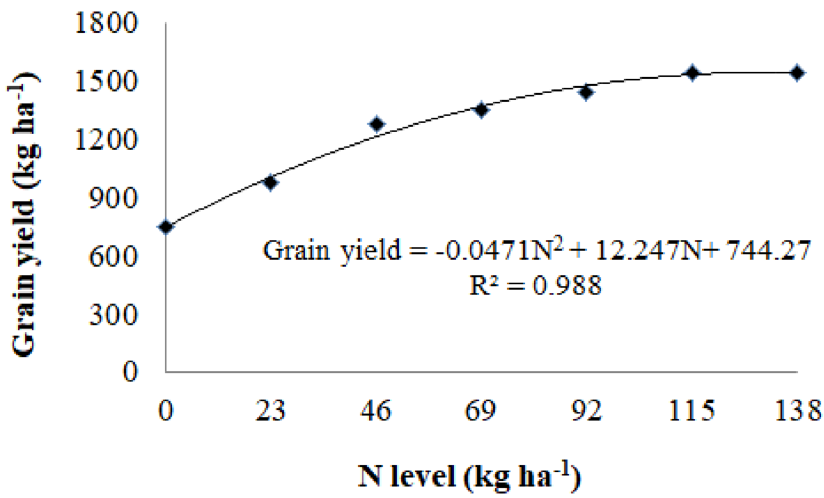

Figure 4. The mean yield response curve to N pooled over years and testing sites

Yield Response of Tef to Phosphorus Fertilizer

Yield response of tef to P fertilizer in the first experimental year showed that except at one testing site, the effect of application of P fertilizer on the grain yield of tef was not found significant ($P>0.05$). Instead, the application of P was found to have a negative effect on the yield of tef on the two testing sites. But, at one of the testing sites (Site 2), a significant ($P\leq0.05$) yield difference from the control (zero P treated plot) was obtained due to the application of 23 kg P_2O_5 ha^{-1} (Table 4). However, in the second experimental year, the application of P was found to have a significant ($P\leq0.01$) effect on the yield of tef (Table 4). The highest grain yields of 2.6 and 1.6 t ha^{-1} at testing sites 1 and 2, respectively, were obtained from the application of 23 kg P_2O_5 ha^{-1}, while, at testing site 3, the highest grain yield was obtained from the application of 46 kg P_2O_5 ha^{-1}. It was on 50% of the testing sites that a significant ($p\leq0.05$) yield response to the application of P fertilizer was found.

The pooled analysis over the six testing sites revealed that the maximum grain yield was recorded from the application of 69 kg P_2O_5 ha^{-1} which was statistically at par with the yield obtained from the application of 23 kg P_2O_5 ha^{-1} (Table 4). There was a significant ($P\leq0.01$) interaction effect of site with treatments on the yield indicating a variability of yield response to the application of P across the testing sites. The lack of response to P fertilizer application on 50% of the testing sites could be attributed to the optimum level of available P in the surface soil of the testing sites (Table 1).

Thus, application of 23 kg P_2O_5 ha^{-1} was found to be the optimum rate for those sites exhibiting significant yield response to application of P and could be used as a maintenance level for those sites which showed non-significant yield response to addition of P fertilizer. The other reason for the non-significant yield response to the addition of P fertilizer might be due to the high P sorption capacity of Vertisols (Sahrawat *et al.*, 1995; Abunyewa *et al.,* 2004) due to the high clay content of the soils which leads to increased surface area for P adsorption. The higher the amount of P adsorbed by the soil and its constituents, the less P will be available for plant uptake (Rashmi *et al.,* 2014).

Table 4. Grain yield (kg ha-1) response of tef to the addition of P fertilizer at the six testing sites in 2014, 2015 and combined over years

Treatment* (kg P_2O_5 ha^{-1})	2014			2015			Combined
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	760.5d	478.5^{d}	477.3^{c}	673.3^{c}	506.7^{c}	722.5^{e}	583.7^{c}
0	1339.3^{a}	837.3^{bc}	1101.5^{a}	2048.3^{b}	1240.0^{b}	1480.1^{cd}	1401.4^{b}
23	1258.8^{abc}	904.5^{abc}	780.7^{b}	2573.3^{a}	1591.7^{a}	1313.3^{d}	1595.7^{a}
46	1215.6^{abc}	820.1^{bc}	923.6^{b}	2160.8^{ab}	1325.0^{ab}	1982.6^{a}	1572.1^{a}
69	1329.8^{ab}	938.2^{ab}	909.8^{b}	2245.8^{ab}	1403.3^{ab}	1833.3^{ab}	1605.2^{a}
92	1292.8^{abc}	932.1^{abc}	792.0^{b}	2138.3^{ab}	1355.0^{ab}	1745.7^{abc}	1542.8^{ab}
115	1190.6^{bc}	1065.1^{a}	885.4^{b}	2208.3^{ab}	1383.3^{ab}	1663.3^{abc}	1580.0^{a}
+Ve control	1161.0^{c}	756.7^{c}	872.2^{b}	2091.7^{ab}	1348.3^{ab}	1651.7^{bc}	1462.1^{ab}
CV (%)	6.2	11.0	11.7	12.5	13.9	10.3	12.7
SEM	74.5	92.6	98.4	252.4	177.5	163.2	180.6
Trt*Site	-	-	-	-	-	-	**

**Means within a column followed by the same letter are not significantly different at p = 0.05. ** = significance at 1% probability level.*

Trend of yield response to P

The yield response curve of the grain yield data from all testing sites in the two experimental years revealed that there was less predictable and nonsignificant relation (r^2=0.0012^{ns}) between the grain yield and the P fertilizer applied (Figure 5). However, the P yield response curve of the mean grain yield data of treatments pooled over years and testing sites as shown in Figure 6 below, showed that there was a strong relation (R^2=0.6612 or 66.1%) of grain yield to the addition of P fertilizer.

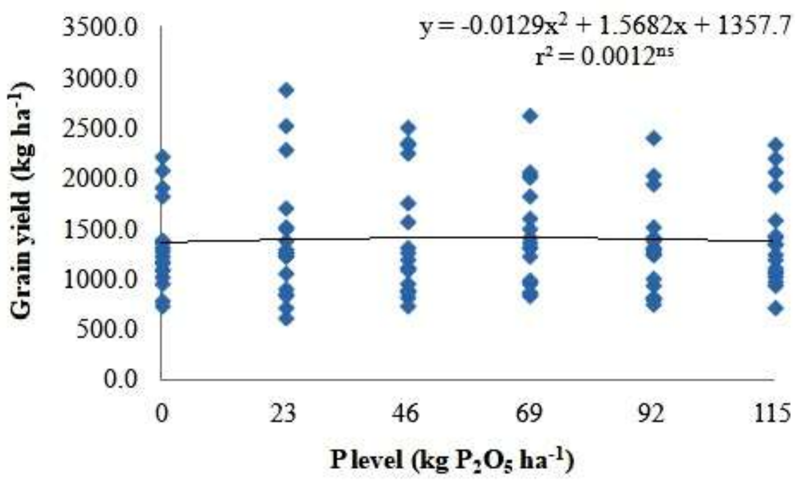

Figure 5. The P yield response curve of the grain yield data of six testing sites

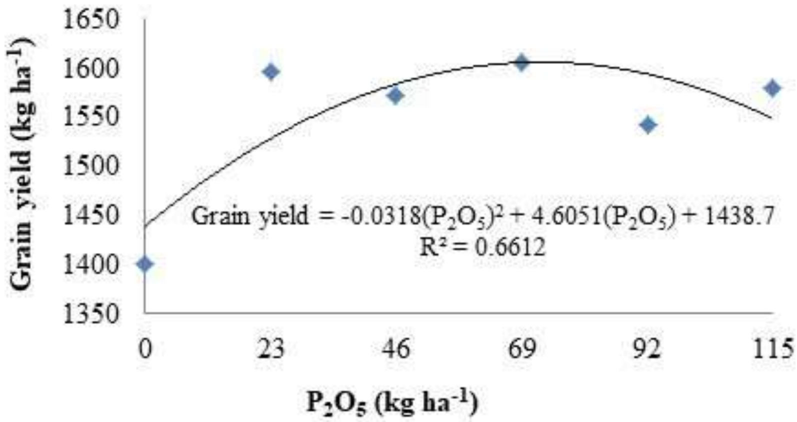

Figure 6. The P yield response curve of the mean grain yield data of treatments pooled over years and testing sites

Response of Tef to Sulfur Fertilizer

The effect of application of S on the yield of tef was found non-significant ($p>0.05$) in all the testing sites both in the first and second experimental years (Table 5) as compared to the zero S treated plot. The pooled analysis result of overall testing sites also revealed that the grain yield was not significantly affected by the application of S (Table 5).

Table 5. Response of tef (Grain yield (kg ha^{-1}) to S rates (in 2014, 2015 and combined over years)

Treatment* (kg S ha^{-1})	2014			2015			Combined
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	594.1^{b}	837.3^{b}	724.4b^{c}	705.0^{b}	310.0^{d}	1065.0^{c}	713.0^{c}
0	1247.8^{a}	1091.7^{ab}	970.0^{a}	2192.5^{a}	1461.7^{abc}	2121.0^{a}	1514.1^{ab}
10	1036.3^{a}	1308.2a	967.8^{a}	2260.0^{a}	1545.0^{ab}	2265.0^{a}	1594.7^{a}
20	1177.3^{a}	1065.7^{ab}	979.8^{a}	2145.8^{a}	1638.3^{a}	2176.9^{a}	1530.6^{ab}
30	1224.8^{a}	1223.4^{ab}	1011.5^{a}	2416.7^{a}	1483.3^{abc}	2220.6^{a}	1596.7^{a}
40	1419.4^{a}	1111.8^{ab}	895.5^{ab}	2273.3^{a}	1325.0^{bc}	1630.0^{b}	1431.5^{b}
50	1366.2^{a}	1192.7^{ab}	696.8^{c}	2410.0^{a}	1553.3^{ab}	1754.1^{b}	1441.7^{ab}
+Ve control	1225.8^{a}	1134.1^{ab}	873.1^{abc}	2255.0^{a}	1230.0^{c}	2126.7^{a}	1474.1ab
CV (%)	17.0	17.7	11.7	15.8	12.1	9.3	14.5
SEM	203.2	198.5	104.2	336.3	159.6	179.5	205.4
Trt*Site	-	-	-	-	-	-	*

Means within a column followed by the same letter are not significantly different at p = 0.05.* *** *= significance at 5% probability level.*

Conclusion and Recommendation

This study was conducted to investigate the yield response of tef to different levels of N, P and S fertilizers under balanced fertilization in three separate experiments. The result revealed that there was a significant ($P \leq 0.01$) and predictable yield response to application of N. The maximum yield was obtained at application of 138 and 115 kg N ha^{-1}. However, statistically equivalent ($P>0.05$) yield was recorded at 92 kg N ha^{-1}. Thus, the yield response curve showed that the grain yield reaches its maximum at 92 kg N ha^{-1} and declines beyond this rate. Tef yield response study to P fertilizer showed a significant response to P at 50% of the testing sites, while at 50% of the rest testing sites, tef yield response to application of P was not found significant ($p>0.05$). Although there was a significant treatment by site interaction effect on the yield, the average effect across all the testing sites and the yield response curve indicated that application of 23 kg P_2O_5 ha^{-1} was the agronomic optimum rate to maximize yield of tef. Application of S, however, was not found to have a significant effect on the yield of tef at all testing sites. Therefore, the application of S cannot be recommended for tef production in the district.

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Diagnostic trial on sorghum (Girana one) for developing site-specific nutrient management practices in low lands of Eastern Amhara

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Abstract

A field experiment was conducted for the identification of yield-limiting nutrients through crop response in Kobo with test crop sorghum (Girana one variety). The experimental design was a randomized complete block design (RCBD) using farmer field as replication. Biological yield data were collected and subjected to analysis of variance (ANOVA). Whenever there was a significant difference between treatments, the means were separated using the least significant difference (LSD) test at P≤0.05. The results showed that the omission of individual nutrients (N, P, K and S) alone or in combination with farmyard manure (FYM) of these nutrients from fertilizer application resulted in a significant sorghum grain yield reduction. The highest grain yield was observed with the treatment receiving NPS+FYM whereas the lowest with omission of all nutrients (control). There was no significant difference in biomass yield between treatments for both years. Application of FYM in combination with inorganic fertilizer (NPS) and NP contained treatments (NPS, NPSK and NPSKZN) could be used as nutrient sources and can meet nutrient requirements for sorghum. The grain yield under different nutrient omitted plots followed the order NPS+FYM, NPS, NPSK and NPSKZN > NP, NS and PS > N, S and P. Application of farmyard manure is essential and the most yield-limiting factor followed by Nitrogen, Sulfur and Phosphorous fertilizer.

Keywords: Crop response, FYM, Omission, Nutrient, Yield

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 at various spatial scales. The Nutrient Expert for sorghum (NE) supports the development and dissemination of site-specific nutrient management (SSNM) options for Sorghum production systems (Ren *et al.*, 2015). NE provides a systematic framework for applying the site-specific nutrient management concept (SSNM) to develop strategies to optimize the management of fertilizer N, P, K, S secondary and micronutrients in heterogeneous production systems. SSNM integrates soil, agronomic and climate information to provide location-specific guidelines on nutrient requirements (Oyinbo, 2019). It aims to (a) account for indigenous nutrient sources, including crop residues and farmyard manure; and (b) apply balanced fertilizer at optimal rates and at critical growth stages to meet the deficit between the nutrients needs of a high-yielding crop and the indigenous nutrient supply.

The optimum productivity of any cropping system depends on an adequate supply of plant nutrients. Even if, all other factors of crop production are in the optimum, the fertility of a soil largely determines the ultimate yield. Soil fertility refers to the nutrient supplying capacity of soil for crop growth. It describes the available nutrients status of the soil and its ability to provide nutrients for optimum plant growth (Dev., 1997). When the soil does not supply sufficient nutrients for normal plant development and optimum productivity, the application of supplemental nutrients is required. Fertilizer is one of the most important sources to meet this requirement. Indiscriminate use of fertilizers, however, may cause adverse effects on soils and crops both regarding nutrient toxicity and deficiency either by overuse or inadequate use (Ray *et al*. 2000). Diagnostic techniques including identification of deficiency symptoms, soil and plant analysis and biological tests are important in determining specific nutrient stresses and quantity of nutrients needed to optimize the yield (Havlin *et al*. 2007). Soil fertility evaluation, thus, is the key to adequate and balanced fertilization in crop production.

To increase the productivity of crops of smallholder farms and therefore improve food security in the study sites, there is a need to identify the soil factors that constrain crop growth. In addition to this one or two types of fertilizer recommendation applies to the whole districts or a wide region. In order to increase the use efficiency of applied nutrients and the cost-effectiveness of resource input, there is a need to target interventions whether related to soil amendments to improve the condition of the soil or to fertilizer application to address nutrient requirements. Knowing the limiting soil factors would inform about the right inputs needed. Therefore, this research was conducted to find out the yield-limiting nutrients and or factors (FYM) based on sorghum-response using nutrient omission technique and to develop Site-Specific Nutrient Management practices under variable soil fertility and climatic conditions.

Material and methods

Site description

The experiment was conducted at kobo which is located 54 km from woldia town in the direction of north. Its altitude ranges from 1000-2800 m.a.s.l. It has an agro-ecology of hot to warm sub moist valley and escarpment. The study district is located at a geographical coordinate point of 12^{o} 09’N latitude and 39^{o} 38’E longitude. Annual rainfall, minimum, and maximum temperature of the study area are 649 mm, 29^{o}c and 15^{o}c respectively. The dominant soil type of the area is euritic fluvisol lying on low plain on valley floor enclosed by low but steep sidehill and drains to rift valley river basin. The soils are deep to very deep mostly alluvial origin and have moderately to imperfectly draining properties. The infiltration rate and permeability are low with high runoff generation potential. But due to flat topography, it is less susceptible to erosion. The major crops grown in the area are sorghum, teff and maize (Getachew, 1993) and currently most of the irrigable area shifts to cash crop production. The livelihood of the population is depending on mixed farming (crop production and livestock production), with about 96% of its population engaged in agriculture.

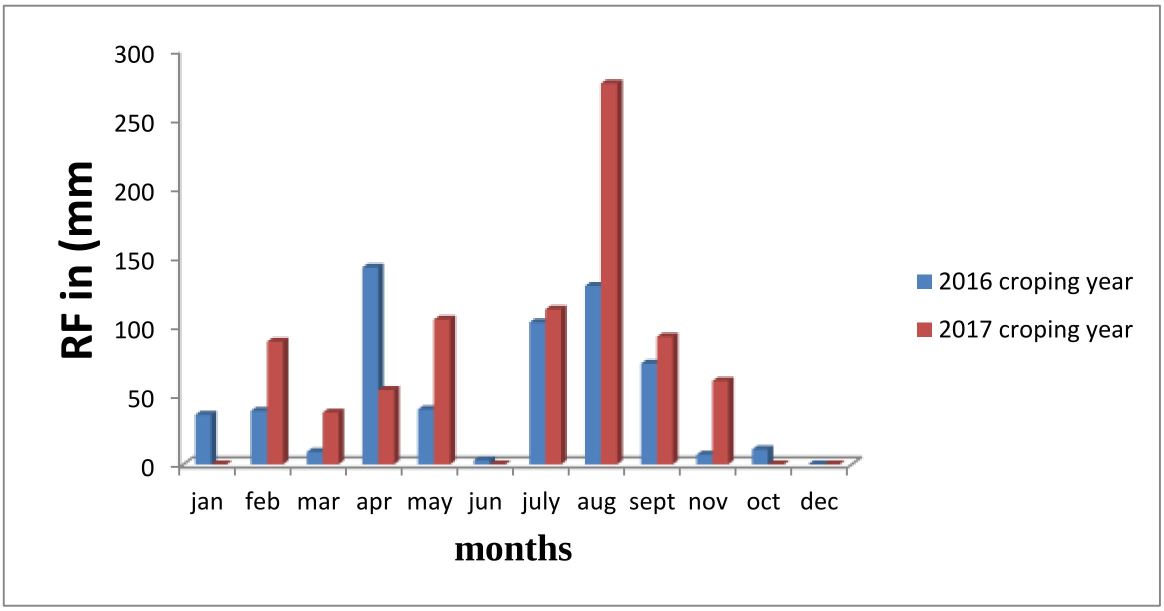

Figure 1. Monthly rainfall distribution of the study area during the two cropping years.

Experimental treatments and design

The experiment was conducted for two years in 2016 and 2017 main cropping seasons at Abuare, Aradom, and Ayub kebeles of the district. The experimental design was randomized complete blocks design (RCBD) with farmer's field as replication. Twelve treatments with 3 m by 4.5 m net plot size were used. Sites were selected carefully to ensure a good representation of the district.

Table 1. Treatments description

Plot	Description
Control	No fertilizer application. Used to measure grain yield as an indicator of the effective indigenous NPS supply from soil, rainwater, crop residue and atmosphere.
N	Provide sufficient N only, other nutrients are assumed to come from the soil
P	Provide sufficient P only, other nutrients are assumed to come from the soil
S	Provide sufficient S only, other nutrients are assumed to come from the soil
PS	N omission plot with sufficient P and S amounts applied. Used to measure grain yield as an indicator of the effective indigenous N supply from soil, rainwater, crop residue and atmosphere.
NS	P omission plot with sufficient N and S amounts applied. Used to measure grain yield as an indicator of the effective indigenous P supply from soil, rainwater, crop residue and atmosphere.
NP	S omission plot with sufficient N and P amounts applied. Used to measure grain yield as an indicator of the effective indigenous S supply from soil, rainwater, crop residue and atmosphere.
NPS	Full NPS input to estimate the nutrient-limited yield gap and evaluate agronomic use efficiencies of N, P, and S. Fertilizer N is applied in two splits :)
NPSK	This treatment will be used to assess the contribution of K with primary nutrients.
NPKSZN	This treatment will be used to assess the contribution of secondary and micronutrients to Sorghum productivity. The secondary nutrients rates already determined from existing work
NPS+FYM	This treatment will be used to assess the contribution of farmyard manure to Sorghum and Teff productivity through its multiple effects including organic matter addition and regulation of nutrient supply and water and air circulation.

Nutrient application rates

Nutrients (NPSK) were applied at rates required to achieve the expected attainable yield without nutrient limitation in each location. Nutrient application rates depend on the maximum attainable yield as determined based on rainfall and agro-ecological potential. The following guidelines were used to determine nutrient application rates:

Table 2. Amount of Nutrients applied

Treatment	Nutrient application rates (kg/ha)								
	N	P	P_2O_5	K	K_2O	S	Zn	**$ZnSo_4$	FYM
Control	0	0	0	0	0	0	0	0	0
N	150	0	0	0	0	0	0	0	0
P	0	55	125	0	0	0	0	0	0
S	0	0	0	0	0	20	0	0	0
PS	0	55	125	0	0	20	0	0	0
NS	150	0	0	0	0	20	0	0	0
NP	150	55	125	0	0	0	0	0	0
NPS	150	55	125	0	0	20	0	0	0
NPSK	150	55	125	60	72	20	0	0	0
NPSKZn	150	55	125	60	72	20	5	25	0
NPS+FYM	150	55	125	0	0	20	0	0	12t/ha
R.NP	69	30	69	0	0	0	0	0	0

Note. *R.NP=Recommended Nitrogen and Phosphorous*

- *The source of S&K was $CaSO_4$ & KCL respectively.*
- *FYM: Recommended rate of 12t/ha in micro-dosing (spot application method).*

Data collected

Grain and biomass yields

Grain yield was measured from the harvested innermost rows and was adjusted to 12.5 moisture content. Fresh biomass weight was measured by weighing the fresh total above-ground biomass and the head of the harvestable rows. Plant height was measured from ground level to the tip of the head at maturity from randomly taken five plant samples of the harvestable rows..

Soil sampling analysis

Composite soil samples were taken before sowing /planting at 0-20cm depth for soil analysis (Total N, available P, OC, texture and pH). The collected soil sample were analyzed according to the following methods; soil pH was determined using a glass electrode of pH meter in 1:2.5

soil water suspension after string for 30 minutes as described by Piper (1966); organic carbon was estimated by wet digestion method of Walkley and Black (1934)'; available P in soil was extracted by Olsen *et al.* (1954) and P in the extract was determined by the ascorbic acid method; total nitrogen in soil was determined by (wet digestion) procedure of Kjeldahl method and soil texture was determined by hydrometer method.

Data Analysis

The data obtained were subjected to analysis of variance using General Linear Model (Proc GLM) with statistix 10 software and treatment effects were compared using the Fisher's Least Significant Differences test at 5% level of significance.

Results and Discussion

Physico-chemical properties of the soil

The first-year soil analysis results (Table 3) showed that the soil had total nitrogen content in the ranges of 0.11-0.32 (%). According to Tekalign et al.(1991) the soil total N was moderate to high. This is because Tekalign and his coauthors defined that soils contain total N of less than 0.05% was considered as very low, 0.05-0.12% as poor, 0.12-0.25% as moderate and more than 0.25% as high. Based on this assumption the experimental site showed moderate to high content of total nitrogen. The soil organic matter ranges from 1.26-2.75% which is categorized under low to medium content of organic matter (Berhanu, 1980). According to Berhanu, soil organic matter content of less than 0.7% is considered as very low, 0.7-2.6 as low, 2.6-5.2% as medium and more than 5.2% as high. The soil analysis results also indicated that the textural class of the experimental site was clay according to USDA textural classification. Thus, the textural class of the experimental soil is ideal for sorghum production. The soil reaction (pH) of the experimental site ranges from 6.4-6.9 which shows a neutral range (Tekalign, 1991), but it is within the optimum range for sorghum production, i.e., 5.5 - 7.0.

The second year results of soil analysis (Table 3) showed that the soil had total nitrogen content in the ranges of 0.1-0.25 (%) which is categorized under poor to moderate total nitrogen. The soil has organic matter which ranges from 0.88-2.2% which was considered as low content of organic matter (Berhanu, 1980). The soil test result revealed that the available phosphorus content of the soil, as per Olsen et al. (1954) rating is in the high range. The existing available soil phosphorus content in the area is adequate for the optimal crop production and thus phosphorus fertilizer application is not praiseworthy. This phosphorus content is accounted for the neutral pH of the soil in which there is no fixation of phosphorus and is therefore conducive for the availability of phosphorus. Similar results were recorded for soil pH and textural class for the second year.

Table 3. value of some parameters of soil samples taken at planting at Kobo in the year 2016&2017

Year	pH	% OM	%T.N	Avail. P (ppm)	Textural class
2016	6.4-6.9	1.26-2.75	0.11-0.32	30.8-34.4	Clay
2017	6.5-6.8	0.88-2.2	0.1-0.25	33.85-44.45	Clay

Grain yield and biomass of sorghum

The application of different inorganic fertilizers provides a significant difference in sorghum grain yield ($P<0.05$) (Table 4). This significant difference was found in combination or alone of the inorganic fertilizers and farmyard manure (FYM). Compared to the control treatment, the highest sorghum yield was obtained from NPS plus FYM application without significant difference from NPS, NPSK and NPSKZN treatments (Table 4). The combination of NPS with FYM gave 2.1ton ha^{-1} yield advantage over the control treatments in the first year. Lower grain yield was found using higher rate of NP than the recommended NP rates implying that the recommended NP rate is enough for that site and adding additional NP gives yield penalty either due to logging effect. This could be justified by the higher biomass yield in higher rate of Np than the recommended NP (Table 4).

Table 4. Effect of different nutrients on sorghum grain and biomass yield at kobo in 2016

Treatments	Grain yield(kg/ha)	Biomass(kg/ha)
Control	3366.8c	9949
N	3816.7bc	9854
P	3453.3bc	10051
S	3548.7bc	9122
NP	3825.4bc	9736
NS	3619bc	8915
PS	4076.7abc	9198
NPS	4302.7abc	11118
NPSK	4979ab	11780
NPSKZn	4932.9abc	12861
NPS +FYM	5538.1a	12441
Rec NP	4503abc	9069
CV(%)	31.56	34.4
LSD(0.05)	1688.4	4138.9

Like the first year result the second year result showed that sorghum grain yield was affected by the application of different inorganic fertilizer which is presented in table 5. As indicated in Table 5 grain yield was significantly affected by the application of the inorganic fertilizers in combination with FYM or alone at ($P<0.05$). Compared to the control treatment, the highest sorghum yield was also obtained from NPS plus FYM application without significance difference from NPS, NPSK and NPSKZN treatments (Table 5). The treatment NPS +FYM provided 2.1ton ha^{-1}yield advantage over the control treatments. Unlike first year, the second year indicates that addition of higher rate of NP gave higher grain yield than recommended NP rate this indicates the recommended rate is lower than the crop requirement.

Table 5. Effect of different nutrients on sorghum grain and biomass yield at kobo in 2017

Treatment	yield(kg/ha)	biomass(kg/ha)
Control	3266.2[c]	11034
N	4888.9[abc]	11665
P	4192[abc]	8390
S	4337.6[abc]	12068
NP	5092[ab]	12830
NS	4654.6[abc]	11317
PS	4144.2[abc]	8271
NPS	4674.9[abc]	10290
NPSK	4613.9[abc]	13002
NPSKZn	4673.4[abc]	13089
NPS +FYM	5448.6[a]	12779
Rec NP	3440[bc]	8565
CV (%)	22.34	36.53
LSD (0.05)	1684.2	6871.3

The two year combined analysis of the result indicated that sorghum grain yield was affected by the application of different inorganic fertilizer alone or incombination with FYM ($P<0.05$) (Table 6). Compared to the control treatment, the highest sorghum yield were obtained from NPS plus FYM application without significance difference from NPS, NPSK and NPSKZN treatments (Table 6). This combination also provided 2.2 ton ha^{-1} yield advantage over the control treatments. This result indicated that omission of the individual nutrients of N, P and S or all together significantly reduced the grain and straw yields of sorghum than the treatment receiving all nutrients. This could be justified by the lower yield of control (no fertilizer; 3316.7 kg ha^{-1}) and higher yield of NPS + FYM (5490.3 kg ha^{-1}). Grain yields with addition of N, P and S were increased by 857, 401 and 495 $kgha^{-1}$ respectively and were significantly higher than the control (no fertilizer) treatment.

The total biomass yields of sorghum were not significantly affected by the application of different fertilizers treatments at ($P< 0.05$) in the year 2016, 2017 and also the combined data over years.

Table 6. Effect of different nutrients on sorghum yield (kg/ha) Combined over years at Kobo in 2016&2017

Treatments	Grain yield	biomass
Control	3316.7[c]	10311
N	4174.1[bc]	10458
P	3717.9[bc]	9805
S	3811.7[bc]	9081
NP	4294[bc]	10767
NS	4001[bc]	8887
PS	4099.2[bc]	8889
NPS	4426.8[abc]	11666
NPSK	4857.3[ab]	11578
NPSKZn	4829.2[ab]	11920
NPS +FYM	5490.3[a]	12531
Rec NP	4148.6[bc]	9476
CV (%)	28.02	33.63
LSD (0.05)	1196.3	3574.4

A nutrients omission trial aims to find out the most limiting nutrients to the growth of a crop . If any element is omitted while other elements are applied at suitable rates and plants growth was affected, then the tested element is a limiting factor for crop growth. Conversely, if any element is omitted but plants are healthy and are not affected, then that element is not a limiting factor for crop production. When a nutrient is deficient in the soil then the growth of a crop and ultimately the yield is affected.

High crop yields can only be achieved when high yielding crop varieties got an important nutrition in a correct amount and proper ratios. In addition to this limitation, low fertilizer efficiency, inadequacy of current fertilizer recommendations and the ignorance of nutrients other than N and P may limit crop production. Accordingly, the yield obtained from the control treatment was significantly lower ($P \leq 0.05$) than the yields obtained due to the application of all of the different fertilizers. This implies that the grain yield was low without application of either of the soil fertility amendments mechanisms. In this aspect, the result of this work is in lined with the work of Kanchikerimath and Singh (2001) who reported that soil organic matter content and soil microbial activities are vital for the nutrient turn over and long term productivity of the soil that nutrient availability is enhanced by balanced application of nutrients and manure. Similarly, Shrotriya (1998) reported that balanced application of N-P caused up to 122% increase in sorghum yield in India. Bumb and Bannante (1996) also confirmed that increased plant growth with optimal N, and P application provides good vegetative cover which resulted in high grain yield of sorghum plant. Large reductions in the grain and straw yield of rice were observed with the omission of Nitrogen and phosphorus as compared to the other nutrient omission treatments. Singh et al. (2018) reported that Omission of N reduced the yield by 47.64 %; P omission by 40.82 % and S omission caused yield reduction of 19.51 %.

Conclusion and Recommendation

The above studies showed that both inorganic fertilizers and farm yard manures have their own roles to play in soil fertility management but none can solely supply all the nutrients for optimum sorghum production. The results revealed that among the different combinations of inorganic and farmyard manure treatments, sorghum responded well to the application of NPS +FYM. Increased in grain and biomass yield in this study may be associated with the supply of essential nutrients. Overall conclusion is that organic sources i.e. FYM applied in combination with inorganic fertilizer (NPS) could be used as nutrient sources and can meet nutrient requirement for sorghum. The grain yield under different nutrient omitted plot followed the order NPS+FYM, NPS, NPSK and NPSKZN > NP, NS and PS > N, S and P. This implies that application of farm yard manure is essential.

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Validation of Soil Test Based Phosphorus Fertilizer Recommendations for Bread Wheat (*Triticum aestivum* L.) on Vertisols of North Shewa Zone

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Abstract

This study was conducted to verify the recommended soil test based calibration equation for phosphorus (P) fertilizer around Moretina Jiru and Syadebirnawayu Woredas for two consecutive years on 16 farmers' fields. In the first year, only two treatments were compared but in the second year, one additional treatment was considered. Before planting, the initial soil P level was analyzed using Olsen method, and the soil P level ranged from 5.8 to 11.4 ppm. Based on the P calibration model of Debre Berhan Agricultural Research Center (DBARC), the fertilizer requirement of the site ranged from 17 to 102 P_2O_5 kg ha^{-1}. Nevertheless, in the second year, the initial P level of the site was between 5.04-14.29 ppm and the need for P_2O_5 ranged from zero to 110.4 kg P_2O_5 ha^{-1} with DBARC model. In contrast, with agronomic phosphorus fertilizer recommendation, the need for P_2O_5 was 138 kg ha^{-1} for both locations for the two years. The first year result revealed that using soil test based fertilizer application, about 51% of the P_2O_5 to be applied could be saved compared to the agronomic fertilizer recommendation (138 P_2O_5 kg ha^{-1}). However, in the second year DBARC and GARC model, the amount of P_2O_5 fertilizer to be applied could be reduced by 65.94% and 44.2%, respectively compared to the agronomic P fertilizer recommendation (138 P_2O_5). The first year result indicated that DBARC phosphorus fertilizer calibration model had a mean grain and straw yield penalty of 24.6 kg ha^{-1} (0.8%) and 25.94 kg ha^{-1} (0.7%) compared to the agronomic phosphorus fertilizer recommendation. Similarly, in the second year DBARC model had a mean grain and straw yield penalty of 336.3 kg ha^{-1} (10.3%) and 18.4 kg ha^{-1} (7.8%) respectively as compared to the agronomic P fertilizer recommendation. The two years result indicated that DBARC P calibration model had a higher net benefit than the agronomic P fertilizer recommendation and resulted in a mean net benefit of 19088 *ETB ha^{-1}. The same was true for the benefit cost ratio.*

Keywords: Nitrogen, phosphorus critical value, phosphorus factor, phosphorus, wheat

Introduction

In Northestern Ethiopia, there is a rapidly growing demand for food due to a rapid population growth. Therefore, cultivations of subsistence crops must be stimulated and production augmented sustainably. The trend in all research endeavors including research on soil nutrients is going through a development process away from agricultural production per se towards sustainable production (Smaling, 1993). Among others, mineral nutrition is becoming one of the most important factors for increasing crop production in Northwestern Ethiopia. Unfortunately, many soils of Ethiopian highlands are inherently poor in available plant nutrients and organic matter content (Tekalign *et al*., 1988, Zeleke *et al*., 2010). Murphy (1963) conducted a survey or rapid appraisal to assess the fertility status of Ethiopian soils and concluded that the major part of Ethiopian soils is deficient in nitrogen and phosphorus. Hence, farmers who attempted to grow crops without or with marginal fertilizer application could not produce enough even to feed their own families for one year.

Phosphorus is of primary concern in the appraisal of the soil resources of Ethiopia (Miressa and Robarge, 1996) since most of the soils in the highland areas of the country, particularly Nitisols are reported to be deficient in phosphorus (Asnakew *et al*., 1991; Desta, 1982; Bekele and Hofner, 1993; Agegnehu *et al*., 2015). Phosphorus is one of the most limiting elements in the tropics and majority of the soils of Ethiopia (Brady and Weil, 2008; Bekele and Hofner, 1993). In P-deficient soils, crops usually recover less than 10% of the applied amount of phosphorus in the first season, even if they respond well and the total recovery after four years is often only 20-30% (Russel, 1972). In addition to the inherently low available P content, the high P fixation capacity of some soils made the problem complex.

The role of chemical fertilizers in increasing yield is evident. Fertilizers accounted for more than 50% of the increase in yield (FAO, 1984). Experience has shown that in seasons with good rain, farmers of Northwestern Ethiopia managed to produce surplus yield through fertilization. The rates applied, however, should meet the demand of the crop, but should not exceed the demand to any major extent. For this purpose, in Ethiopia, some blanket fertilizer recommendations have been developed and introduced into the extension system. This approach, however, had shortcomings in extrapolating the results to farmer fields, because the available nutrient status on the experimental fields was lower than, equal to or higher than that of the farmers' fields. Hence, fertilizer recommendations should take into account the available nutrient already present in the soil (Mengel, 1982).

To take in to account of the available nutreints in the soil and undertake more scientific and precise option of fertilizer recommendation, soil laboratories are being built in many Regional States of the country including the study area. Nevertheless, since no universally accepted method exists for indexing the availability of nutrients, reliable methods must be selected through research to meet the specific conditions under which the crops are intended to grow. Bray-II and Olsen methods have been proven to be the best indices for Ethiopian soils (Tekalign and Haque, 1991; Sahlemedihin and Taye, 2000). Using these indices, mathematical models that integrate the soil test indices with fertilizer rate requirements can be developed for each crop species on specific soil types and agro-ecologies. Research works on soil test-based fertilizer recommendations are at preliminary stages in Ethiopia, although some recent research recommendations have been made for some crops (e.g., Agegnehu and Lakew, 2013; Agegnehu *et al*., 2015). Other researchers also reported research findings on soil test crop response studies in different parts, crops and soils of Ethiopia (Getachew and Berhane, 2013; Gebremedhin *et al*., 2015; Girma *et al*., 2018; Dagne, 2019; Gidena, 2016) However, the effort must be further strengthened. Therefore, the objectives of this study were to: 1) develop mathematical models that will give phosphorus fertilizer recommendations using Olsen phosphorus levels according to P availability indices; 2) verify the recommended soil test based calibration equation for P; and demonstrate the advantage of soil test based recommendation over agronomic fertilizer recommendation for the study site.

Materials and methods

Description of the Study Area

The experiment was conducted in *Moretina Jiru* and *Saya deber ena Wayu* districts, North Shewa Zone of the Amhara Regional State, about 195 and 176 km northeast of Addis Ababa, respectively. The capital of *Moretina Jiru* and *Saya deber ena Wayu* are *Enewari* and *Deneba* respectively. The geologic materials at and around the districts consist of the Aiba basalt of the middle-late Oligocene era of the Paleocene period. The areas are characterized by a unimodal rainfall pattern and receive an average annual rainfall of 929 and 1276.3 mm, respectively. The annual average maximum and minimum air temperatures are 21.4 and 9.0 °C at *Enewari* and 22.3 and 6.9 at *Deneba*, respectively. Vertisols, are the dominant soil type in both districts. The crops widely grown in the study area include wheat, teff, faba bean and lentil; whereas chickpea, grass pea and others have low area coverage and they are mainly grown on residual soil moisture at the end of the rainy season. Figure 1 shows the geographical location of the experimental sites.

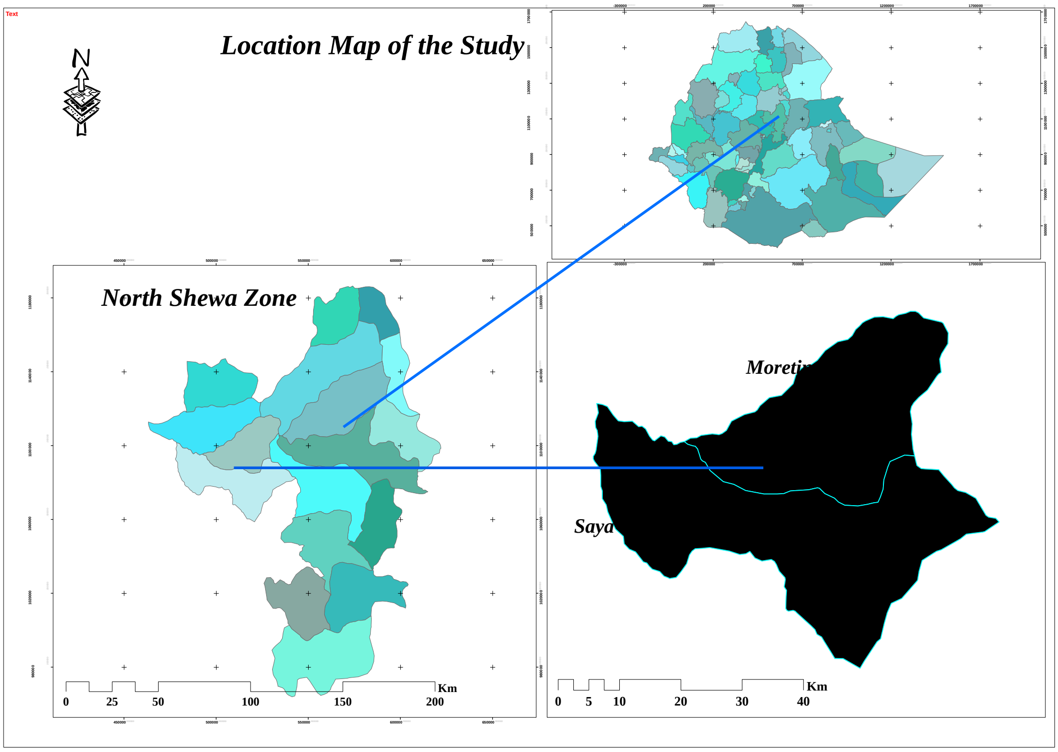

Figure 1. Location map of the study sites

Determination of P-critical and P-factor

The phosphorus calibration study was conducted in two phases. In the first phase, the optimum rate of N (192 N) that gave the highest yield was determined at Debra Birhan agricultural research center. In the next phase, the calibration study was conducted and the P critical and requirement factor were determined for the development of the final equation:

$Pr = (Pc - Po) * Pf$ ………………..equation 1 (***DBARC Model***)

Where

- Pr= P fertilizer requirement (kg ha^{-1})
- Pc= Critical P concentration =12.56 (mg kg^{-1})
- Po = Initial P values for the site
- Pf = P requirement factor =6.41
- DBARC-Debrebirhan agricultural Research center

$Pr = (Pc - Po) * Pf$ ………………..equation 2 (*GARC model*)

Where

- Pr= P fertilizer requirement (kg ha^{-1})
- Pc= Critical P concentration =15.8 (mg kg^{-1})
- Po = Initial P values for the site
- Pf = P requirement factor =5.4
- GARC-Gonder agricultural research center

Based on this equation, the verification of the developed model was implemented at *Enewari* and *Deneba* areas on 16 sites by using each farmer as a replication. The research was conducted for two years in the main rainy-season. The soils at both locations were generally referred to as Vertisol. The composite soil samples collected before planting were analyzed using the Olsen method (Sahlemdihin and Taye, 2000). Based on the available phosphorus and the above equation the phosphorus requirement of each farmer's field was calculated. The test crop for the experiment was wheat (*Menzaie variety*) at a seed rate of 175 kg ha^{-1}. Nitrogen was applied for all plots at the rate of 192 kg ha^{-1} half at planting and half at the tillering stage of the crop.

Treatments

1. ***Agronomic phosphorus fertilizer recommendation***. This is the P fertilizer previously recommended for the study areas. The agronomic P recommendation for the areas is 138 P_2O_5 and this fertilizer is recommended for all farmers plots without considering the inherent soil P level.
2. ***Soil test based phosphorus fertilizer recommendation (DBARC Model).*** This fertilizer recommendation is based on the soil P level and considers the inherent soil P levels of the farmer's field. For this recommendation, soil samples were collected from each farmer's field. The samples were analyzed for available P and hence this P level was modeled with DBARC phosphorus calibration equation (equation 1).
3. ***Soil test based phosphorus fertilizer recommendation (GARC model).*** This fertilizer recommendation is also based on the soil P level and consider the inherent soil P levels of farmers field. For this recommendation, soil samples were collected from each farmer's field. The samples were analyzed for available P and hence this P level was modeled with GARC phosphorus calibration equation (equation 2).

In the first year, the trial included two treatments (agronomic phosphorus fertilizer recommendation and Debra Birhan Agricultural Research Center (DBARC). In the second year Gonder Agricultural Research Center (GARC) model was also incorporated as the third treatment.

Results and Discussion

Initial soil P and phosphorus fertilizer requirement for the first year

The initial phosphorus level of the soil ranged from 5.8 to 11.4 ppm and hence based on the developed model the need for P_2O_5 fertilizer ranged from 17 to 102 kg ha^{-1} (Figure 2B). However, with agronomic fertilizer recommendation, the need for P_2O_5 was found to be 138 kg ha^{-1}, indicating that the P calibration model of DBARC could save about 51% of the P fertilizer to be applied.

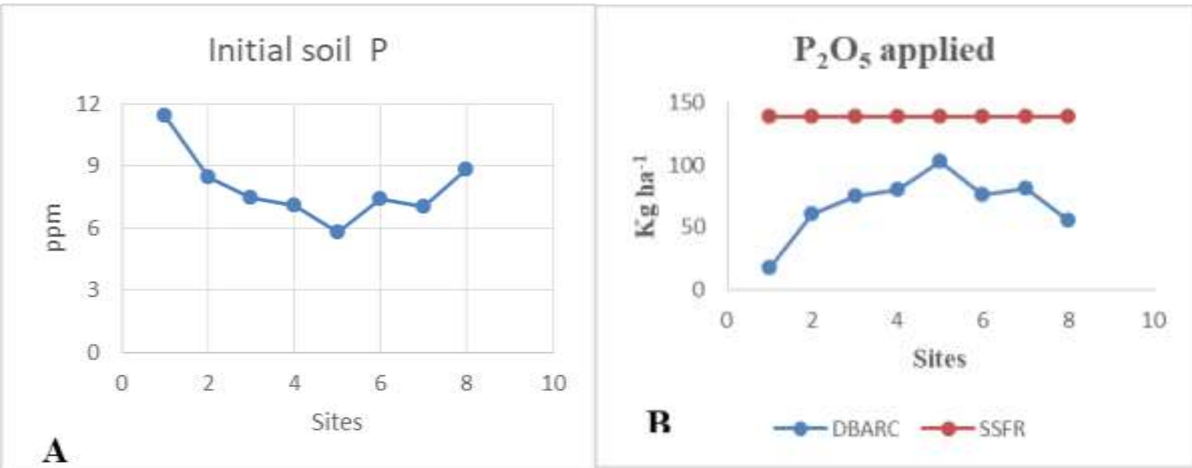

Figure 2. A-Initial soil phosphorus level (ppm), **B-**P_2O_5 kg ha^{-1}applied at each farm for the first year

*DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; SSFR: agronomic phosphorus fertilizer recommendation.

Initial soil P and P fertilizer requirement factor for the second year

The initial soil P-value ranged from 5.04 ppm to 14.29 ppm, indicating that the soil phosphorus level ranged from low to medium phosphorus, respectively (Figure 3A). Thus, based on the phosphorus requirement equation developed by DBARC, the needs for P_2O_5 were between 110.4 kg and 0 kg ha^{-1}. However, based on the P requirement equation developed by GARC, the need for P_2O_5 ranged from 133.6 kg ha^{-1} to 18.56 kg ha^{-1}. The mean phosphorus fertilizer applied to the soil also showed great difference and the mean P_2O_5 requirements of the soil were 138, 77 and 47 Kg ha^{-1} for agronomic phosphorus fertilizer recommendation, GARC and

DBARC model respectively. The results of the study also demonstrated that about 65.94% and 44.2% of P_2O_5 ha^{-1} could be saved by using DBARC and GARC P calibration model, respectively compared to the agronomic phosphorus fertilizer recommendation (138 kg P_2O_5). Likewise, GARC P calibration model resulted in a 30 kg P_2O_5 penalty compared with DBARC model. Similarly, Gebremedhin *et al*., (2015) reported that based on soil test based phosphorus fertilizer recommendation saves 23.8 kg P_2O_5 compared with blanket recommendation of 46 P_2O_5 in wheat-growing area of *Hintalo-wajirate* district

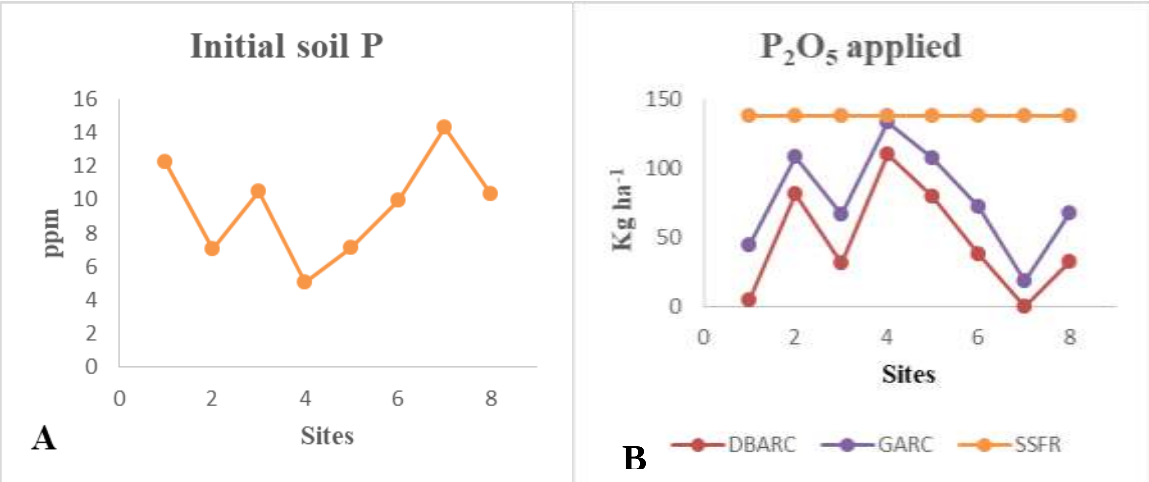

Figure 3. A- Initial soil phosphorus level, **B-**P_2O_5 applied at each farm for the second year

*DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; SSFR: agronomic phosphorus fertilizer recommendation; GARC: Gondar Agricultural Research Center phosphorus calibration model.

Grain yield

In the first year of the experiment, the statistical analysis showed that there was a non-significant difference between the model and agronomic fertilizer recommendation (Table 1) and the model worked best for most of the sites but failed to show the expected result for few locations (Figure 4A). Implying that there is high possibility of using the model in most sites instead of agronomic phosphorus fertilizer recommendation for the areas. For instances, for site 2, 3 and 8 the model resulted in yield advantages of 15.4% (535 kg ha^{-1}), 2.3% (59 kg ha^{-1}), and 6.8% (213 kg ha^{-1}) compared to the agronomic phosphorus fertilizer recommendation (138 kg ha^{-1} P_2O_5) respectively. However, in site 1, 4, 5, 7 and 8 agronomic phosphorus fertilizer recommendations (138 kg ha^{-1} P_2O_5) produced grain yield advantages of 4.4% (118 kg $ha^{-1)}$), 6.6% (230 kg ha^{-1}), 8.8% (279 kg ha^{-1}), 10.2% (304 kg ha^{-1}) and 3.2% (73 kg ha^{-1})

over the DBARC model, respectively. Generally, agronomic fertilizer recommendation had a mean grain yield advantage of 0.8% (24.6 kg ha^{-1}) over the DBARC model.

In the second year, the DBARC model worked best in some sites and produced a comparable and even higher grain yield than the agronomic phosphorus fertilizer recommendation (Figure 4B). In sites 1 and 2, DBARC model had a comparable wheat grain yield over agronomic phosphorus fertilizer recommendation, but in site 8, the model had a grain yield advantage of 339.3 kg ha^{-1} (7.9%). In contrast, in sites 2, 3, 4, 5 and 7, agronomic phosphorus fertilizer recommendation resulted in grain yield advantages of 411.5 kg ha^{-1} (8.9%), 798.2 kg ha^{-1} (24.4%), 543.3 kg ha^{-1} (9.7%), 149.5 Kg ha^{-1} (4.2%) and 876.6 kg ha^{-1} (20.9%), respectively over DBARC P calibration model. Generally, agronomic phosphorus fertilizer recommendation produced a yield advantage of 336 kg ha^{-1} (7.8%) over DBARC model. As compared to DBARC model, GARC model showed comparable and even higher yield on most of the testing sites. In sites 2, 4, 5 and 8, GARC model had gain yield advantages of 7.2 kg ha^{-1} (0.2 %), 193.9 kg ha^{-1} (5.4%) and 685.8 kg ha^{-1} (16%), respectively compared with agronomic phosphorus fertilizer recommendation.

Nevertheless, on sites 1, 3, 6 and 7, GARC model resulted in grain yield penalty of 702.9 kg ha^{-1} (14.9%), 318.7 kg ha^{-1} (9.8%), 329 kg ha^{-1} (10.8%), respectively compared to agronomic phosphorus fertilizer recommendation. Generally, the result indicated that GARC model had mean a yield penalties of 79.9 kg ha^{-1} (1.8%) and 256.4 kg ha^{-1} (6%) compared to agronomic phosphorus recommendation and DBARC P calibration model, respectively. In line with the present study, Gebremedhin *et al.*, (2015) reported that soil test based phosphorus fertilizer recommendation increase wheat yield by 14% compared with blanket recommendation (50 urea: 100 DAP). Similar results were also reported by Girma *et al*., (2018) for faba bean on nitisols, *Gidena* (2016) for teff on vertisols, Getachew and Berhane (2013) for malting barley on nitisols.

Table 1. Yield response of wheat as influenced by the treatment

Treatment	Grain Yield (kg ha^{-1})	Straw Yield kg ha^{-1})
First Year		
DBARC	2953	3872.18
Agronomic P Fertilizer recommendation	2977.6	3898.2
LSD	530.3	251.9
CV (%)	6.82	13.04
α = 0.05	Ns	Ns
Second Year		
DBARC	3989.6	5559.83
GARC	4246.1	5615.11
Agronomic P Fertilizer recommendation	4326.9	5579.41
LSD (0.05)	338.7	780.8
CV (%)	7.54	5.48
α = 0.05	Ns	Ns

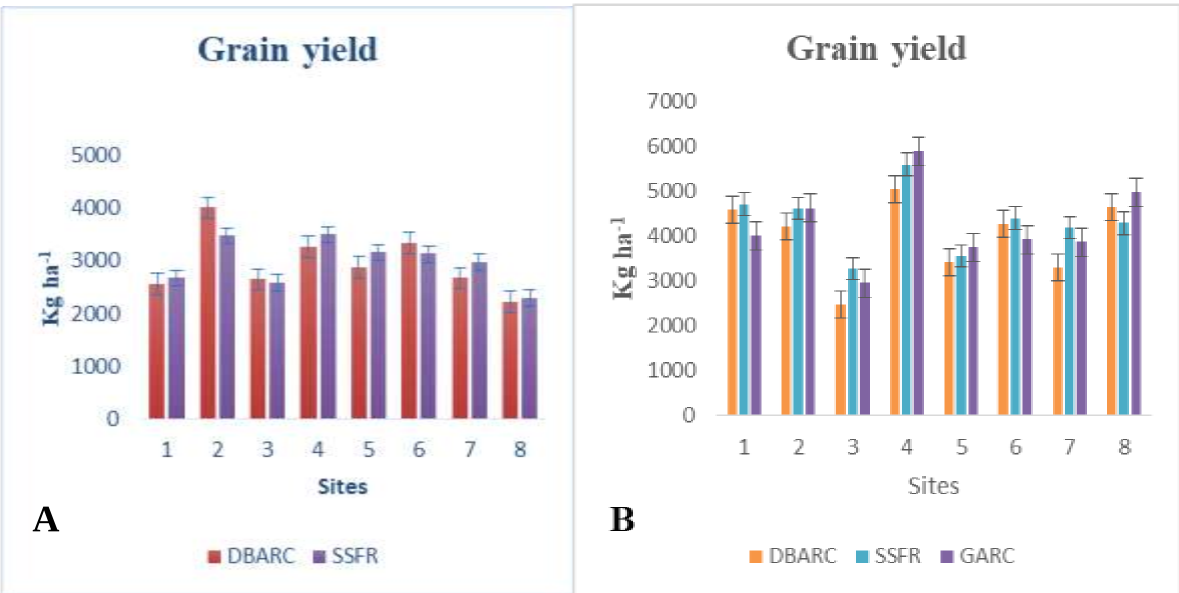

Figure 4: A-Grain yield of first year, **B-**Grain yield of second year

**DBARC means Debra Birhan agricultural research center phosphorus calibration model; SSFR, agronomic phosphorus fertilizer recommendation; GARC, Gondar agricultural research center phosphorus calibration model.*

Straw yield

In the first year, the model worked best for most of the tested sites. In sites 2, 3 and 6 DBARC model had straw yield advantages of 563.6 kg ha^{-1} (12.7 %), 62.15 kg ha^{-1} (1.7%) and 224.4 kg ha^{-1} (5.5 %), respectively. However, on sites 1,4,5,7 and 8, agronomic phosphorus fertilizer recommendation (138 kg ha^{-1}) resulted in straw yield advantages of 124.3 kg ha^{-1} (3.5%), 242.3 kg ha^{-1} (5.5%), 293.9 kg ha^{-1} (7.2%), 320.2 kg ha^{-1} (8.2%) and 76.9 kg ha^{-1} (2.4%), respectively. Generally, agronomic fertilizer recommendation produced a mean straw advantage of 25.9 kg ha^{-1} (0.7 %) as compared to the model.

In the second year, Figure 9 indicates that in most of the sites the DBARC phosphorus calibration model showed the expected result. In sites, 1, 2, 4, 5 and 8 the model outwitted that of agronomic phosphorus fertilizer recommendation (Figure 5B). In those sites, the model had straw yield advantages of 355.7 kg ha^{-1} (5.3 %), 81.5 kg ha^{-1} (1.7%), 2214 kg ha^{-1} (26.8%), 696 kg ha^{-1} (11.2%) and 300 kg ha^{-1} (5.7%), respectively. But on sites 3, 6 and 7 agronomic phosphorus fertilizer recommendation (138 kg ha^{-1}) resulted in straw yield advantages of 1656.2 kg ha^{-1} (73.3%), 787.9 Kg ha^{-1} (13.9%), and 1350.9 kg ha^{-1} (25.6%), respectively compared to the DBARC phosphorus calibration model. GARC model also showed the expected result and in sites 1, 2, 4, 5, 6 and 8 the model had straw yield advantages of 874.3 kg ha^{-1} (13.7 %), 384.7 kg ha^{-1} (8 %), 299.1 kg ha^{-1} (4.9 %), 84.6 kg ha^{-1} (1.5 %), 61.9 kg ha^{-1} (0.9 %) and 984.8 kg ha^{-1} (19.9 %) respectively compared to agronomic phosphorus recommendation. However, on the remaining sites (3 and 7) the GARC model resulted in a straw yield penalty of 805.4 kg ha^{-1} (20.6 %)
and 1589.2 Kg ha^{-1} (23.9 %) respectively.

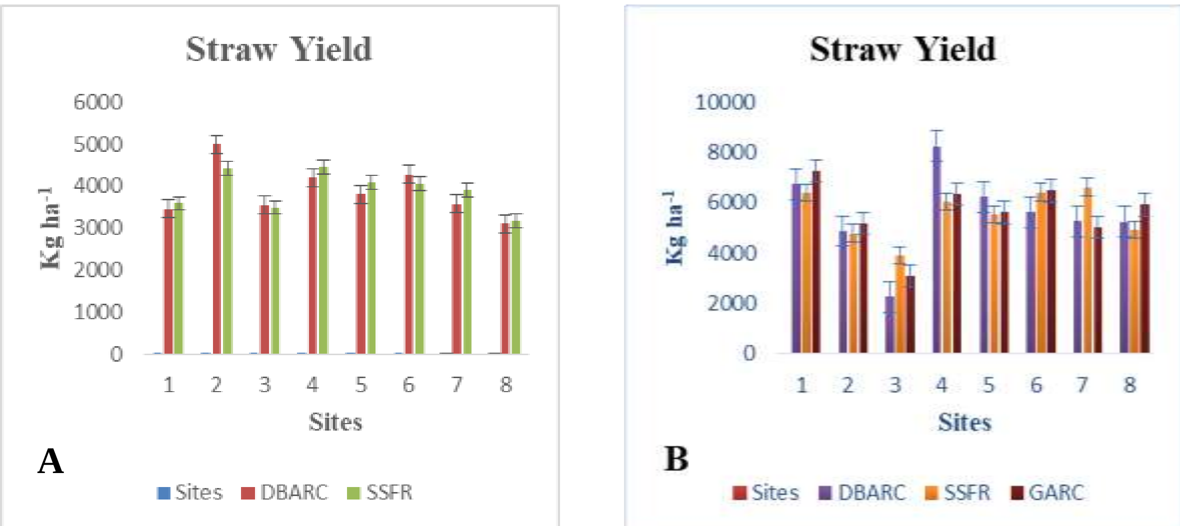

Figure 5. A-Straw yield of first year**, B-**Straw yield of second year

*DBARC means Debra Birhan agricultural research center phosphorus fertilizer calibration model; SSFR, agronomic phosphorus fertilizer recommendation; GARC, Gondar agricultural research center phosphorus fertilizer calibration model.

Cost-Benefit Analysis

The two years results indicated that DBARC phosphorus calibration model resulted in the highest net benefit compared to the agronomic phosphorus fertilizer recommendation and had a mean net benefit of 19088 ETB ha^{-1}. The same was true for the benefit-cost ratio . The result also revealed that GARC phosphorus calibration model also resulted in the highest net benefit (26457 ETB ha^{-1}) and benefit-cost ratio as compared to agronomic phosphorus fertilizer recommendation.

Table 2. Cost-benefit analysis of the soil test phosphorus calibration treatments

Treatment	GY (Kg ha)	SY (kg ha)	WP (ETB Kg)	TWP (ETB ha)	SP (ETB Kg)	TSP (ETB ha)	GB (ETB ha)	TC(ETB ha)	NB (ETB ha)	BCR
Mean of 1st year										
SSFR	2978	3898	8	22332	1.5	5847	28179	16638	11541	1.7
DBARC	2953	3872	8	22148	1.5	5808	27956	14911	13045	1.9
Mean of 2nd year										
SSFR	4326	5578	7.5	34608	1.5	8367	42975	17587	25388	2.4
GARC	4246	5615	7.5	33969	1.5	8423	42391	15934	26457	2.7
DBARC	3990	5560	7.5	31918	1.5	8340	40257	15125	25132	2.7
Grand mean of 2 years										
SSFR	3652	4738	7.8	28470	1.5	7107	35577	17113	18465	2.1
DBARC	3471	4716	8	27033	2	7074	34107	15018	19088	2.3

**GY: Means grain yield; SY: Straw yield; WP: Wheat price; TWP: Total wheat price; SP: Straw price; TSP: Total straw price; GB: Gross benefit; TC: Total cost; NB: Net benefit; BCR: Benefit-cost* ratio; *ETB: Ethiopian birr; SSFR: agronomic phosphorus fertilizer recommendation; DBARC: Debra Birhan Agricultural Research Center phosphorus calibration model; GARC: Gondar Agricultural Research Center model.*

Conclusion and Recommendation

Routine soil analysis for fertilizer recommendations is considered as an important component contributing to increased crop yields and maintaining soil productivity. The present study was conducted in wheat-producing areas of North Shewa zone on vertisols to verify the recommended soil test based calibration equation for P fertilizer. Accordingly, a non-significant difference between the model and agronomic fertilizer was found. Hence, it is possible to use the site-specific phosphorous fertilizer recommended model for wheat production in the study sites and similar agroecology and soil types. The P fertilizer model developed by DBARC had a mean phosphorus fertilizer saving advantage of 58.5% compared with agronomic fertilizer recommendation.

The two years result indicated that DBARC P calibration model had a higher net benefit than the agronomic P fertilizer recommendation and resulted in a mean net benefit of 19088 ETB ha^{-1}. Therefore, from this study, it is recommended that soil test based fertilizer recommendation shall be used for farmers having access to soil laboratories, and hence the P critical for the test crop was found to be 12.56. Besides (1) the facility and capacity of regional and different agricultural research center soil laboratories should be strengthened, (2) farmers access for soil laboratories should be secured (3) similar calibration study should be conducted to different soil type, agro-ecologies and test crop.

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Response of Potato (*Solanum tuberosum* L.) to nitrogen and phosphorus at Sekota and Lasta districts of Eastern Amhara, Ethiopia

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Abstract

Production and productivity of potato in Ethiopia is far below the world average due to soil fertility depletion, pest and diseases. Nutrient depletion because of soil erosion is a serious problem in Ethiopian highlands including Wag-Lasta areas. Essential nutrients like, nitrogen and phosphorus are the most important influential element for the production of potatoes. However, they are deficient in most Ethiopian soils and thus an application of these nutrients could increase significantly the crop yields. Therefore, the experiment was conducted at Sekota and Lasta Lalibela districts of eastern Amhara, Ethiopia with the objective of investigating the effects of nitrogen and phosphorus fertilizers for yield and yield component of potato under irrigation conditions. Four rates of nitrogen (0, 46, 92, and 138 kg N ha^{-1}) and phosphorus (0, 23, 46, and 69 Kg P_2O_5 ha^{-1}) were combined with factorial arrangement and laid out in a randomized complete block design with three replications. The result of the study revealed that nitrogen and phosphorus had a significant effect on plant height, marketable and total yield of potato at Kechin Abeba. But phosphorus did not show a significant effect on plant height and unmarketable yield at Sekota district of Woleh irrigation command area. The highest yield 45.55 t ha^{-1} was obtained from the combined application of 138 N and 23 P_2O_5 in Lalibela and 17.12 & 16.99 t ha^{-1} were found from the application of 138 kg N ha^{-1} with 46 kg P_2O_5 ha^{-1} and 138 kg N ha^{-1} with 23 kg P_2O_5 ha^{-1} from Sekota district of Woleh irrigation command area respectively. Therefore, the application of 138 kg ha^{-1} N with 23 kg ha^{-1} P_2O_5 is the appropriate nutrient rates for optimum productivity of Potato at Lalibela (Kechin Abeba) and Sekota (Woleh) irrigation command areas and the similar agro-ecologies.

Key words: Marketable yield, Nitrogen, Phosphorous, unmarketable yield, Total yield

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crop in the world. In the volume of production, it ranks fourth in the world after maize, rice, and wheat, with an estimated production area of 18.9 million hectares (Naz *et al*., 2011). Its yield in sub-Sahara Africa is below 10 t ha^{-1} while the attainable yields with good crop management are well above 30 t ha^{-1}. In Ethiopia, due to soil fertility depletion, lack of good quality seed, inadequate application of fertilizers, pests and disease, irregularity of water supply and traditional irrigation schemes and schedules, it's productivity is very low (Haverkort et al., 2012 and Emana and Nigussie, 2011). In addition to this, continuous cropping without replacing the removed nutrients from crop biomass and another organic source is a major problem of nutrient depletion in Ethiopia (Haileslassie *et al.,* 2005).

Plants require essential nutrients for their optimum growth and development, among them N and P are the most important ones because they are required in large quantities. The deficiency of these nutrients is manifested in the detrimental effects on the growth and development of the plants (Tisdale et al., 1995).

To meet the demand for the growing world population, fertilizer plays an indispensable role in achieving optimum crop production and productivity (Mengel and Kirkby, 1996). Applications of nitrogen and phosphorus fertilizers have a good yield response for different crops including potato in Ethiopia. Research conducted by Firew *et al.,* (2016) showed that combined application of nitrogen and phosphorus fertilizers had increased the yield of potato by 12.26 t ha^{-1} as compared to control (0 N, 0 P). Similarly, Wubengeda *et al., (*2016) reported that by increasing the rates of the two (N and P) nutrient the yield and yield components of potato was increased. Desalegn *et al.,* (2016) also, reported that increasing the rates of nitrogen and phosphorus can enhances the tuber yield by 361 and 358 % as compared with unfertilized treatment. Generally, the above-mentioned studies showed that appropriate agronomic practices including site-specific fertilizer recommendation plays a significant role in potato production. However, in the study areas, farmers utilized inorganic fertilizers with a blanket recommendation to increase potato production. Site-specific fertilizer recommendations play a significant role in potato production. But, there was no appropriate fertilizer rate recommendation for potatoes in the study areas. Therefore, the experiment was conducted to determine the optimum rates of nitrogen and phosphorus fertilizers for potato production at Sekota and Lasta districts of Amhara Region Ethiopia.

Material and Methods

Description of the study area

The experiment was conducted in 2015 and 2017 irrigation season at two sites; Sekota district Woleh and Lasta district Kechin Abeba. The sites are located (11° 57' 31.14'' and 12° 31'44.57''latitude, 39° 04'01.07'' and 39° 02'55.6'' longitude with analtitude of 2120 and 2101 meter above sea level (m.a.s.l), respectively (Fig 1). The schemes (Woleh and Kechin Abeba) can irrigate an area of 137.25 ha and 75 ha of land respectively. The topographical feature of the area is characterized by mountainous, plateaus, and hills. Soil erosion is a common problem in the areas. Due to this reason fertility status of the soil is very low (Table 1). Mixed agriculture is a common farming system in the study areas.

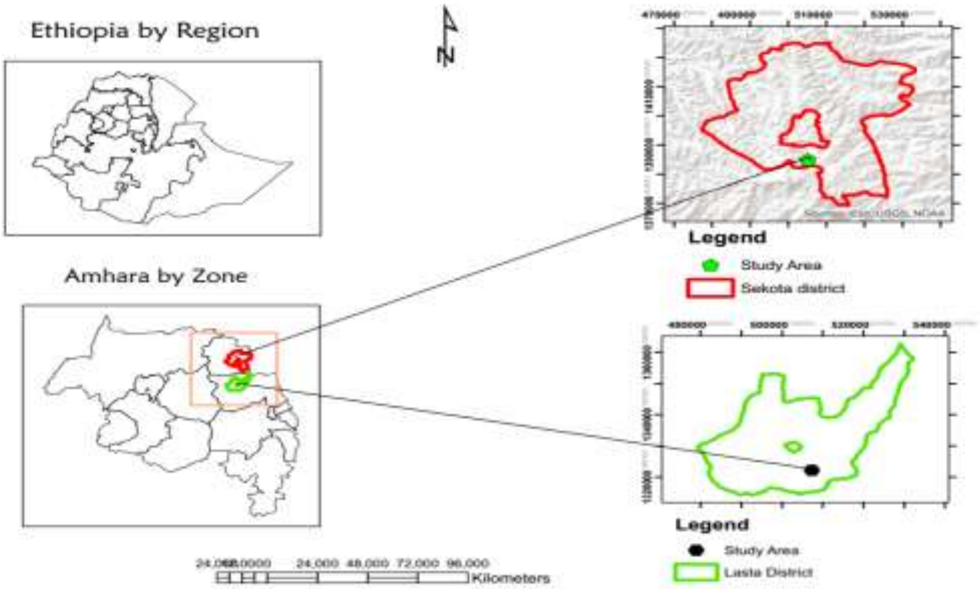

Figure 1. Map of the study area

Experimental treatments, design and procedures

Four levels of nitrogen (0, 46, 92, 138 kg ha^{-1}) and phosphorus (0, 23, 46, 69 kg ha^{-1}) were arranged in a factorial combination, giving a total of 16 treatments set in a Randomized Complete Block Design (RCBD) with three replications. The entire rate of P_2O_5 and the half rate of N fertilizers were applied at the time of planting. The remaining half of N was applied 45 days after planting. Urea (46% N) and Triple Super Phosphate (46% P_2O_5) were used as fertilizer sources for N and P, respectively. Medium size and well-sprouted potato tubers were planted at a spacing of 75 cm between rows and 30 cm between plants. The total plot size was 3mx3m (9 m^2), the spacing between plots and replications were 0.5 and 1 m, respectively. Cultural practices like cultivation, weeding and ridging were practiced as per recommendation. Watering was done within 5 days interval based on the recommendation and Gera variety was used for the study.

Soil physical and chemical properties Analysis

To determine the nutrient content of the soil before planting, composite soil samples were collected from 0-20 cm depth using the Edelman auger from the experimental sites. Samples were air-dried and ground to pass through a 2-mm sieve to get the fine earth fraction (<2 mm separates). Particle size distribution (sand, silt, and clay separate) was determined by hydrometer method as outlined by Bouyoucos (1965). 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 (Carter and Gregorich 2008). Organic carbon of the soil was determined following the wet digestion method as described by Walkley and Black (1934). Total nitrogen was determined by the Kjeldahl digestion, distillation and titration method (Bremner and Mulvaney, 1982) and available phosphorus was determined by the standard Olsen method (Olsen *et al.*, 1954).

Data collection and analysis

Plant height (cm), marketable tuber yields (ton), unmarketable tuber yield (ton) and total tuber yield (ton) were collected from the middle rows of the experimental plots. Data were subjected to analysis of variance using proc GLM (general linear model) procedure of SAS 9.0 software (SAS 2004). Treatments means were compared with LSD at 5% significance level.

Partial budget analysis

Partial budget analysis was carried out for every treatment based on CIMMYT (1988) to indicate the economic superiority of alternative treatments over the control treatment. Fertilizer cost and mean price of potato were collected from the districts. The average yield was adjusted downward by 10% from the exact yield to reflect the difference between the experimental yield and yield of farmers. MRR (%) was calculated as changes in net benefit divided by changes in variable cost.

Results and discussion

Pre planting soil property of the study sites

At Woleh, soil pH, EC and total nitrogen were numerically higher than at Kechin Abeba, but organic carbon and available phosphorus were low (Table 1). The sites had a textural class of clay loam and soil pH value of the surface soil at Woleh and Kechin Abeba were 7.3 and 7.6 respectively. According to Landon, (1991) soil pH rating is classified as neutral and slightly alkaline whereas, the electrical conductivity of the sites was free from salt (Landon 1991). Organic carbon content of the trial sites was very low and low at Woleh and Kechin Abeba respectively whereas, total nitrogen was at low category (Tadesse 1991). This might be due to the fact that the area had a long history of agriculture without replacing the complete removal of cover crop and burning crop residue as fuel which are the main cause for nutrient losses. According to Olsen (1954), the available phosphorous was high in both sites.

Table 1: soil sample result before planting

Sites	pH	EC	OC (%)	TN (%)	Avai.P (ppm)	Particle size distribution			
						Sand %	Silt %	Clay %	Textural class
Woleh	7.6	0.13	0.43	0.04	15.45	32.7	33.7	33.7	Clay loam
Kechin Abeba	7.3	0.12	0.55	0.02	18.04	30	30	40	Clay loam

EC; electrical conductivity, OC; organic carbon, TN; total nitrogen, Avai.P; available phosphorous and ppm; parts per million

Interaction effect of N and P nutrients on tuber yield and yield components of potato

A significant interaction (N*P) was observed for plant height and marketable yield in both years but total tuber yield interacted in the year of 2015 at Lalibela, Kechin Abeba irrigation command area (Table 2. In the same year, the main effect of phosphorous was on marketable and total yield as well as plant height of potato in this irrigation command area. Similarly, the main effect of nitrogen was significantly affected all parameters and the main effect of phosphorous was t only on the marketable and total yield of potato in the 2017 irrigation season at Kechin Abeba (Table 3).

Whereas at Woleh irrigation command area except plant height significant interaction was observed on the other stated parameters (Table 4). The main effects of nitrogen and phosphorous fertilization were significantly influenced the marketable , unmarketable and total yield of potato but, phosphorous had no effect on the plant height. In all parameters, the 2017 cropping season exceeded the 2015 production year (Fig 2). This is probably due to variation in irrigation water availability in the year between 2015 and 2017 (Table 5). There was a shortage of irrigation water in the year of 2015 irrigation season in the command area.

Table 2. ANOVA for the effect of N and P on the yield and yield parameters of potato (2015)

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
N	3	518.94*	101.55*	4.14*	138.09*
P	3	92.15*	11.94*	1.11^{ns}	12.04*
NXP	9	44.91*	12.75*	0.89^{ns}	12.57*
Error	32	19.38	2.50	0.57	3.81
Total	47				

*Where, ns: non-significant and *: significant.*

Table 3. ANOVA for the effect of N and P on the yield and yield parameters of potato 2017 at kechin Abeba

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield(t ha^{-1})	Total yield (t ha^{-1})
N	3	638.44*	418.95*	5.60*	451.10*
P	3	5.56^{ns}	67.91*	0.27^{ns}	65.04*
N*P	9	45.77*	69.57*	0.82^{ns}	71.06
Error	32	15.56	4.50	1.20	4.72
Total	47				

*Where, ns: non-significant and *: significant.*

Table 4. Combined ANOVA for the effect of N and P on the yield and yield parameters of potato at Woleh

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
N	3	193.65*	159.35*	5.79*	233.68*
P	3	35.86^{ns}	17.02*	2.76*	30.54*
NXP	9	51.45^{ns}	221.53*	1.33*	9.44*
Error	57	34.54	3.32	0.35	3.44
Total	72				

*Where, ns: non-significant and *: significant*

Plant height

Plant height was significantly affected by the application of nitrogen and phosphorous fertilizers in Kechin Abeba (Table 2 and 3). The highest plant height 72.58 cm was recorded from the application of 138 kg ha^{-1} N in the 2017 irrigation season whereas the highest plant heights 54.85 cm was recorded from application of 92 kg ha^{-1} N in the year of 2015. The increasing rate of nitrogen and phosphorus fertilizer in the irrigation season of 2015 increases plant height by 14.81 and 4.97cm whereas, in the irrigation season of 2017 application of nitrogen alone at a rate of 138 kg ha^{-1} increases plant height by 16.14 over the control treatment. The current study in this particular site was in line with Zelalem *et al.,* (2009) who reported that nitrogen and phosphorus at a rate of 207 and 60 kg ha^{-1} increases plant height by 24 cm and 10.5cm respectively. Similarly, Israel *et al.,* (2012), Alemayehu *et al.,* (2015) and Fayera, (2017) have found that increasing the application of nitrogen and phosphorus significantly increased the plant height of potatoes.

Table 5. Effect of Nitrogen and phosphorus on plant height (cm) at Kechin Abeba and Woleh sites

N level kg ha^{-1}	Plant height (cm) (at Kechin Abeba)		Plant height (cm) (at Woleh)		
	2015	2017	2015	2017	Combined over year at Woleh
0	40.05	55.86	46.63	39.66	43.15
46	46.67	61.94	48.89	41.95	45.42
92	54.85	68.14	51.13	43.65	47.39
138	52.35	72.58	53.13	46.50	49.82
LSD $_{(0.05)}$	3.24*	3.28*	3.18*	5.69*	3.39*
P_2O_5 level kg ha^{-1}					
0	46.93	65.34	49.28	42.07	45.67
23	49.45	63.75	50.36	40.44	45.40
46	45.65	64.66	50.64	45.59	48.11
69	51.90	64.81	49.50	43.66	46.58
LSD(0.05)	3.24*	3.28^{ns}	Ns	Ns	ns
CV(%)	9.08	6.10	7.43	15.95	12.65

*Where, ns: non-significant and *: significant*

In Woleh the main effect of nitrogen fertilization had significantly influenced plant height of potatoes but, their interaction exhibited a non-significant effect (table 4). The highest plant height (49.82cm) was obtained from applied fertilizer rates of 138 kg ha^{-1} N at Woleh while the lowest plant height (43.15) was obtained from the control treatment (Table 5). The application of phosphorous fertilizer didn't show a significant effect on the plant height during the study (Table 5). The current study Woleh site was in line with Sanjana *et al.,*

(2014) who reported that increasing the rate of nitrogen up to 375 kg ha^{-1} increases the plant height of potato.

Marketable yield

Both the main and interaction effects of nitrogen and phosphorus fertilizer application affected the marketable yield of potatoes at Kechin Abeba and Woleh. The increasing rate of nitrogen and phosphorus significantly increases the marketable yield of potato in both sites. The highest marketable yield (45.55 & 19.57 t ha^{-1}) were recorded from 138 kg ha^{-1} nitrogen combined with phosphorus at a rate of 23 kg ha^{-1} in 2017 and 2015 respectively (Table 6) whereas the lowest marketable yield (17.71 t ha^{-1}) and (8.1 t ha^{-1}) was recorded from treatment (0, 69 NP) in 2017 and 2015 respectively. The increasing rate of phosphorous alone decreases potato tuber yield by 28 and 14 % in 2015 and 2017 irrigation season. The marketable yield of potato gained in the year of 2017 irrigation season was exceeded the irrigation season of 2015. This is probably due to irrigation water availability in the year between 2015 and 2017. There was irrigation water scarcity in the year 2015 in the irrigation command area. But, the superior treatment in the year of 2015 and 2017 irrigation seasons were showed a similar trend.

In the case of Woleh, the highest marketable yield (17. 12 t ha^{-1}) was recorded from 138 kg ha^{-1} nitrogen combined with phosphorus at a rate of 46 kg ha^{-1} whereas the lowest marketable yield (8.16 t ha^{-1}) was recorded from the control treatment (0, 0 NP kg ha^{-1}) (Table 7). There was tuber yield reduction in Woleh and Kechin Abeba in 2015 by half as compared to tuber yield gained in 2017 Kechin Abeba. This was attributed to the fact that water is the most important limiting factor for potato production and it's possible to increase production levels by well-scheduled irrigation programs throughout the growing season (Liu *et al.,* 2006). Similarly, (Demlie, 2012) observed that 64% and 39 % tuber yield reduction were recorded from the application of 25%, and 50% (deficit) of the total crop water requirement at all stages, respectively. Therefore, this yield reduction observed in Woleh and Kechin Abeba in 2015 was most probably due to irrigation water scarcity, because water is essential for the germination of seeds, growth of plant roots, and nutrition, photosynthesis, transpiration and to maintain the turgidity of cell walls and multiplication of soil organisms. However, the marketable yield was increased by 24.95 t ha^{-1} and 8.96 t ha^{-1} over control treatment at Kechin Abeba and Woleh respectively. This might be because nitrogen supply plays a major role in the growth and development of plants as well as yield. This is because nitrogen is an essential constituent of protein and chlorophyll (Sandhu et al. 2014). Besides, phosphorus performs plants functions such as a forming of the macromolecular structures such as nucleic acids (RNA and DNA) and in the phospholipids of cell membranes (Marschner 2002). The current study is in agreement with previous studies such as Zelalem *et al.,* (2009), Israel *et al.,* (2012), Gebremariam, (2014), and Alemayehu *et al.,(*2015), who reported that increasing rate of nitrogen increases marketable tuber yield significantly. Similarly, Desalegn *et al.,* (2016) observed an increment of potato marketable yield with increasing of NP fertilizer in southern Ethiopia.

Table 6. Effect of N and P on marketable potato tuber yield at Kechin Abeba 2015 and 2017

	2015				2017			
	P_2O_5 t ha^{-1}				P_2O_5 t ha^{-1}			
N kg ha^{-1}	0	23	46	69	0	23	46	69
0	11.26	11.66	11.87	8.10	20.60	21.89	23.66	17.71
46	16.76	17.91	17.56	12.96	23.82	28.53	28.93	27.24
92	15.01	15.68	19.23	14.29	26.54	19.67	29.23	33.52
138	14.95	19.57	17.02	16.77	14.95	45.55	37.70	29.35
LSD(0.05)	2.63*				3.53**			
CV(%)	10.52				7.58			

Where, ns: non-significant,: significant, **: highly significant, t; ton*

Table 7. Combined analysis of potato marketable yield (t ha^{-1}) at Woleh

	P_2O_5 t ha^{-1}			
N kg ha^{-1}	0	23	46	69
0	8.16	11.00	10.77	11.76
46	13.66	13.49	14.28	13.61
92	12.04	15.23	14.58	14.15
138	15.99	16.99	17.12	16.76
LSD (0.05)	3.15*			
CV (%)	14.55			

*Where, ns: non-significant and *: significant, t; ton*

Unmarketable and total yield of potato

Both the main and interaction effect of nitrogen and phosphorus fertilizer application had affected the unmarketable and total yield of potato significantly at Woleh but, at Kechin Abeba only the application of nitrogen affected significantly the unmarketable and total yield of potato (Table 2, 3, and 8). The highest unmarketable yield (2.88 & 4.06 t ha^{-1}) was recorded at a rate of 92 kg ha^{-1} N in the year 2015 and 2017 respectively at Kechin Abeba (Table 8). Phosphorus fertilizer application did not affect the total yield of potato in the year of 2017 but, in the year of 2015, the highest yield was recorded at an application rate of 23 kg ha^{-1} P_2O_5. The highest total yields of 25.39 and 38.82 t ha^{-1} at Kechin Abeba was recorded at a rate of 138 kg ha^{-1} N in 2015 and 2017 respectively. In the case of Woleh the highest total yield (19.39 t ha^{-1} & 16.84 t ha^{-1}) was obtained from the application of 138 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 and the lowest (11.80 & 14.21 t ha^{-1}) were obtained from the unfertilized treatment in the years of 2015 and 2017 respectively. Similarly highest unmarketable yield was obtained from the application of N 138 and P_2O_5 46 kg ha^{-1} (Table 8).

Table 8. Effect of nitrogen and phosphorus on unmarketable and total yield (t ha^{-1}) of potato at Woleh

	Kechin Abeba				Woleh					
N level kg ha^{-1}	Unmarketable yield		Total yield		Unmarketable yield			Total yield		
	2015	2017	2015	2017	2015	2017	Combined	2015	2017	Combined
0	1.45	2.87	12.18	23.88	1.32	1.65	1.48	12.76	10.84	11.80
46	2.14	2.47	18.44	30.29	2.41	1.96	2.18	18.83	12.45	15.64
92	2.88	4.06	20.94	31.68	2.34	1.89	2.11	18.04	14.66	16.35
138	2.31	3.36	25.39	38.82	3.19	2.17	2.68	20.60	18.18	19.39
LSD $_{(0.05)}$	0.58*	0.91*	1.01*	1.80*	0.41*	0.39*	0.34*	1.11*	1.41*	1.07*
P_2O_5 level kg/ha										
0	2.37	3.14	16.87	34.53	19.45	1.71	1.83	15.52	12.90	14.21
23	2.40	3.23	18.61	30.85	20.83	1.91	2.00	18.99	13.51	16.25
46	1.75	3.38	17.23	29.31	33.88	1.83	2.61	18.69	15.00	16.84
69	2.26	3.02	16.24	29.98	18.38	2.22	2.03	17.03	14.71	15.87
$LSD_{(0.05)}$	0.58*	Ns	1.01*	2.54*	4.13*	0.39*	0.34*	1.11*	1.41*	1.07*
CV(%)	34.51	34.35	11.33	6.96	20.82	24.87	28.08	7.41	12.10	11.75

*Where, ns: non-significant and *: significant*

Partial budget analysis

Application of nitrogen and phosphorous at a rate of 138 kg ha^{-1} and 23 kg ha^{-1} respectively gave the highest marketable yield (15.29 t ha^{-1}) and net benefit (164597 Ethiopian Birr) at Woleh irrigation command area (Table 9). The MRR (1606.90 %) was gained from the treatment of 138 N and 23 P_2O_5 kg ha^{-1} this implies that for each one Birr that invested in the new technology, the producer can receive to recover the one Birr invested plus an additional return of 16.06 Ethiopian Birr.

Table 9. Partial budget analysis at Woleh

N	P_2O_5	Unadjusted yield(t ha^{-1})	Adjusted (t ha^{-1})	Gross benefit (Ethiopian Birr)	Costs that varies (Ethiopian Birr)	Net benefit (Ethiopian Birr)	MRR%
0	0	9.86	8.874	97614	0	97614	
0	23	11	9.9	108900	580	108320	1845.86
46	0	11.66	10.49	115434	1008	114426	1426.64
0	46	10.77	9.69	106623	1160	105463	D
46	23	13.49	12.14	133551	1588	131963	3023.62
0	69	11.76	10.58	116424	1740	114684	D
92	0	12.04	10.83	119196	2016	117180	D
46	46	14.28	12.85	141372	2168	139204	1248.45
92	23	15.23	13.70	150777	2596	148181	2097.43
46	69	13.61	12.24	134739	2748	131991	D
138	0	15.99	14.39	158301	3024	155277	1657.94
92	46	14.58	13.12	144342	3176	141166	D
138	23	16.99	15.29	168201	3604	164597	1606.90
92	69	14.15	12.73	140085	3756	136329	D
138	46	17.12	15.40	169 488	4184	165304	121.90
138	69	16.76	15.08	165924	4764	161160	D

D stands for dominated treatment

Conclusion and recommendation

Application of nitrogen and phosphorus fertilizer had a significant effect on the tuber yield of potato. This study confirmed that nitrogen and phosphorus fertilizers and their interaction had a sound and promising impact on marketable and total tuber yield of potato. The result showed that by applying nitrogen and phosphorous at rates of 138 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 gave a yield advantage of 108.21% and 121.12% over the control treatment at Woleh and Kechin Abeba irrigation command area. Therefore, the application of 138 kg ha^{-1} N and 23 kg P_2O_5 ha^{-1} is the appropriate rate for optimum productivity of Potato for Woleh and Kechin Abeba under irrigation and the same agro-ecologies.

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Effect of Nitrogen under Balanced Fertilization on Food Barley at Basona Warana District of North Shewa Zone of Amhara Region, Ethiopia

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Abstract

The present experiment was conducted at Basona Warana district of North Shewa Zone during main rainy season of 2013 to 2016 to determine the effect of application of different doses of nitrogen (N) on yield and yield attributes of food barley (var. HRo713). The treatments included the control (0), 46, 92, 138,176 and 222 kg N ha^{-1} and 69 P_20_5, 80 K_20, 30 S, 0.5 B, 2 Zn and 2 Cu kg ha^{-1} were applied uniformly to all plots. The treatments were laid out in a completely randomized block design with three replications. At each location every year, the 6 N levels were assigned to plots of each block randomly. Results indicated that nitrogen rates significantly affected growth and yield component of barley as compared to the control treatment with balanced fertilization. The application of N significantly increased plant height and yield of barley. Also the highest grain and straw yields of barley were recorded from the application of nitrogen at the rate of 222 kg ha^{-1}. The economic analysis revealed that the highest net return of Birr 42,698.7ha^{-1} and marginal rate of return 471.1% were obtained from the addition of 222 kg N ha^{-1}. In fact, consistent yield increments were observed with increased N rates up to 222 kg N ha^{-1}, but the rate beyond 92 kg N ha^{-1} will be practically difficult for adoption. Rather, it would be advisable that the farmer to invest in to integrated soil fertility management (ISFM) to improve overall soil biophysical and chemical properties because soil organic carbon content is very low, which has direct implication on the efficiency of applied N fertilizer. Therefore, application of 92 kg N ha^{-1} under balanced fertilization could be feasible and recommended for farmers producing food barley in Basona Warana district of North Shewa and areas with the same agro-ecological condition. But additional field verification trials will be needed to get the recommendation wider applicability.

Keywords*:* Balanced fertilization, Food barley, Nitrogen fertilizer

Introduction

Barely (*Hordeum Vulgare L.*) is one of the most important food crops produced in the world. It ranks the fourth in the total cereal production in the world after wheat, rice and maize (FAO, 2004). Many countries grow barley as a commercial crop; Russia, Canada, Germany, Ukraine and France are the major barley producers, accounting for nearly half of the total world production (Edney and Tipples, 1997). It is also one of the most important staple food crops produced in the highland areas of Ethiopia. Its grain is used for the preparation of different foodstuffs, such as *Injera, Kolo, bread,* and local drinks, such as *tela, borde* and beer. Currently, the production and consumption of barley has increased all over the world due to its health and nutritional value in human diets. The straw is also used as animal feed, especially during the dry season (Hailu and Joop, 1996).

In Ethiopia, barley ranks fourth both in area coverage and production among cereals (CSA, 2018). The yield of barley is 2.16 t ha^{-1} (CSA, 2018), which is very low compared to its potential yield of over 6 t ha^{-1} on experimental plots (Berhane *et al.,* 1996). Despite the importance of barely, there are several factors affecting its yield and production. The most important factors that reduce yield of barley in Ethiopia include poor soil fertility, water logging, drought, frost, soil acidity, diseases and insect pests, 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 management practices in the past have resulted low fertility (Berhanu *et al.*, 2005; Getachew *et al*., 2014). Particularly, deficiency of nitrogen and phosphorus is the main factor that severely reduces the yield of barely (Desta, 1983; Getachew *et al*., 2011). Poor crop management practices including mono-cropping practices are also among the major production constraints affecting the productivity of barley (Abraham *et al*., 2011; Getachew *et al*., 2014)

Utilization of fertilizers are an integral part of improved crop production technology and their proper management to crops is important for maximum yield production (Corbeels *et al.,* 1999). Results of several studies also have shown that nitrogen fertilizer increases grain yield and its protein content (Asadi *et al*., 2013). Although some trials were conducted on the response of barley to N fertilizer, the studies undertaken so far on the determination of optimum nitrogen fertilizer rates for barley were not under balanced fertilization in the study area. The present study was, therefore, carried out to find out the effect of different levels of applied nitrogen fertilizer under balanced fertilizer application and to determine economically optimum N arte for barley production.

Materials and methods

Description of the study area

The experiment was conducted at Goshebado and Gudoberet areas of Basona Warana district, North Shewa Zone of the Amhara Regional State, 147 and 172 km northwest, and East of Addis Ababa, respectively. The dominant soil type of the study area is classified as Vertisols having low organic matter (Abayneh *et al.*, 2006; Gryseels and Anderson, 1983). Geographically, the experimental sites were located at a range of 09^0.43'.58.4" to 09^0.44'45.8" N and 039^0.25'.39.1"to 039^0.27'.29.4" E and an altitude of 2796 to 2990 m.a.s.l at Goshebado and 09^0.46'.21.2" to N 09^0.47'.06.5" and 039^0.39'.37.3" to 039^0.40'.08.5" E and an altitude of 2914 to 3043 m.a.s.l at Gudoberet. . It has unimodal rainfall pattern, with a maximum and minimum rainfall of 293.07 mm and 4.67 mm, which peaks in July and December, respectively. The mean annual rainfall is 934.2 mm. The mean annual maximum temperature is 19.82^{o}C and monthly values range between 18.4 ^{o}C in August and 21.8 ^{o}C in June. The mean annual minimum temperature is 6.4 ^{o}C and monthly values range between 2.8 ^{o}C in November and 8.8 ^{o}C in June. The coldest month occurs in November while the hottest months are May and June (Figure 1).

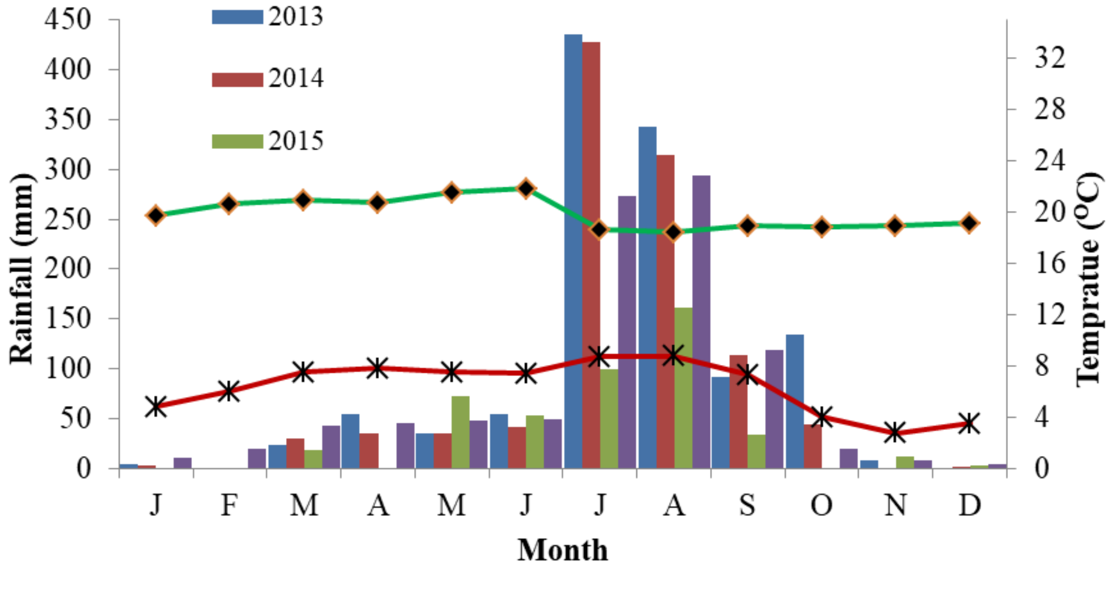

Figure 1. Mean and Monthly Rainfall, mean monthly minimum and maximum temperature of the study areas.

Experimental design and procedure

The experiment was carried out on farmers' fields during the main rainy seasons for three consecutive years (2013-16). Before starting the experiment, initial composite soil samples (0-20 cm depth) were collected from the experimental plots in a zigzag method each year. The experiment was laid out in randomized complete block design (RCBD) with three replications and a unit plot size was 3.6 x 3.4 m (12.24m^2), with 1m alley between each replication and the plots were separated by 0.5 m.

According to farmers' conventional practices, the experimental field was first prepared by using oxen-drawn implement (locally known as *Maresha*). The treatment consisted of six levels of nitrogen (0, 46, 92, 138,176 and 222 kg ha^{-1}) with combination of 69 P_20_5, 80 K_20 30 S, 0.5 B, 2 Zn and 2 kg Cu ha^{-1} fertilizers. The full amount of P, K, S 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 ($CaS0_4$) and urea respectively. The remaining half urea for N was applied as top dressing 45 days after sowing (at tillers development stage). Micronutrients (Zn, B, and Cu) in the form of $ZnS0_4$, Borax and $CuS0_4$ respectively were applied as foliar two times at tillers developments stage of the crop. Barley (*var. HB1307*) seed was drilled in row with 20 cm apart between rows at the rate of 138 kg ha^{-1}.

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 rates of N fertilizer under balanced fertilization. Least Significant Difference (LSD) test at $P \leq 0.05$ was used to separate means whenever there were significant differences among different treatments.

Economic analysis

Variable costs incurred for the production of barley and local market price of barley were recorded for partial budget analysis to examine the effect of application of balanced nutrient on barley yield. To minimize overestimation of yield from the experimental plot, mean grain and straw yield were adjusted downward by 10% to actual filed condition according to CIMMYT (1988).

Results and discussion

Soil physicochemical properties

The pre-experiment analysis of selected soil physical and chemical properties used in the study area is presented in Table 1. The pH of the soil ranged from 5.87 to 6.88 for Goshebado and 6.20 to 6.41 for Gudoberet which showed that the soil of the study area was slightly acidic to neutral (Tekalegn, 1991). According to Landon (1991), the soils were low to medium in total nitrogen (TN), very low and high in available phosphorus (Av. P), and low in organic carbon (OC).

Table 1. Selected physicochemical properties of experimental soils before planting of barley

Parameters	2013/14	2014/15	2015/16	Soil test interpretation
pH (1:2.5)	6.59	6.08	6.14	Slightly acidic to acidic
Total nitrogen (%)	0.12	0.09	0.09	Very low to medium
Organic carbon (%)	1.31	0.89	0.86	Low
Av. P (ppm)	9.98	9.09	8.34	Low
Sand (%)	22.4	32.0	29.0	-
Clay (%)	49.6	37.0	47.0	-
Silt (%)	28.0	31.0	24.0	-
Soil Texture	Clay	Clay loam	Clay	-

Effect of nitrogen on growth and yield of barley

The result showed that plant height was significantly ($P < 0.01$) affected by N fertilizer rates (Table 2). The highest plant height was recorded with application of 222 kg N ha^{-1} and the lowest value was from the control across three years. The possible reason for attaining maximum values of growth parameters of barely with application of 222 kg N ha^{-1} might be that nitrogen is the major component of chlorophyll and proteins which enhanced growth and development of plants (Kandil, 2013). The other reason might be that the application of higher nitrogen rates with balanced fertilization had a pronounced effect on increasing the vegetative growth of crop pants. In consistent with the present study, other research findings also indicated that nitrogenous fertilizer significantly increased plant height (Mesfen and Zemach, 2015; Wakene *et al.*, 2014; Getachew *et al*., 2014).

Table 2. Mean square values for yield and yield attributes of food barley as affected by different level of nitrogen and years

Parameters	Mean square source of variation				
	Year(2)	Rep (2)	N (5)	Year X N (10)	Error (20)
PH (cm)	837.06**	171.86*	1433.83**	8.60ns	42.65
GY (kg ha^{-1})	1446151.1*	1314980.8ns	26068951.2**	235822.2ns	364595.9
STY (kg ha^{-1})	1859473.1ns	889011.0ns	51434727.2**	269855.6ns	1267475.0

PH=Plant height, GY=Grain yield, STY=Straw yield

Table 2. Effect of different rates of nitrogen fertilizer under balanced fertilization on plant height of food barley

N level (kg ha^{-1})	2013/14	2014/15	2015/16	Mean
0	66.20^{d}	73.58^{d}	75.83^{e}	71.87^{d}
46	71.43^{c}	78.93^{c}	81.75^{d}	77.37^{c}
92	75.95^{bc}	86.03^{b}	87.28^{c}	83.09^{b}
138	80.05^{b}	89.07^{b}	89.54^{c}	86.22^{b}
176	88.50^{a}	94.83^{a}	94.47^{b}	92.60^{a}
222	91.26^{a}	96.70^{a}	98.06^{a}	95.34^{a}
LSD (0.05)	4.58	3.41	3.08	4.33
CV (%)	4.85	3.29	2.93	7.74

Means in a column with different letters are significantly different at 5% level.

The analysis of variance showed that grain and straw yields of barley at both locations were significantly ($P < 0.01$) influenced by the application of different rates of N fertilizer (Table 3). Barley grain and straw yields consistently increased with the increase in the rate of nitrogen application. The maximum grain and straw yields of 5224.1 and 6785.7 kg ha^{-1} were obtained from the addition of 222 kg N ha^{-1}, respectively. The application of 222 kg ha^{-1} N under balanced fertilization resulted in barley grain and straw yield increments of 172% (3499.8 kg) and 207% (4574.4 kg) compared to the control without nitrogen application under balanced fertilization. The increase in grain yield ha^{-1} as a result of increased nitrogen fertilizer application could be attributed to the enhanced development of yield components of barley which ultimately increased grain yield and total biomass of barley. Overall, the results of the study exhibited a significant effect of nitrogen fertilizer on growth and yield of barley, which agrees with the findings of other studies (Alam et al., 2007; Getachew *et al*., 2014).

Table 3. Effect of different rates of nitrogen fertilizer rate with balanced fertilization to barley

N (kg ha^{-1})	Grain yield (kg ha^{-1})				Straw yield (kg ha^{-1})			
	2013/14	2014/15	2015/16	Mean	2013/14	2014/15	2015/16	Mean
0	2194.6^{e}	1970.4^{f}	1607.8^{d}	1924.3^{e}	2648.2^{f}	2152.3^{f}	1833.3^{e}	2211.3^{e}
46	2939.5^{d}	2861.5^{e}	2582.1^{c}	2794.4^{d}	3662.2^{e}	3352.1^{e}	3060.8^{d}	3358.3^{d}
92	3760.5^{c}	3767.1^{d}	3828.4^{b}	3785.4^{c}	4105.7^{d}	4359.5^{d}	4108.8^{c}	4191.3^{c}
138	3968.1^{c}	4289.2^{c}	4017.2^{b}	4091.5^{c}	5268.4^{c}	5286.3^{c}	5148.5^{b}	5234.4^{b}
176	4762.4^{b}	4909.1^{b}	4098.0^{b}	4589.9^{b}	6358.5^{b}	5956.3^{b}	5389.7^{b}	5901.5^{b}
222	5218.1^{a}	5537.7^{a}	4916.7^{a}	5224.1^{a}	6841.2^{a}	6856.6^{a}	6659.3^{a}	6785.7^{a}
LSD (0.05)	292.46	452.57	347.20	399.99	437.29	338.70	448.89	745.58
CV (%)	6.42	9.72	8.27	16.17	7.59	6.07	8.59	24.40

Means in a column with different letters are significantly different at 5%

Nitrogen fertilizer rates significantly correlated with barley grain yield. The relationship of nitrogen fertilizer application and barley grain yield was fitted to quadratic equation (Figure 2). Grain yield increased rapidly as N application rate increased significantly from 0 to 222 kg ha^{-1}, which implies that significantly higher grain yield could be attained at the highest N application rate at the study sites (Figure 2). Similarly, Getachew et al., (2015) reported that yield and yield components of barley were significantly correlated with N rates.

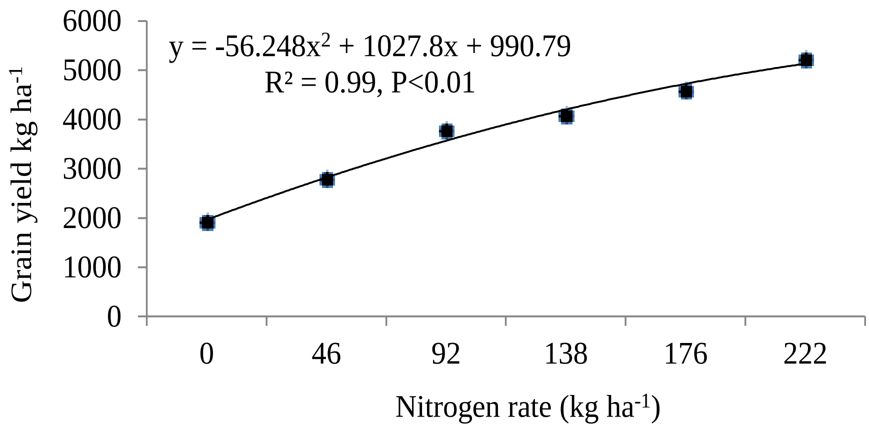

Figure 2. The relationship of N fertilizer rates with the grain yield of barley

Partial Budget Analysis

According to CIMMYT (1988), the partial budget analysis of N-fertilizer on food barley revealed that the highest net benefit was obtained from the application of 222 N kg ha^{-1}. The maximum net benefit of 42698.7 ETB ha^{-1} with the optimum marginal rate of return was recorded at the rate of 222 kg N ha^{-1}, followed by nitrogen application rate of 176 kg N ha^{-1} (Table 4). MRR of Nitrogen at all rates including 92 kg ha^{-1}rate was above the 100% minimum and this in line with CIMMT, (1988). But investing on additional nitrogen fertilizer rate above 92 kg ha^{-1}gave less MRR. Therefore, the treatments that have highest Marginal rate of return (MRR %), is Nitrogen at 92 kg ha^{-1} rate for food barley production is recommended.

Table 4. Partial budget and marginal rate of return analysis

N (kg ha^{-1})	TVC (ETB)	Grain (kg ha^{-1})	Straw (kg ha^{-1})	TR (ETB)	NR (ETB)	MRR(Ratio)	MRR(%)
0	4041.0	1732	2031	18658.2	14617.2	-	-
46	5,141.0	2515	2998	27221.0	22080.0	6.8	678.5
92	6,241.0	3407	3998	36712.6	30471.6	7.6	762.9
138	7,341.0	3682	4666	40564.7	33223.7	2.5	250.2
176	8,249.7	4131	5337	45766.4	37516.7	4.7	472.5
222	9,349.7	4702	6057	52048.4	42698.7	4.7	471.1

TVC=Total Variable cost, TR=Total Revenue, NR=Net Return and MRR=Marginal Rate of Return

Conclusion and Recommendation

The results of the study revealed that the application of 92 kg N ha^{-1} gave better barley grain yield and economic benefit than yields obtained without N application over three cropping seasons. Based on the findings of this study, the combined application of 92 kg N ha^{-1} with 69 P_20_5, 80 K_20 30 S, 0.5 B, 2 Zn and 2 kg Cu ha^{-1} fertilizers could be recommended for food barley production for the study areas and similar agro-ecologies.

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Response of soybean to inoculation with *bradyhrizobia spp.*: effect on root nodulation, yield and residual soil nitrogen

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Abstract

Legume crops depend on biological nitrogen fixation through symbiosis with rhizobia to partially or fully meet their N requirement. Soybean is an exotic crop to Ethiopia and thus inoculation with effective rhizobia strains is important to improve its productivity. This study was done with the objective of evaluating the effect of different indigenous and commercial rhizobia strains on nodulation and yield of soybean. The study was conducted in Jabi tehahn district of West Gojam Zone of Amhara Region, Ethiopia in 2015 and 2016. The study was comprised of rhizobia strains MAR-1495, SB-12 and TAL-379 factorial combined with 0 and 23 kg P_2O_5 ha^{-1} and there was a control (non-inoculated and non-fertilized) treatment. The treatments were laid in randomized complete block design with three replications. The agronomic data analysis result showed that there was a statistically significant ($P<0.05$) effect of the use of the rhizobia strains and P fertilizer on nodulation and yield of soybean. The highest grain yield of 2.7 t ha^{-1} was obtained from the combined use of 23 kg P_2O_5 ha^{-1} with the strain MAR-1495 statistically at par with the grain yield recorded from MAR-1495 alone. The strain SB-12 alone also increased the yield significantly as compared to the control treatment. Grain yield advantages of 30.8 and 21.8% over the grain yield obtained from control treatment were found from the strain MAR-1495 and SB-12 alone, respectively. The maximum number of effective nodules per plant was recorded from MAR-1495+23 kg P_2O_5 ha^{-1} statistically at par with the number of effective nodules counted from MAR-1495 alone. The residual soil nitrogen analysis indicated that the residual soil N differences of 0.029 and 0.011% (0.29 and 0.11 g total N per 1 kg soil, respectively) from MAR-1495 and SB-12 inoculated treatments against the non-inoculated once respectively, while the lowest residual soil N was recorded from the control treatment. Therefore, inoculation of soybean with MAR-1495 primarily and SB-12 as an alternative strain can be recommended for maximum soybean production in Jabi-Tehnan district and similar agro-ecologies.

Keywords: Inoculation, MAR-1495, Nodulation, SB-12, Soybean

Introduction

Nitrogen and phosphorus are the two major nutrients that limit plant growth in smallholder farms in Africa. Leguminous plants require large amount of nitrogen (N) for grain yield (Hungria and Kaschuk, 2014) but it is difficult for smallholder farmers with limited resources to supply the required high N quantities. Most low income farmers tend to plant legumes without any major external inputs; thus obtaining low grain yields. Under such conditions, legumes depend on biological nitrogen fixation through symbiosis with rhizobia to partially or fully meet their N requirement (Hungria and Kaschuk, 2014).

Rhizobia are bacteria that fix atmospheric N through symbiosis with leguminous plants in a process referred as biological N fixation (BNF). It is estimated that about 50 to 300 kg N ha^{-1} can be fixed by rhizobia bacteria (Bokhara and Sakurai, 2005). Thus, their contribution to the N economy of the soil is quite substantial. Moreover, BNF is believed to consume less energy than nitrogen fixation through the mineral process (Dubey, 2006). For these reasons, inoculation with strains of rhizobia has become an important agronomic practice to augment N supply to legumes and reduce the amount of inorganic N fertilizers required. In addition, legumes are presumed to rely less on external inorganic N sources than non-leguminous crops.

Soybean is a grain legume cultivated in many areas in the world from tropics to temperate regions with a seed yield of 1.4-2 t ha^{-1}. The seed (bean) contains about 18% oil and 38% protein and the extraction residue represents more than 40% of the utilization value of the plant (Asiedu, 1989). Soybean fixes up to 200 kg N ha^{-1} $year^{-1}$ when in symbiotic association with *Bradyrhizobium japonicum* (Zhang et al., 2002) reducing the need for potentially environmental damaging N fertilizer (Aseidu, 1989).

Soybean is a recently introduced crop to Ethiopia and its average yield per hectare is by far below the world's average. To acquire a high yield and use its potential, the crop needs association with *Bradyrhizobium japonicum* to fix atmospheric nitrogen. However, as the crop is exotic indigenous rhizobia bacteria in the district where this study was conducted were not found effective and competitive compared to a commercial rhizobia strain TAL 379 in producing effective nodulation and increasing yield (Tesfaye et.al. 2010). This indicates a need for further screening and selection of alternative and effective commercial rhizobia strains through research. This study was therefore proposed to evaluate the effect of different indigenous and commercial rhizobia strains on nodulation and yield of soybean.

Materials and methods

Study site description

This study was conducted in Jabi-Tehnan District of West Gojam Zone of Amhara region in Ethiopia in 2015 and 2016 main cropping seasons. The study district is located between the coordinates of $37^o5'59''$ - $37^o29'59''$ E and $10^o21'26''$ - $10^o57'20''$ N with altitudinal ranges of 1500-2500 meters above sea level. The dominant soil type in the study site is Rhodic Nitisols. The district receives a mean annual rainfall of 1250 mm with mean minimum and maximum temperatures of 14 and 32 ^oC, respectively. The physico-chemical characteristics of surface soil (0-20 cm) for the study area were as given below (Table 1).

Table 1. Some physico-chemical characteristics of surface soils of the study area

Soil parameter	Value
Organic carbon (%)	0.55-3.10
Total nitrogen (%)	0.044-0.136
Available phosphorus (mg kg^{-1} soil)	2.6-6.16
Cation exchange capacity CEC (meq 100 g^{-1}soil)	14.8-22.6
Base saturation (%)	36-55
Texture class	Clay

Experimental procedure and treatments

The study was conducted on three farmers' fields in 2015 and two farmers' fields in 2016. The farmers' field was plowed and prepared with oxen-drawn traditional *Maresha* and was divided into experimental plots which had an area of 4 m * 3 m. The space between each plot and block was 1 m. An improved variety of soybean *Gishama 335* was planted in a row with 40 cm and 10 cm spacings between rows and plants, respectively. The P fertilizer was applied in diammonium phosphate form at a rate of 23 kg P2O5 ha^{-1} at planting. Soybean seeds were soaked in water andsugar (90:10 ratio) solution, inoculated with respective strains after gently decanting the excess water under shade just before planting. Three rhizobia strains, MAR-1495, SB-12, TAL-379 were factorially combined with 0 and 23 kg P_2O_5 ha^{-1}. Control (non-inoculated and non-fertilized) treatment was added for comparison purposes. Nitrogen fertilizer at a rate of 9 kg ha^{-1} was applied to all plots in the form of Urea to plots where P fertilizer was applied. The treatments were laid in RCBD design with three replications.

Soil sample collection and analysis

Composite surface (0-20 cm) soil samples were collected at planting for the determination of pH, texture, organic carbon, total nitrogen and available phosphorus analysis. Similarly, surface soil samples at a depth of 0-20 cm were taken plot-wise at harvesting for the determination of residual nitrogen to evaluate the carryover effect of rhizobia bacteria inoculation on soil available nitrogen for the subsequent cropping season. Each soil sample collected was thoroughly mixed and air-dried at room temperature. Air-dried soil samples were ground and passed through a 2 mm sieve. The physico-chemical characteristics of the soil samples were analyzed at Adet Agricultural Research Center Soil testing laboratory in Bahir dar Ethiopia following the standard soil testing procedure.

Data collection and analysis

Nodule count data was collected at 50% flowering stage randomly from five plants in the border rows. The inner rows excluding the border were harvested at maturity and yield and yield-related parameters were measured. The grain yield measured was adjusted to 14% moisture content. The agronomic and soil data collected were analyzed statistically using SAS statistical software version 9.0 (SAS, 2009). Mean separation was made by using the Least Significance Difference (LSD) at 5% level of significance.

Results and discussion

Soybean dry matter yield and yield components

First year (2015)

The first year result indicates that there was a significant effect of treatments on the yield of soybean in the two sites (Table 2 and 3). At the first testing site, the highest grain yield (3.37 t ha^{-1}) and dry matter yield (8.43 t ha^{-1}) was measured from the combined use of the strain MAR-1495 with 23 kg P_2O_5 ha^{-1}. The maximum 100 seed weight (18.3 g) was also measured from the combined use of the strain MAR-1495 with 23 kg P_2O_5 ha^{-1}. Statistically similar and comparable yield was recorded from the use of the strains MAR-1495 and SB-12 alone.

Table 2. Effect of phosphorus and inoculation on yield and yield components of soybean at testing site 1 in 2015

Treatment*	Plant height (cm)	Pod no. per plant	100 seed weight (g)	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	83.0	32.9	15.7bc	2238.8c	6423.6cd
2. MAR-1495	90.0	33.3	16.9abc	3034.6ab	7472.4b
3. SB-12	82.7	33.0	15.4bc	3141.1ab	7484.4b
4. TAL 379	81.9	29.3	15.1c	1984.8c	5618.4d
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	95.9	30.7	18.3a	3374.9a	8430.6a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	84.1	25.8	17.5ab	2574.8bc	6894.2bc
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	92.7	27.2	17.1abc	2554.9bc	7326.4bc
Grand Mean	87.2	30.3	16.64	2678.5	7073.3
CV (%)	9.2	24.1	7.36	14.9	7.1
LSD (5%)	NS	NS	2.28	740.6	935.6

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

However, at site 2, the dry biomass and grain yield obtained from inoculation alone with the strain MAR-1495 outweighed the other treatments (Table 3). Morover, this did not show statistically significant grain and biomass yield with that of SB-12, MAR-1495 plus P, and SB-12 plus P treatments. The plant height and average pod number per plant showed no significant effect among treatments at both testing sites. The lowest grain and biomass yields were recorded from the control treatment in both testing sites.

Table 3. Effect of P and inoculation on yield and yield components of soybean at testing site 2 in 2015

Treatment*	Plant height (cm)	Pod no. per plant	100 seed weight (g)	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	64.9	34.3	14.6	1547.1c	4357.7d
2. MAR-1495	75.9	31.0	15.8	2642.2a	6628.5a
3. SB-12	73.1	38.7	16.8	2375.7ab	6083.3ab
4. TAL-379	71.6	29.3	15.5	1837.8bc	5138.9cd
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	76.5	31.0	16.6	2610.0a	6524.3a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	75.9	30.6	17.0	2474.9a	6371.5ab
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	72.3	38.3	15.7	1682.9c	5343.7bcd
Grand Mean	72.9	33.3	16	2167.2	5778.3
CV (%)	6.9	15.3	6.64	15.3	10.3
LSD (5%)	NS	NS	NS	588.7	1062.6

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

At the third testing site (on a research station), however, the yield difference obtained from the control treatment versus both the use of the strains alone and their combined use with P fertilizer (Table 4) was insignificant. This might be most likely due to the availability of residual soil N and P in the surface soil of the research site as a result of long years of N and P fertilization which might have led to nodulation failure and insignificant response to the addition of P fertilizer.

Furthermore, the combined analysis pooled over the three testing sites revealed that there was a statistically significant effect of the use of the strains MAR-1495 and SB-12 with 23 kg P2O5 ha^{-1} and use of MAR-1495 and SB-12 alone on the yield of soybean as compared to the control treatment (Table 5).

Table 4. Effect of P and inoculation on yield and yield components of soybean at testing site 3 in 2015

Treatment*	Plant height (cm)	Pod no. per plant	100 Seed weight (g)	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	84.7	26.9	16.7	3024.4	7320.2
2. MAR-1495	80.5	21.4	17.9	3100.3	6937.5
3. SB-12	81.9	26.9	17.3	3012.8	6843.8
4. TAL-379	78.7	24.7	16.8	2938.8	6812.9
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	87.3	26.3	17.3	3124.4	7621.5
6. SB-12 + 23 kg P_2O_5 ha^{-1}	86.9	25.2	17.4	3105.2	7350.7
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	87.2	23.3	16.5	3229.8	7201.4
Grand Mean	83.9	24.9	17.1	3076.5	7155.4
CV (%)	5.3	17.5	4.96	7.6	6.6
LSD (5%)	NS	NS	NS	NS	NS

** NS: Non-significant at P=0.05.*

The pooled analysis of overall testing sites, as shown in Table 5 below, revealed that there was a statistically significant difference among plant height, 100 seed weight, grain and dry matter yield due to the effect of treatments. The maximum plant height (86.6 cm), 100 seed weight (17.4 g), grain yield (3.03 t ha^{-1}) and dry matter yield (7.5 t ha^{-1}) was measured from the combined use of the strain MAR-1495 with 23 kg P_2O_5 ha^{-1} followed with insignificant difference by the grain yield (2.9 t ha^{-1}) and dry matter yield (7.0 t ha^{-1}) obtained from the use of the strain MAR-1495 alone. The use of strain SB-12 had also statistically similar and comparable yield advantages as compared to the yield measured from strain MAR-1495 with 23 kg P_2O_5 ha^{-1}. The lowest yield (2.3 t ha^{-1}) was recorded from the control treatment.

Table 5. Pooled analysis of the effect of P and inoculation on yield and yield components of soybean over the three testing sites in 2015

Treatment*	Plant height (cm)	Pod no. per plant	100 Seed weight (g)	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	77.6c	31.4	15.6c	2270.1c	6033.8c
2. MAR-1495	82.1abc	28.6	16.8ab	2925.7a	7012.8ab
3. SB-12	79.2bc	32.9	16.5abc	2806.0ab	6718.8b
4. TAL-379	77.4c	27.8	15.9bc	2253.8c	5856.7c
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	86.6a	29.3	17.4a	3036.4a	7525.5a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	82.3abc	27.2	17.3a	2718.3ab	6872.1b
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	84.1ab	29.6	16.4abc	2489.2bc	6623.8b
Grand Mean	81.3	29.5	16.6	2640.1	6662.5
CV (%)	7.4	18.6	6.6	13.8	8.6
LSD (5%)	5.8	NS	1.05	350.1	554.9

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Second year (2016)

The second year data analysis results indicated that there was a significant effect of treatments on the grain and dry biomass yield of soybean at two testing sites (Table 6 and 7). At the first testing site, the highest yield was recorded from the use of strains SB-12 with 23 kg P_2O_5 $ha^{-1}$and MAR-1495 with 23 kg P_2O_5 ha^{-1} (Table 6). However, a statistically similar yield advantage was obtained from the use of the strain MAR-1495 alone at both testing sites. The combined analysis over the two testing sites also revealed that the maximum grain yield of 2.2 t ha^{-1} was obtained from the use of the strain MAR-1495 with 23 kg P_2O_5 ha^{-1} followed by the grain yield of 2.1 t ha^{-1} from the strain SB-12 with 23 kg P_2O_5 ha^{-1} and the grain yield of 2.0 t ha^{-1} from MAR-1495 alone (Table 8). There were no significant yield differences among the above treatments. Similarly, there was no significant yield differences between separate application of MAR-1495 and SB-12.

Table 6. Effect of P and inoculation on the yield and yield components of soybean at testing site 1 in 2016

Treatment*	Plant height (cm)	Pod no. per plant	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	72.1	30.2	1998.8c	3871.5d
2. MAR-1495	65.5	30.7	2386.0ab	4517.4bcd
3. SB-12	72.0	29.1	2088.1bc	5541.2a
4. TAL-379	67.5	32.3	1928.9c	4128.5d
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	76.6	29.8	2580.8a	5024.3abc
6. SB-12 + 23 kg P_2O_5 ha^{-1}	79.3	36.3	2628.1a	5138.9ab
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	69.5	35.9	2185.7bc	4274.3cd
Grand Mean	71.8	32.0	2256.6	4642.3
CV (%)	8.4	12.9	9.6	10.0
LSD (5%)	NS	NS	385.6	826.5

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Table 7. Effect of P and inoculation on yield and yield components of soybean at testing site 2 in 2016

Treatment*	Plant height (cm)	Pod no. per plant	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	58.5	22.5	901.7b	2227.1b
2. MAR-1495	63.7	26.3	1541.9a	3349.0a
3. SB-12	62.7	26.1	1471.8a	3180.6a
4. TAL-379	59.9	22.6	1618.0a	3520.8a
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	69.4	27.8	1576.1a	3312.5a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	62.1	27.7	1310.1ab	3020.8ab
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	65.5	29.8	1327.0a	3066.0ab
Grand Mean	63.1	26.1	1374.2	3065.3
CV (%)	11.5	10.3	14.9	13.9
LSD (5%)	NS	NS	416.3	873.3

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Table 8. Effect of P fertilizer and inoculation on yield and yield components of soybean pooled over the two testing sites in 2016

Treatment*	Plant height (cm)	Pod no. per plant	Grain yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
1. Control	65.3	26.3c	1450.3c	3049.3c
2. MAR-1495	64.6	28.5abc	1964.0ab	3933.2ab
3. SB-12	67.4	27.6bc	1779.9b	4360.9a
4. TAL-379	63.7	27.5c	1804.5b	3885.4ab
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	73.0	28.8abc	2179.0a	4339.6a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	70.7	31.9ab	2100.9a	4291.7a
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	67.5	32.9a	1756.3b	3670.1b
Grand Mean	67.4	29.1	1849.3	3914.5
CV (%)	10.1	12.7	12.4	11.6
LSD (5%)	NS	4.4	286.1	567.4

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Similarly, the combined analysis result over the two experimental years revealed that there was a highly significant effect of treatments on the yield of soybean (Table 9). The highest grain and dry matter yields of 2.7 t ha^{-1} and 6.4 t ha^{-1}, respectively were obtained from the use of the strain MAR-1495 with 23 kg P_2O_5 ha^{-1}. The use of the strain MAR-1495 alone had a statistically similar yield advantage as compared to its combined use with 23 kg P_2O_5 ha^{-1} and increased the yield by 30.8% when compared with the control treatment. Inoculation of soybean with the strain SB-12 had a statistically similar yield advantage as that of the strain MAR-1495 and had a 21.8% yield advantage over the yield obtained from the control treatment. A similar result was reported by Fitsum et.al. (2016) at Pawe. In line with this, the results of Mahmood et al. (2009) revealed that the application of *rhizobial* inoculant alone significantly increased nodulation of soybean. The reason might be due to inoculation with *Rhizobia*, which increased the number of bacteria and hence more nodules per plant were produced.

Table 9. Effect of use of different rhizobia strains and P fertilizer on the yield (kg ha^{-1}) of soybean combined over years

Treatment*	Plant height (cm)	Pod no. per plant	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})
1. Control	72.7c	29.3	1942.2e	4840.0e
2. MAR-1495	75.1bc	28.5	2541.0ab	5780.9bc
3. SB-12	74.5bc	30.8	2366.2bc	5708.2bc
4. TAL-379	71.9c	27.6	2093.3de	5152.7de
5. MAR-1495+ 23 kg P_2O_5 ha^{-1}	81.1a	29.1	2730.2a	6387.6a
6. SB-12+ 23 kg P_2O_5 ha^{-1}	77.7ab	29.1	2497.8ab	5950.5b
7. TAL-379+ 23 kg P_2O_5 ha^{-1}	77.4ab	30.9	2196.1cd	5442.4cd
Grand Mean	75.7	29.3	2334.8	5601.4
CV (%)	8.6	16.7	13.6	9.6
LSD (5%)	4.8	NS	236.2	401.4

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Nodule formation

The maximum effective average number of nodules (14.9) per plant was recorded from the combined use of MAR-1495 with 23 kg P_2O_5 ha^{-1} fertilizer followed with insignificant difference by the average effective nodule number (11.6) per plant recorded from the use of the strain MAR-1495 alone (Table 10). The number of effective nodules per plant recorded in this study are supported by Pedersen (2003; 2004), who reported that a successful nodulation by the V3 to V4 growth stage should produce 8 to 10 healthy nodules per plant. Tolera et. al. (2015) also reported that higher nodule dry biomass and dry plant biomass were produced from soybean inoculated with rhizobia strain MAR-1495.

Table 10. Effect of inoculation trains and P on nodulation of soybean in 2015

Treatment*	Effective nodule number per plant		
	Site 1	Site 2	Combined
1. Control	0.4c	1.6d	1.0d
2. MAR-1495	5.0a	18.1ab	11.6ab
3. SB-12	4.2ab	12.9abc	9.4bc
4. TAL 379	1.3bc	8.3cd	5.9cd
5. MAR-1495 + 23 kg P_2O_5 ha^{-1}	4.6ab	20.2a	14.9a
6. SB-12 + 23 kg P_2O_5 ha^{-1}	6.2a	15.9abc	10.1abc
7. TAL-379 + 23 kg P_2O_5 ha^{-1}	6.6a	11.3bc	8.9bc
Grand Mean	4.1	12.6	8.8
CV (%)	40.7	34.2	48.9
LSD (5%)	3.4	7.7	5.12

** Means within a column followed by the same letter are not significantly different at p = 0.05. NS: Non-significant at P=0.05.*

Residual soil nitrogen

The statistical analysis result of the surface soil total nitrogen content in percent indicated that although statistically insignificant, at site I, the highest residual total nitrogen (0.239%) was recorded from plots where MAR-1495 was inoculated followed by the residual soil total nitrogen (0.200%) where SB-12+P was applied. While, at the other testing site, the highest residual soil nitrogen was recorded from plots where TAL-379 and SB-12 were inoculated followed by MAR -1495 (Table 11).

Table 11. Effect of inoculation on residual soil total nitrogen (%)

Treatment*	Site 1	Site 2	Combined
1. Control	0.1877	0.1731	0.1804
2. MAR-1495	0.2392	0.1796	0.2094
3. SB-12	0.1758	0.2145	0.1913
4. TAL-379	0.1849	0.2244	0.2007
5. MAR-1495+ 23 kg P_2O_5 ha^{-1}	0.1878	0.1944	0.1911
6. SB-12+ 23 kg P_2O_5 ha^{-1}	0.2007	0.1743	0.1901
7. TAL-379+ 23 kg P_2O_5 ha^{-1}	0.1872	0.1661	0.1787
Grand Mean	0.194	0.188	0.1918
CV (%)	17.5	17.6	17.9
LSD (0.05)	NS	NS	NS

**NS: Non-significant at P=0.05*

Conclusion and recommendation

The use of the rhizobia strains MAR-1495 and SB-12 combined with P fertilizer (23 kg ha^{-1} P_2O_5) gave the highest yield. However, the use of the rhizobia strains MAR-1495 and SB-12 alone gave significantly higher yields than the control treatment with sizeable yield advantages. Moreover, significant residual soil nitrogen was recorded from plots where MAR-1495 and SB-12 were inoculated which is beneficial for subsequent crop production. Thus, sole use of the strains MAR-1495 primarily and alternatively the strain SB-12 can be recommended for soybean production in Jabi tehnan district and similar agro-ecologies.

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Performance of UREA^{stabil} in the Nitisols and Vertisols of North-Western Ethiopia

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Abstract

Nitrogen is a critical yield-limiting plant nutrient for crop production in Ethiopia. The demand for synthetic fertilizer is significantly increasing. Urea is the main source of synthetic nitrogen fertilizer that is mainly applied to the surface resulting in significant nitrogen loss. UREA^{stabil} fertilizer is urea with N-(n-butyl) thiophosphoric triamide (NBPT) that reduces the rate of urea hydrolysis by urease to reduce nitrogen loss and increase crop productivity. The research was conducted in Yilmana Densa district in the Amhara National Regional State of Ethiopia for two years to evaluate the performance of UREA^{stabil} compared to the conventional urea. The research evaluated the effect of UREA^{stabil} fertilizer technology: on two dominant cereal crops: bread wheat (Triticum aestivum) and tef (Eragrostis tef), on two major soils (Nitisol and Vertisol), at different rates and with and without splinting. The finding of this research denies our prior hypothesis that UREA^{stabil} could give better yields of teff and wheat with lower rates of nitrogen at a single application rate compared to the conventional urea. Reducing the amounts of nitrogen by one third using UREA^{stabil} resulted in an intolerable significant yield penalty for all the study sites and both years on wheat. Both the grain and straw yields were increased by splitting the UREA^{stabil,} indicating that the enzyme that hydrolysis urea was merely inhibited. Split application of the maximum UREA^{stabil} rate (130% nitrogen) gave non-significant and equivalent yields with conventional urea of the same rate. Considering a non-significant yield difference between the conventional urea and from UREA^{stabil} for all crops, soils, rates, and forms of applications UREA^{stabil} is not promising. The additional cost that may associate with UREA^{stabil} makes it less preferable to conventional urea. Further research with different rates of NBPT as well as different nitrification inhibitors needs to be evaluated for their efficiency to improve crop yield and reduce nitrogen loss for different crops, different soils, and agro-ecologies.

Keywords: Conventional urea, Grain yield, nBTPT, Urease inhibitor, UREA^{stabil}

Introduction

The agricultural productivity of Ethiopia depends mainly on the amount and distribution of the rainfall as well as on the state of soil fertility. The state of soil fertility has been the major reason for wealth disparities among and between Ethiopian farmers. Synthetic fertilizers have been used to improve the state of soil fertility and to increase crop productivity since the 1970s in the country; and yet with very high potential for further yield gap closings (Dercon and Hill, 2009). Nitrogen is the most yield-limiting nutrient under all soils, landscapes, agro-ecologies, and regions of the region (Tadele et al., 2018). It is also a universal yield-limiting nutrient (Hirel et al., 2007). Synthetic nitrogen fertilizer accounted for about 50% of food increased in the world (Yang et al., 2016). The primary sources for synthetic nitrogen fertilizers in Ethiopia is urea as it has high contents of nitrogen (46%), its low cost, ease of handling, storage, and transport makes urea to be used worldwide for the agricultural production that accounts for about 56% (Mira et al., 2017). However, the recovery of nitrogen from urea is only about 30-40% (Zhou et al. 2003), 30-50% (Abalos et al., 2014), 50% (Janssen et al., 1990), 30-65% (Herrera et al, 2016). According to Zaman et al. (2013), the key nitrogen losses could be summarized as NH_3 volatilization, NO_3^- leaching and N_2O emission.

Integrated soil fertility management, selection of fertilizer sources, identifying and applying at a critical time, improving the reaction of urea fertilizer through various modifications increase the nitrogen fertilizer recovery and efficiency as well as reduce environmental impacts. Among the measures, a split application of urea is reducing the nitrogen losses (Hinton et al., 2015). New technologies that reduce the loss of nitrogen by modifying the conventional urea are getting the attention of researchers and development practitioners. These technologies release nitrogen more slowly than the conventional urea and hence improve the recovery of fertilizers (Trenkel, 2010, Feng et al., 2016). UREA[stabil] is one of the slow-releasing nitrogen fertilizers and hydrolysis of urea is reduced by the presence of N-(nbutyl) thio-phosphoric-triamide that slows down urease activity of urea hydrolysis thereby improve recovery of nitrogen applied (Abalos et al., 2012; Krajewska, 2009, Watson et al., 2008). This fertilizer technology increased crop productivity (Abalos et al., 2014, Qiao et al., 2015). However, the effect of urease inhibitor (nBTPT) depends on the climate, soil, crop and management (Thapa et al., 2016). Therefore the present research was conducted to evaluate the advantages of UREA[Stabil] Compared to the conventional urea in increasing the productivity of two major cereal crops: Bread wheat (Triticum aestivum) and Tef (Eragrostis tef) for Nitisols and Vertisols of northwestern Ethiopia.

Materials and methods

Description of the study areas

The research was conducted in Yilmana Densa district of the west Gojjam zone of the Amhara National Regional State of Ethiopia (Figure 1). Yilmana Densa is located at about 42 km from Bahir Dar; the capital city of the Amhara National Regional State on the way to Addis Abeba through Mota.

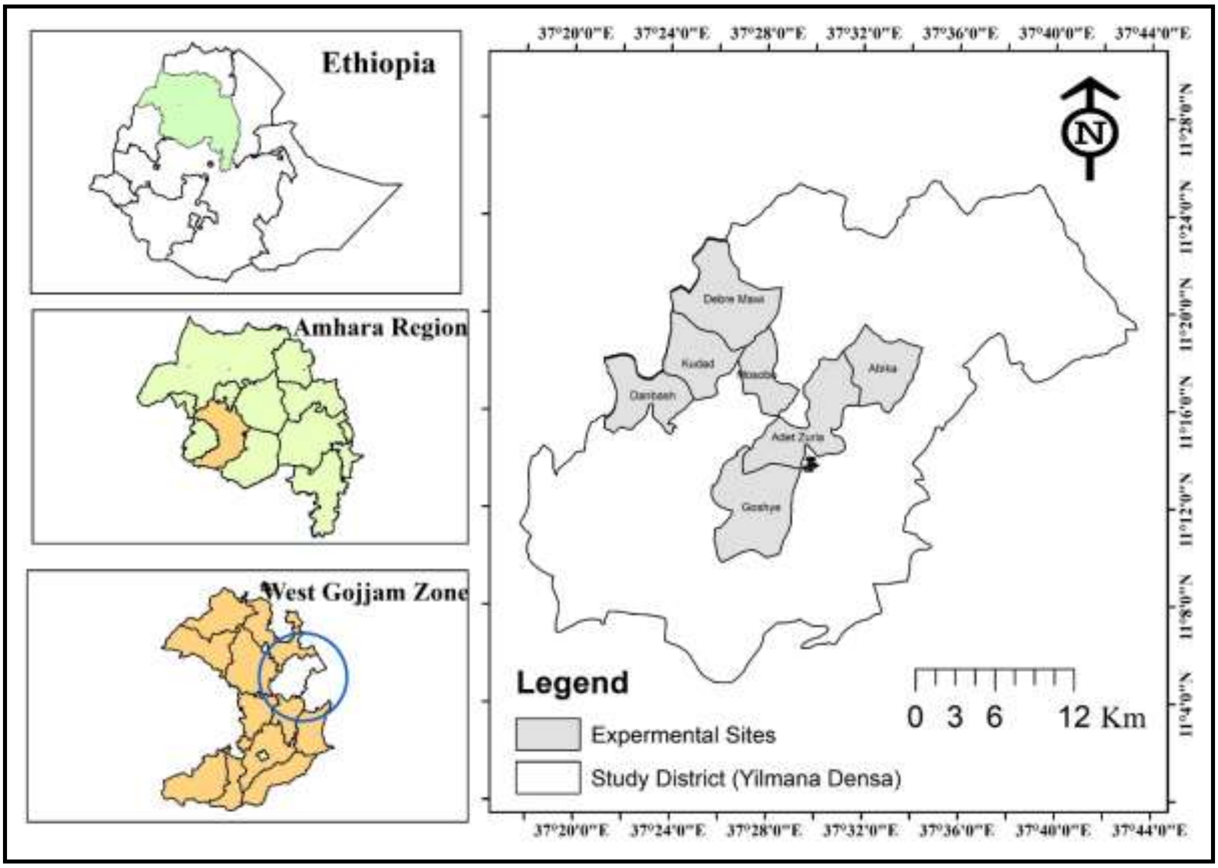

Figure 2. Location of the study

The mid-altitude takes the lion's share of the district. The district receives a uni-modal type of rainfall that begins in May-June and ends in October with an annual average rainfall that ranges from 1100 to 1270 mm and a temperature range of 8.8 to 25.2 ^{O}c (Destaw and Yalemthsehay, 2015). The dominant soils according to the FAO/UNESCO classification system (IUSS Working Group WRB, 2015) the soils of the study sites are Nitisols and Vertisols. The farming system is characterized by a mixed livestock raising and crop production. Tef (Eragrostis tef) and bread wheat (Triticum aestivum) are the leading cereal crops in the study area. Yilmana Densa is one of the highly populated districts of the Amhara National Regional State (CSA, 2007).

Experimental set-up

The experiment was conducted for two consecutive rainy seasons with the treatment setups shown in Table 1. This on-farm research was conducted on multi-locations of Nitisols and Vertisols. The test crops were bread wheat and tef with varieties TAY and kuncho, respectively.

Table 1. Treatment set up

Treatments	Rates of Nitrogen (kg/ha)*		
	Wheat (Nitisols)	Tef (Nitisol)	Tef(Vertisol)
Control (without N)	0	0	0
Recommended N from Urea*	92 (30/62)	40 (13/27)	60 (20/40)
67% of the rec. N from UREA[stabil] at planting	61	27	40
Recommended N from UREA[stabil] at planting	92	40	60
Recommended N from UREA[stabil]*	92 (30/62)	40 (13/27)	60 (20/40)
133% of the rec. N from UREA[stabil] at planting	122	53	80
133% of the recommended N from UREA[stabil]*	122(41/81)	53 (18/35)	80 (27/53)
133% of the recommended N from UREA*	122(41/81)	53 (18/35)	80 (27/53)

**Numbers in bracket indicated nitrogen rates (Kg/ha) applied as 1/3 at planting and 2/3 at the tillering stage while those rates without brackets indicated that they were not splitted; 46, 60 and 40* P_2O_5 *kg/ha were applied as a basal at planting for wheat, Tef (N) and Tef (V); respectively.*

A randomized completed block design (RCBD) with three replications was used. Both crops were planted in rows with seed rates of 125 kg/ha and 10 kg/ha for wheat and tef respectively. Major agronomic data including grain and biomass yields were collected. The grain weight and moisture content of wheat were simultaneously taken and finally adjusted to 12.5% moisture content. Collected data were subjected to the analysis of variance (ANOVA) using SAS software (SAS, 2003). The ratio of yield response was calculated by dividing the yield of treatments to the yield of the recommended nitrogen for each crop.

Soil sampling, preparations, and analysis

Composite soil samples were collected at depth of 0-20 cm before planting for each site. Samples were air-dried, ground and sieved. Soil pH was determined in a 1:2.5 soil to water suspension following the procedure outlined by Sahilemedihn and Taye (2000). Soil organic carbon content was determined by the wet digestion method using the Walkley and Black procedure (Nelson and Sommers, 1982). Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982) while the available phosphorus was determined following the Olsen procedure (Olsen and Sommer, 1982). The exchangeable potassium was measured by flame photometer after extraction of the samples with 1N ammonium acetate at pH-7 following the procedures described by Sahilemedihn and Taye (2000).

Results and discussion

Soil properties of the study sites

The pH of the soil ranged between 4.82 to 5.48 for the Nitisols and 5.01 to 7 for the Vertisols. The soil organic carbon was below the critical level of 2% (Murphy, 2014). It was varying between 1.11 to 1.67% for the Nitisol and 0.57% to 1.35% for Vertisols. The total nitrogen was lower for both soils that ranged from 0.15% to 0.21% for the Nitisol and 0.09 to 0.15% for the Vertisol. The available phosphorus was also in the ranges of 8.24 to 14 mg/kg for the nitisol and 13 to 17 for the vertisol. The exchangeable potassium ranged from 0.83 to 1.31 cmol (+)/kg of soil for the Nitisol and 0.86 to 1.16 cmol (+)/kg of soil for the Vertisol and all of them are above the critical levels of 0.25 cmol (+)/kg of soil (IPI, 2016).

Yield response of crops to UREA^{stabil}

Yields from treatments without nitrogen (control) were significantly ($P < 0.05$) lower than other treatments (Table 2), indicating nitrogen is still the major yield-limiting plant nutrient in the farming system of northwestern Ethiopia as stated by Tadele et al. (2018). Reducing the rate of nitrogen to 67% (61 kg/ha) using UREA^{stabil} without splitting significantly decreased both grain and straw yields for all sites in both years (Table 2) as compared to the recommended rate (92 kg/ha) using conventional urea. The grain yield penalty ranged between 700 and 900 kg/ha (mean 889 kg/ha). The highest straw yield penalty (1514.3kg) was observed for the second year (Table 2). The overall implication of the finding for wheat indicated that UREA^{stabil} was not better than the conventional urea to improve wheat productivity with rates less than the conventional urea. Application of the same rates of nitrogen (92 kg N/ha) from conventional urea and UREA^{stabil} (without split) resulted in insignificant yield differences (Table 2) with better yields from conventional urea. However, the split application of UREA^{stabil} resulted in a better but insignificant yield compared to the same rates of nitrogen with conventional urea (Table 2). Application of recommended nitrogen (92 kg/ha) from UREA^{stabil} with and without split indicated a non-significant yield difference but yield increased (278 kg/ha on average) by splitting than a single dose. The grain yield using 92 kg N/ha from UREA^{stabil} by splitting was only slightly lower than from

122 kg N/ha UREA^{stabil} without splitting (70 kg/ha). However, upon splitting, their difference increased to 374.2 kg/ha. This again justifies the importance of splitting and the weakness of UREA^{stabil} against fast hydrolysis. Increasing recommended nitrogen from UREA^{stabil} up to 122 kg N/ha (130%) gave a higher yield over a single application of the same rate but the equivalent yield was found with conventional urea of the same rate. The response ratio of the grain yield and straw yield clearly showed that the overall implications of using UREA^{stabil} (Figure 2) was not better than the conventional urea.

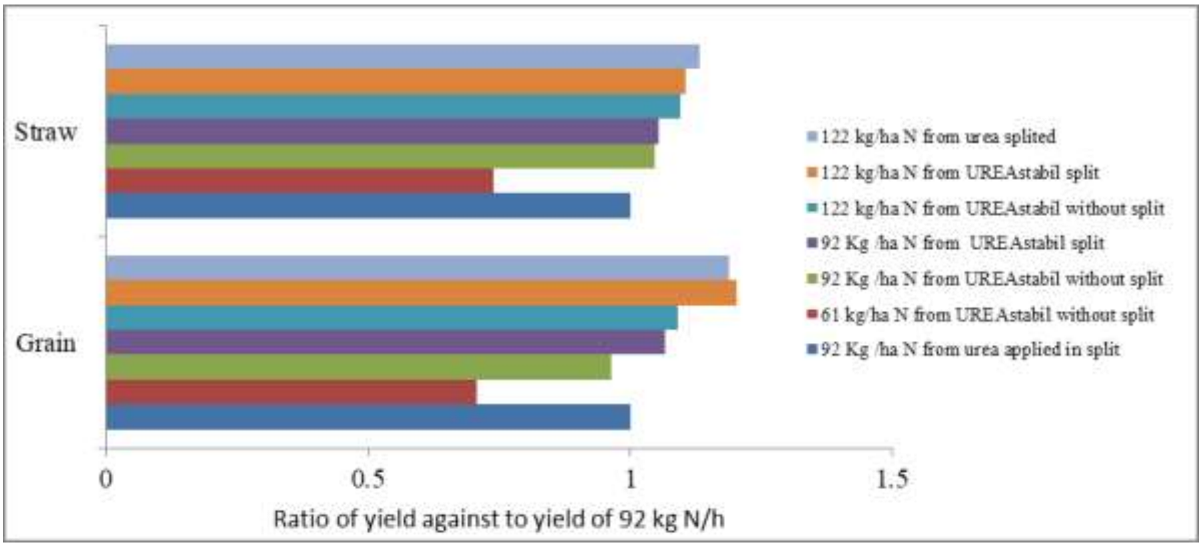

Figure 3. Grain and straw yields response ratios of bread wheat to treatments against the recommended nitrogen (92 kg N/ha with split)

The findings of the research for tef showed lower yields from treatments without nitrogen than other treatments (Table 3 and Table 4). Unlike the yield response of wheat, the yield response of tef to conventional and UREA^{stabil} was irregular (Table 3) and hence difficult to draw conclusions that might be due to a smaller rate used (40 kg N/ha) for the Nitisols that needs future considerations. In 2017 applying 27 kg N/ha (67% of the recommended nitrogen) from UREA^{stabil} on the Nitisol showed a yield reduction; pronounced on the straw yield than the grain yield while in 2018 there were little yield differences among and between treatments that received nitrogen and there was no uniform trend of increase or decrease as a result of UREA^{stabil}. The significant yield difference ($P < 0.05$) was only observed between the control (without nitrogen fertilizer) and other treatments.

The yield response of tef on Vertisol did not support our hypothesis that the rate of nitrogen from UREA^{stabil} could be reduced significantly to bring about equivalent yield to the recommended rate of nitrogen using conventional urea (60 kg N/ha) (Table 4). Both grain and straw yields were reduced when the rate of nitrogen reduced from 60 to 40 kg N/ha (Table 4 and Figure 3).

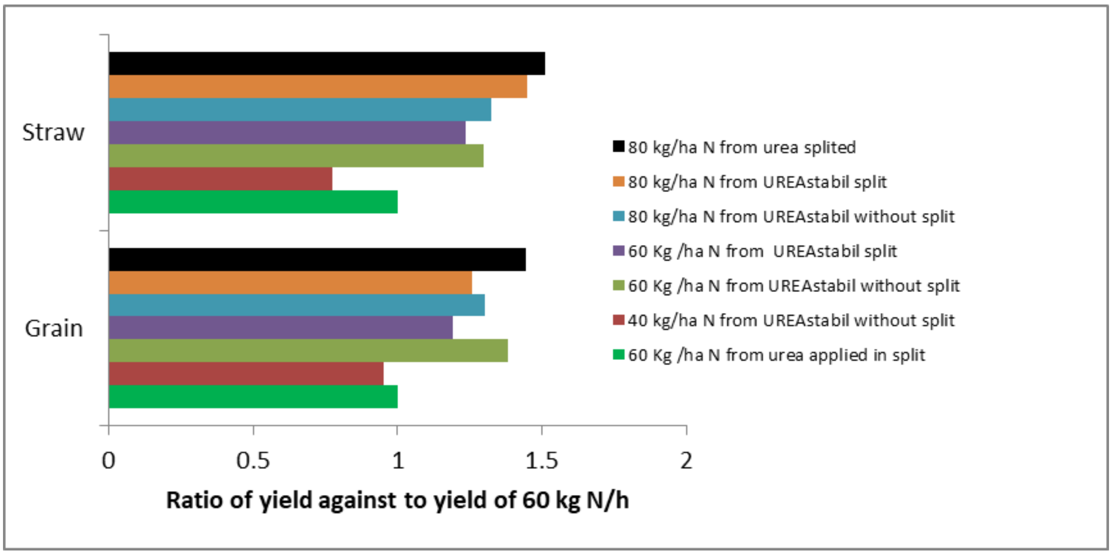

Figure 3. Grain and straw yields response ratios of tef to treatments against the recommended nitrogen (60 kg N/ha with split) in Vertisol

Combined analysis of the grain yield showed that the application of a full dose of UREA^{stabil} at planting (no spilt) surpassed the splitted application with no significant differences (P > 0.05), (Table 4 and Figure 3). The response ratio of the yield compared to the recommended nitrogen from urea (60 kg N/ha) was above one except for 40 kg N/ha (67% recommended N from UREA^{stabil}) indicating that the recommended rate was biological optimum (Figure 3). The grain yield of tef from 60 kg N/ha (1448.9 kg/ha) with a single application from UREA^{stabil} was equivalent to the maximum yield (1512 kg/ha) observed from the application of 80 kg N/ha from conventional urea. Application of 80 kg N/ha from UREA^{stabil} by split or single dose was not better than nitrogen from conventional urea with similar rates. The yield was proportionally increased with increasing rates of nitrogen from conventional urea.

Table 2. Grain yield response of wheat (Kg/ha) for urea and UREA^{stable}

Treatments	Year 1 (2017)				Year 2 (2018)				
	Site 1	site 2	site 3	Mean	Site 1	site 2	site 3	Mean	Combined
Grain Yield (Kg/ha)									
Control (without N)	301.0	1341.0	469.2	703.7	567.0	1037.0	484.0	696.0	699.9
92 kg/ha N from Urea*	2010.9	2927.6	2651.5	2530.0	2730.0	3121.0	2929.0	2926.7	2728.4
61 kg/ha N from UREA^{stabil}	1293.5	2743.6	2159.0	2065.4	1726.0	2614.0	1054.0	1798.0	1931.7
92 kg/ha N from UREA^{stabil}	1824.5	2863.7	3042.9	2577.0	2314.0	3109.0	2638.0	2687.0	2632.0
92 kg/ha N from UREA^{stabil*}	2264.6	2645.7	3334.0	2748.1	2672.0	2788.0	3754.0	3071.3	2909.7
122 kg/ha N from UREA^{stabil}	2274.2	3363.9	2798.9	2812.3	2974.0	3351.0	3115.0	3146.7	2979.5
122 kg/ha N from UREA^{stabil*}	2390.7	3032.3	3331.2	2918.1	3710.0	3643.0	3596.0	3649.7	3283.9
122 kg/ha N from UREA*	2502.2	2949.0	3159.7	2870.3	3691.0	3538.0	3637.0	3622.0	3246.2
LSD ($\alpha = 0.05$)	308.4	887.07	829.5	564.3	596.2	703.5	574.9	442	375.3
CV (%)	9.6	18.7	18.3	24.9	13.5	14.0	12.5	18.4	23.3
Straw yield (Kg/ha									
Control (without N)	624.9	1668.3	456.8	916.7	943.0	1254.0	1161.0	1119.3	1018.0
92 kg/ha N from Urea*	2803.9	3368.7	2487.4	2886.7	3806.0	3728.0	4871.0	4135.0	3510.9
61 kg/ha N from UREA^{stabil}	1623.2	2719.4	3350.3	2564.3	2493.0	3298.0	2071.0	2620.7	2592.5
92 kg/ha N from UREA^{stabil}	2620.0	2923.3	3438.6	2994.0	3650.0	35310	5890.0	4357.0	3675.5
92 kg/ha N from UREA^{stabil*}	2550.2	2930.5	3078.0	2852.9	3734.0	2915.0	7027.0	4558.7	3705.8
122 kg/ha N from UREA^{stabil}	3049.9	3210.2	3080.7	3113.6	4135.0	3967.0	5635.0	4579.0	3846.3
122 kg/ha N from UREA^{stabil*}	3118.6	2477.0	2965.1	2853.6	5040.0	3965.0	5727.0	4910.7	3882.2
122 kg/ha N from UREA*	3146.0	3023.2	2905.1	3024.8	4434.0	4171.0	6206.0	4937.0	3980.9
LSD ($\alpha = 0.05$)	1021.1	1134.6	1459.0	701.0	1213.6	830.3	1368.5	1028.4	757.0
CV (%)	24.0	22.9	31.0	27.8	19.9	14.3	16.7	28.3	35.0

** indicates that nitrogen was applied in split*

Hence, the finding of this research is in line with the finding from a one-year experiment in the Northern parts of Ethiopia (Sofanyas et al. 2018). They reported a yield advantage of 655.7 kg/ha (13.62%) grain wheat using 64 kg N/ha from conventional urea over the same rate of nitrogen from UREA^{stabil}. They made further research recommendations on the split application of UREA^{stabil}. The finding of our research did not support our key interest to avoid split nitrogen application and reduce associated costs using UREA^{stabil} than using the conventional urea. This finding is not in line with the findings of authors (Hinton et al., 2015; Huérfano, 2015, Thapa, et al., 2016, Trenkel, 2010). The additional cost of UREA^{stabil} over the convention urea ranges from 6% (Sofanyas et al., 2018) and 20% (Růžek et al., 2014). Zaman et al., (2013) also indicated that for 25 kg N/ha, the cost of recommended nBTPT is 3.2 US dollars/ha, higher than the cost of urea per hectare for their study area. Accordingly, our finding unjustified the use of UREA^{stabil} for the soils and crop types covered by the research. A similar finding was reported for potato (Drapal et al., 2013) where the conventional urea at a rate of 90 kg N/ gave a yield advantage of 10.2% tuber yield than UREA^{stabil} with the same rate of nitrogen. Rose et al., (2018b) also did not get any evidence of nitrogen recovery and yield advantage from enhanced fertilizers including urease inhibitors on rice. The overall yield advantage of UREA^{stabil} observed from the study opposed to other findings (Abalos et al., 2014, Qiao et al., 2015, Rose et al., 2018a, Thapa et al., 2016, Zaman et al., 2013). Zaman et al., (2013) found a 16.1% yield advantage using urease inhibitor (nBTPT) over the conventional urea with the same rates of nitrogen (30 kg N/ha). Moreover, many authors proved that the recovery of nitrogen improved using nitrification inhibitors and urease inhibitors (nBTPT (Abalos et al., 2012, Abalos et al., 2014, Krajewska, 2009, Drapal, et al., 2013, Ni et al., 2014, Rose et al., 2018, Růžek et al., 2014, Tapha et al., 2016, Watson et al., 2008). The poor performance of UREA^{stabil} to our finding could be related to the quantity of urease inhibitor (nBTPT), and the efficiency of nBTPT depends on factors including soil properties (McGeough et al., 2016, Watson et al., 2008, Watson et al., 1994), temperature (Abalos et al., 2017, Abalos et al., 2014, Watson et al., 2008), rainfall (Abalos et al., 2017) and management (Abalos et al., 2014). In Brazil, Mira et al., (2017) found reduced loss of nitrogen from urea in the ammonia using urease inhibitor nBTPT up to 1000 mg /kg urea. According to the authors, rates of nBTPT in Brazil were based on the findings in the temperate region (240 to 500 nBTPT mg/kg urea) that necessarily could not reflect the tropical regions. With a similar argument and finding of Mira et al., improving the efficiency of UREA^{stabil} by increasing the rate of nBTPT should be considered in the farming system of Ethiopia.

Table 3. Yield response of tef (Kg/ha) for urea and UREA^{stabil} in Nitisol

Treatments	Year 1 (2017) Site 1	Year 1 (2017) site 2	Year 1 (2017) Mean	Year 2 (2018) Site 1	Year 2 (2018) site 2	Year 2 (2018) Mean	Combined
Grain Yield (Kg/ha)							
Control (without N)	450.8	238.0	344.4	324.7	142.7	233.7	289.1
40 kg/ha N from Urea*	1079.2	823.0	951.1	834.4	1065.6	950.0	950.6
27 kg/ha N from UREA^{stabil}	918.8	813.0	865.9	1048.7	1083.2	1066.0	966.0
40 kg/ha N from UREA^{stabil}	1115.1	1016.0	1065.6	1103.1	1054.7	1078.9	1072.3
53 kg/ha N from UREA^{stabil*}	1076.0	795.0	935.5	1063.8	898.0	980.9	958.2
53 kg/ha N from UREA^{stabil}	1161.5	601.0	881.3	661.5	1105.5	883.5	882.4
53 kg/ha N from UREA^{stabil*}	1198.4	874.0	1036.2	800.8	1105.5	953.2	994.7
53 kg/ha N from UREA*	1045.3	1216.0	1130.7	930.5	971.1	950.8	1040.8
LSD (α = 0.05)	215.1	425.5	273.9	507.4	755.3	640.0	593.1
CV (%)	12.4	30.8	26.0	34.7	16.5	28.1	26.5
Straw yield (Kg/ha)							
Control (without N)	1424.2	804.0	1114.1	1498.2	247.9	873.1	993.6
40 kg/ha N from Urea*	3504.2	2511.0	3007.6	3879.2	3778.1	3828.7	3418.2
27 kg/ha N from UREA^{stabil}	2675.0	2260.0	2467.5	4185.7	4034.0	4109.9	3288.7
40 kg/ha N from UREA^{stabil}	3468.2	3229.0	3348.6	4313.5	4518.2	4415.9	3882.3
53 kg/ha N from UREA^{stabil*}	3924.0	2278.0	3101.0	4144.5	3008.2	3576.4	3338.7
53 kg/ha N from UREA^{stabil}	4151.0	2108.0	3129.5	2880.2	4519.5	3699.9	3414.7
53 kg/ha N from UREA^{stabil*}	4374.5	3136.0	3755.3	3313.8	4285.2	3799.5	3777.4
53 kg/ha N from UREA*	4267.2	3368.0	3817.6	3835.2	4367.4	4101.3	3959.5
LSD (α = 0.05)	852.7	924.2	916.7	2375.4	1359.2	2817.0	2227.3
CV (%)	14.18	21.7	26.5	39.1	16.6	30.9	30.7

** Indicates that nitrogen was applied in split*

Table 4. Yield response of tef (Kg/ha) for urea and UREA^{stable} in Vertisol

Treatments	Grain Yield (Kg/ha) Year 1 (2017)	Year 2 (2018)			
	Site 1	Site 1	Site 2	Mean	Combined
Control (without N)	629.2	301.9	310.0	306.0	413.7
60 kg/ha N from Urea*	1367.7	859.4	914.8	887.1	1047.3
40 kg/ha N from UREA^{stabil}	1171.1	1009.0	810.2	909.6	996.8
60 kg/ha N from UREA^{stabil}	2259.1	981.3	1106.5	1043.9	1448.9
60 kg/ha N from UREA^{stabil*}	1876.3	897.5	915.6	906.6	1249.1
80 kg/ha N from UREA^{stabil}	1598.7	1150.2	1343.5	1246.9	1364.1
80 kg/ha N from UREA^{stabil*}	1643.0	1112.5	1191.5	1152.0	1315.6
80 kg/ha N from UREA*	2152.0	1152.1	1233.8	1193.0	1512.6
LSD (α = 0.05)	895.0	385.5	346.6	233.4	440.1
CV (%)	32.5	23.6	20.5	20.9	40.0
Straw yield(kg/ha)					
Control (without N)	1922.9	1031.5	481.7	756.6	1145.3
60 kg/ha N from Urea*	3059.4	3099.0	1647.7	2373.4	2602.0
40 kg/ha N from UREA^{stabil}	2631.0	2053.5	1377.3	1715.4	2020.6
60 kg/ha N from UREA^{stabil}	4668.0	3393.8	2060.2	2727.0	3374.0
60 kg/ha N from UREA^{stabil*}	4373.7	3394.2	1584.4	2489.3	3215.6
80 kg/ha N from UREA^{stabil}	3713.8	4120.6	2510.6	3315.6	3448.4
80 kg/ha N from UREA^{stabil*}	4440.3	4429.2	2454.4	3441.8	3774.6
80 kg/ha N from UREA*	4657.0	4618.8	2516.3	3567.6	3930.7
LSD (α = 0.05)	1726.0	802.8	536.9	1090.9	1015.8
CV (%)	27.1	14.0	17.0	36.4	36.7

** indicates that nitrogen was applied in split*

Conclusion and recommendation

A two-year field experiment was carried in the northwestern parts of Ethiopia for wheat and tef under Nitisols and Vertisols to evaluate the performance of UREA^{stabil} compared to the conventional urea. The findings of this research denies our prior hypothesis that UREA^{stabi} could give better yields of tef and wheat at low rates of nitrogen with single applications compared to the conventional urea. Under both soils and for both crops, the application of UREA^{stabil} did not show a significant yield advantage over the conventional urea. Split application of UREA^{stabil} showed better yields over a single application. Therefore, there was no evidence in our research that supports the advantage of UREA^{stabil} over the conventional urea. Nevertheless, N-(n-butyl) is a proven technology to inhibit the activity of urease and hence reduce the loss of nitrogen. However, the rate of the inhibitor under different environments including Ethiopia needs further considerations of research. Moreover, further research on quantifying the nitrogen losses, grain and straw qualities (protein content) and nitrogen recovery using urease inhibitors, nitrification inhibitors and controlled releasing fertilizers should be targeted.

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Phosphorus Rate Determination for Field pea (*Pisum sativum* L.) Production Under Irrigation

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Abstract

Field Pea (Pisum sativum L.) is among the most cultivated and popular legume crops grown in Ethiopia and many other countries in the world. Howeve, the yield per hectare decreased tremendously for the last two decades due to depletion of soil nutreints specifically phosphorous. Therefore it was peramaount important to return the yield potential of this crop by aplying chemical fertilizers(NP). Hence field experiment was conducted at Adet Agricultural Research center, Koga irrigation scheme to determine the rate of phosphorus fertilizer for field pea production under irrigation conditions for two years. The experiment was arranged in a randomized completed block design and had four replications. Five phosphorus fertilizer rates(0, 23, 46, 69, and 92 P_2O_5) were considered as treatments.The DAP as (18-46-0), 36 kg ha^{-1} N was added as a starter source for all plots. This was done by considering the highest rate of DAP (i.e., 150 kg ha^{-1}) and adjusting the nitrogen for the remaining treatments by urea. The results indicated that the application of 46 kg ha^{-1} P_2O_5 fertilizer gave the higher grain yield (2.37 t ha^{-1}) of field pea and it has 35 % of yield advantages as compared to the control. On the other hand, compared to the control phosphorus application at the rate of 23, 46, 69, and 92 P_2O_5 increased the mean grain yield of field pea by 38%, 53%, 48%, and 43% respectively. However, plant height, pods per plant, and hundred seed weight were not significant among phosphours nutrient rates. The outcomes of the partial budget analysis showed that the maximum net benefit was obtained from the application of 46 kg ha^{-1} P_2O_5 and it was economically feasible. Therefore, the use of this rate of P_2O_5 fertilizer is recommended to maximize field pea in the Koga irrigation scheme and similar agroecology under irrigation.

Keywords: Field pea, Irrigation, Koga, Phosphorus, Yield

Introduction

Field pea is the second most important legume crop in Ethiopia after faba bean in terms of both area coverage and the total amount of production. Field Pea (Pisum sativum L.) is among the most cultivated and popular pulse crops grown in Ethiopia and low in its productivity due to several determinant factors. The field pea has contributed nutrient values for the consumers; for instance, protein, carbohydrates, phosphorus, iron, calcium, and vitamins A and B (Watt and Merrill, 1963). Expanding the production of field peas such as green pods and dry seeds with standard quality is considered as an important issue and could be achieved through using phosphorus and foliar application of humic acid.

Phosphorus is among the most needed elements for crop production in many tropical soils. However, many tropical soils are p deficient (Osodeke and Uba, 2005). Phosphorus is required for plant growth and development and significantly influencing plant growth and metabolic activities. Phosphorus with a combination of nitrogen is the main yield-limiting plant nutrient in most parts of the world. More than 30% of the world's arable land crop production is determined by P availability (Tesfaye et al., 2007). Phosphorus may become a critical factor for the production of pulse crops under the lowest nutrient content areas; this is due to the basic need for P in the nitrogen fixation process (Tsvetkova and Georgiev, 2007). The highest requirement for P inthe pulse crops is related to the presence of P in the highest rates of energy transfer that must carry out in the nodule. Besides, phosphorus has an increasing effect on plant growth, development, and yield throughout its requirement as an energy source and perform important metabolic processes and activities for the plant (Srivastava et al., 1998). However, the availability of P nutrient to plants in acidic soils such as Koga irrigation scheme and similar agroecologies is hampered due to sever soil acidity (Eriksson, 2009). Furthermore, improved production technologies related to field pea production are limited. The yield of recommended varieties in Ethiopia on station ranges from 2 to 5.5 t ha^{-1} with broadcasting sowing and a seed rate of 75 to 150 kg ha^{-1}. The optimum rate of P fertilizer for field pea was lacking in the areas. This is because, phosphorus fertilizer rate depends on soil test levels, yield goals, cropping history, and potential crop yield. For field peas, soil P should be at least about 20 ppm. The use of P fertilizer levels at the rates of 10, 20, and 30 kg P ha^{-1}enhanced the average seed yields of field pea by 36 %, 67 %, and 57%, respectively compared to the control units (Agegnehu, 2009). This indicates a good response of field pea to P fertilizers. Furthermore, irrigated field pea gave 1 ton yield advantage over the main season in variety adaptation trials using 100 kg ha^{-1} DAP and sowing with 20X10 cm inter-row and intra row spacing in the Koga irrigation scheme (unpublished annual report, 2012). However, there is no recommended package of phosphorus fertilizer for the main season and off-season for the production of field pea. Therefore, this activity was conducted to determine the optimum rate of phosphorus fertilizers for field pea production under irrigated condition.

Materials and Methods

Description of the study area

The study was conducted at Adet agricultural research centre**,** Koga irrigation scheme starting from the end of November to the beginning of April for -three consecutive years of the irrigation seasons. The research centre is authorized body responsible for accessing the experimental site towards permitting to conduct the research. Thus, this study confirmed that it did not affect the protected species or other practices in the surrounding environment and the site is designed for only research purposes. The site is located at 11^{o} 20'57.9"N latitude,37^{o} 7’29.7"E longitude and at an elevation of 1955 m above mean sea level (m.a.s.s). The scheme is specifically situated adjacent to the town of Merawi in the North Mecha Woreda, West Gojjam zone in Amhara regional state (Eguavoen and Tesfai, 2011). The Koga watershed has the potential to irrigate 7000 ha of arable land. The climatic condition of the study area lies within a cool semi-humid agroecosystem that attributes separate dry and wet season (Gebeyehu and Soromessa, 2018). The research site is characterized as unimodal rainfall pattern which occurs from May to September while the months from October to April were considered as the dry season. However, very small rain occurs irregularly during April and May (Figure 4). The experimental site was situated in the lower catchment and consisted of three major soil classes. Among the main soil classes, Alfsols (Nitosols) are the dominant soil types that contribute to clay textural class (Yitaferu et al., 2013; Gebreselassie, 2002) and (Table 7). Very low available phosphorus content occurred due to the high acidity of the soil (Pam and Murphy, 2007).

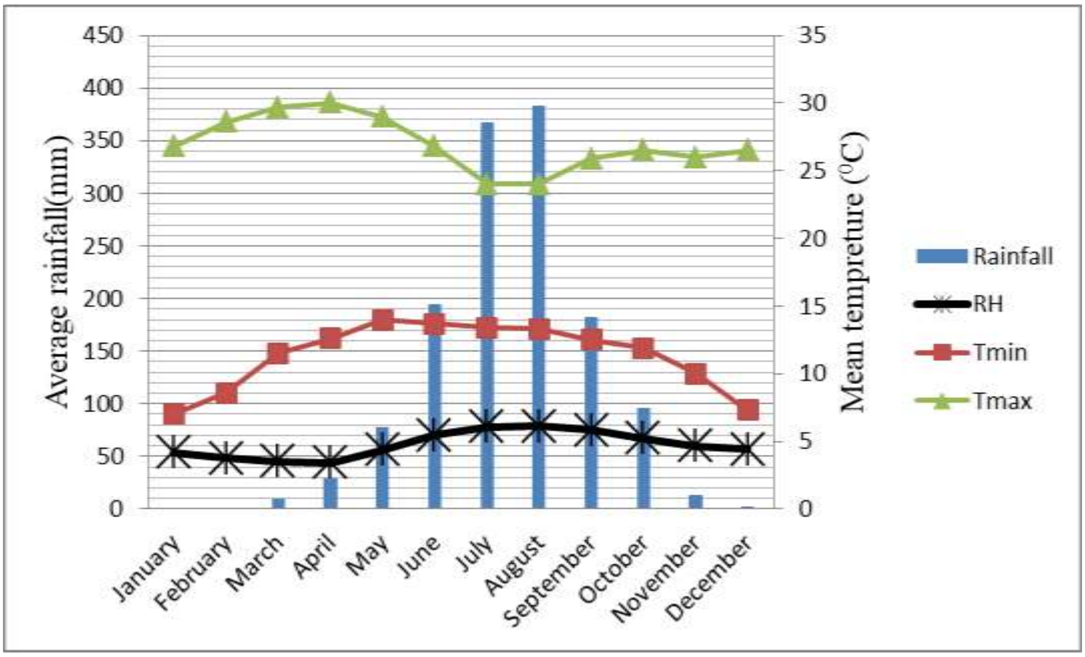

Figure 4. Climatic characteristics of the study area

Table 7. Selected physical and chemical soil properties of the experimental site

Physical parameters	Values	Chemical soil parameters	Values
FC (%)	34.1	PH (%)	4.6
PWP (%)	22.6	EC (ms/cm)	0.18
BD (gcm^{-3})	1.12	CEC (%)	22.2
Sand (%)	24.1	OM (%)	3.18
Clay (%)	67.3	N (%)	0.20
Silt (%)	30.6	Av.P (ppm)	8.72
Texture	Clay	Fe (ppm)	16.5

Where; FC = field capacity, PWP = permanent welting point, BD = bulk density, CEC = cathion exchange capacity, and OM = organic matter, Av. P = available phosphorus

Experimental design

The experiment was organized and formulated in a randomized complete block design consisted of four replications. The experiment comprises five different levels of phosphorus fertilizers (0, 23, 46, 69, and 92 P_2O_5 kg ha^{-1}) as treatments. The numbers of plots considered were twenty and the experimental plots had an area of 12.2 m^2 (3.2 X 4.0 m per plot). The intra and inter-row spacing were 40 and 5 cm respectively. There was also a1m and a 2m gap between plots and replications respectively to enable management practices with a uniform amount of water applications in furrow irrigation over the growing period. A recently recommended variety of field pea (Birkitu) by Adet agricultural research centre for the Koga irrigation scheme was used at a seed rate of 75 kg ha^{-1}. All agronomic management practices were conducted uniformly for all plots. And before planting levelling of experimental plots were performed to achieve fair water distribution. DAP was applied side-banded at sowing about 5cm far from the seed. Irrespective of how much would lime improve the phosphorus use efficiency, equal lime rate was applied for all plots (the trial was done on-site treated with lime at a rate of 2 ton ha^{-1}). The rate of starter N used was considered based on the maximum rate of DAP fertilizer used in this trial (Table 8). The reason for the use of starter nitrogen was to support nutrient supply until the crop begins nitrogen fixation and it was applied uniformly for all tested plots.

Table 8. Starter amount of urea fertilizer applied at each treatment during the experiment

Treatments (P_2O_5 levels)	N in DAP (kg ha^{-1})	N in Urea (kg ha^{-1})	Total starter N (kg ha^{-1})	Total starter Urea (kg ha^{-1})
0	0	36	36	78.26
23	9	27	36	58.69
46	18	18	36	39.13
69	27	9	36	19.57
92	36	0	36	0

Data collection

In this research, the data collected includes phenological and agronomic data (growth data). The phenological data comprises days to 50 % flowering, grain yield and days to 90% maturity whereas the growth data collected in this experiment were: plant height, seed per pod and pod per plant at harvest for ten randomly selected plants while the number of branches per plant, stand count at three to four weeks after planting, and 100 seed weight were also collected during the experiment.

Soil sampling and analysis

Composite surface soil samples were collected after harvest at a depth of 0 to 20 cm (topsoil) using auger. The soil parameters analyzed comprise available phosphorus (P), organic matter (OM), soil PH, and organic carbon (OC). The organic carbon of the sampled soil was determined by the Walkley-black wet oxidation method (Walkely and Black, 1945; FAO-UNESCO, 1974) where the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution. During the analysis of soil organic carbon in the laboratory, the reagents used include; potassium dichromate, sulfuric acid, orthophosphoric acid, ferrous ammonium sulfate solution, and diphenylamine indicator. The available P was extracted with sodium bicarbonate solution at PH = 8.5 following the procedure according to (Bray and Kurtz, 1945) and using the apparatus a spectrophotometer. The spectrophotometer was manufactured by UK PRC Milton Roy Company in 1994 having a specification of spectronic 501/601 spectrophotometer and model 6320D. The appropriate chemicals used for the analysis of available phosphorus in the lab incorporates; sodium hydro oxide, sodium bicarbonate solution as extractant, sulfuric acid solution, and p-nitrophenol indicator (Syers et al., 2008). The soil PH was measured potentiometrically in the supernatant suspension of a 1:2.5 with soil and water mixture using a pH meter with a range of 0 to 14 pH and the application of deionized water, pH 4 and pH 7 buffer solutions are used as chemicals for analysis (Syers et al., 2008).

Partial budget analysis

To identify economically feasible recommendations, partial budget and sensitivity analysis were conducted. The mean grain yield data were adjusted down by 10% to reflect the farmer's field yield and subjected to partial budget analysis CIMMYT (1998). One kg field pea grain costs 35 birrs) from the local market prices. The current average price of phosphorus fertilizer based on DAP and Urea was 13.40 and 12.60 Ethiopian birr kg^{-1}(ETHB) respectively. The Gross benefit was calculated as grain yield (kg $ha-^{1}$) multiplied by grain price that farmers receive for the sale of the crop (35 birr $kg-^{1}$). The fertilizer costs that varied for each treatment were calculated and treatments were ranked in the ascending order of total variable cost. dominance analysis was conducted to identify the dominated traetments by substracting the net benefit of the first traetment from the second, the second treatment from third and so on. The net benefit was estimated by subtracting the total variable cost from the gross benefit. Then the marginal rate of return was calculated using the procedures described as follows: MRR= (change in net benefit/ change in total variable cost)*100.

Data analysis

All the data collected were exposed to the analysis of variance (ANOVA) and computed by SAS (version 9.0) software based on randomized complete block design. The least significant difference (LSD) at 5% confidence interval was used for mean comparison of grain yield, biomass, plant height, pods per plant, seed per pod, and 100 seed weight.

Results and Discussion

Analysis of soil physico-chemical properties

The pH of the soil at the experimental field was found in the range of 5.5 to 5.6 which is acidic in the general classification. The result lay within the range of most agricultural soils of the North-western Amhara region and following the other reports. According to (Landon, (1991), the content of phosphorus in the soil was rated (mg kg^{-1}) in different classes. Therefore, the available P content of the soil less than 3 is very low, 4 to 7 is low, 8 to 11 is medium, and greater than 11 is high. In this experiment, the available P content of the sampled soil is very low, which ranges from 2.06 to 3.2 mg kg^{-1} (Table 9).

Table 9. Soil Chemical properties at depth of (0-20 cm) for the experimental site after harvesting

Treatments	PH(1:2.5H_2O)	Av.P (ppm)	OM (%)	SOC (%)
0	5.508	2.06	3.163	1.834
23	5.635	2.378	3.035	1.760
46	5.545	2.022	3.165	1.836
69	5.476	3.213	3.071	1.781
92	5.607	3.009	3.092	1.793
LSD	0.312	1.41	0.54	0.32
CV	3.6	36.3	11.4	11.4

Av.P = available phosphorus, OM=organic matter, SOC = soil organic carbon

Effect of phosphorus nutrient rates on yield and yield components of field pea

Due to different management problems such as watering and pest management, the yield and yield component data were not satisfactory and below the lower limit of field pea yield in the year 2015. Hence, this year's data were not included in the analysis. However, the combined analysis of variance over the two years (2014 and 2016) revealed that phosphorus nutrient rates had significant effect on the grain and biomass yield of field pea (Table 4). The application of 46 P_2O_5 kg ha^{-1} fertilizer gave a higher but non-significant yield (2371kgha^{-1}) followed by 69 P_2O_5 kg ha^{-1} fertilizer rate (2296 kg ha^{-1}). As compared with the control treatment, 46 P_2O_5 kg ha^{-1} has a 53% yield advantage. Furthermore, phosphorus nutrient application at the rates of 23, 69, and 92 kg ha^{-1} P_2O_5 resulted in an increased grain yield over the non-fertilized treatments by 38%, 48%, and 43% respectively. This result had the same trends as the other investigations reported by Getachew (2009). Getachew (2009) found that the application of phosphate nutrient at the rates of 10, 20, and 30 kg P_2O_5 ha^{-1}enhanced mean grain yields of field pea by 36, 67, and 57%, respectively compared to the control. For seed yield and plant height, the means and the 95 % confidence interval indicated an increment pattern following the fertilizer rates.

Table 4. Effect of phosphorus ratess on grain and biomass yields of field pea at Koga irrigation site in 2014 and 2016.

	2014		2016		Combined	
P_2O_5 kg ha^{-1}	G. Yield (kg ha^{-1})	Biomass (kg ha^{-1})	G. Yield (kg ha^{-1})	Biomass (kg ha^{-1})	G. Yield (kg ha^{-1})	Biomass (kg ha^{-1})
0	1662.2c	4322.9	1430b	6300b	1549^{b}	4653^{b}
23	2177.7b	5156.3	2053.4a	9039.3a	2134^{a}	6096^{ab}
46	2645.8a	6301.1	116.3a	328.6a	2371^{a}	929^{a}
69	2548.4a	6510.1	058.9a	218.8a	2296^{a}	704^{a}
92	2305.5ab	5937.5	098.6a	109.8a	2215^{a}	373^{a}
P (0.05)	**	Ns	**	**	*	*
CV	8.5	13.8	10.63	10.67	12.9	16.9

Means followed by the same letter within a column are not significantly different from each other at P< 0.05 according to Fishers LSD; LSD = Least significant difference; CV=Coefficient of variation; ns = -non-significance, PH=plant height

The combined analysis of variance over the years (2014 and 2016) revealed that the main effect of phosphorus nutrient rates on plant height, pods $plant^{-1}$, seeds pod^{-1}, and hundred seed weight were not affected by the various levels of phosphorus fertilizers (Table 5). The result of the analysis of variance in 2014 showed that plant height, pod per plant, seed per pod and biomass yield were not significantly affected by the effect of phosphorus nutrients (Table 4&5). Whereas hundred seed weight and grain yield was significantly differed in the same year (Table 4&5). Similarly, the result of analysis of variance for the year 2016 showed that plant height, pod per plant, and seed per pod were not significantly affected by the effect of phosphorus nutrient rates (Table 5). However, hundred seed weight, biomass and grain yield was significantly differed between P_2O_5 fertilizer rates in this year (Table 4&5).

Table 5. Effect of phosphorus nutrient rates on yield components of field pea in the years 2014 and 2016 irrigation season at Koga irrigation site

	2014				2016				Combined			
P_2O_5 kg ha^{-1}	PH (cm)	Pods $plant^{-1}$	Seed pod^{-1}	100 seed wt (gm)	PH (cm)	Pods $plant^{-1}$	Seed pod^{-1}	100 seed Wt (gm)	PH (cm)	Pods $plant^{-1}$	Seed pod^{-1}	100 seed Wt (gm)
0	99.27	7.3	5.67	24.67a	83.2	4.3	5.7	18a	90.10	5.5	5.7	19.57
23	110	7.67	5.67	20b	93.1	4.85	5.45	18a	100.3	6.0	5.5	18.86
46	115.73	8	5.33	20.33ab	90.25	4.15	5.45	16.5b	101.2	5.9	5.5	18.14
69	126.07	10.33	6.33	18.33c	93.4	5.0	5.45	16.5b	108.6	7.3	5.9	17.29
92	116.27	8	6	18.33c	95.45	4.85	5.65	16.5b	103.2	6.3	5.7	17.29
P(0.05)	Ns	Ns	Ns	**	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns
CV	7.2	21.58	9.2	4.3	9.29	1.08	9.17	5.54	14.4	36	8.6	9.6

Means followed by the same letter within a column are not significantly different from each other at P< 0.05 according to Fishers LSD; LSD = Least significant difference; CV=Coefficient of variation; ns = non-significance, PH=plant height

Partial budget analysis

The result of partial budget analysis indicated that the cost for the different fertilizers was varied due to their different levels of phosphorus nutrients. However, the fertilizer application, weeding, and harvesting costs were similar for all treatment. Based on this assumption, estimating the minimum rate of return acceptable to producers in the recommendation domain is important. The marginal rate of return of the non-dominated treatment (Table 6) showed that 23 and 46 kg P_2O_5 ha^{-1} records a positive marginal rate of return 3202.29 birrs and1241.23 birrs, respectively. According to CIMMYT (1998), on-farm economic analysis of major cereals reported that MRR >100 % is acceptable. Therefore, from this experimental study, two treatments provided MRR greater than 100%. Hence, treatments those receive 23 kg P_2O_5 ha^{-1} records the highest MRR and is within the acceptable range. However, the net benefit obtained by using 46 kg $P_2O_5ha^{-1}$ is greater than using 23 kg P_2O_5 ha^{-1} and hence, it is recommended that farmers should use 46 kg P_2O_5 ha^{-1} which is cost-effective and economically feasible.

Table 6. Partial budget analysis of field pea production under various levels of P_2O_5

P_2O_5 $kgha^{-1}$ levels	GY(kg)	AGY(kg)	GB(birr)	TVC	NB	Dom	MRR(%)
0	1529.5	1376.55	48179.25	1040.76	47138.49	-	
23	2106.8	1896.12	66364.2	1591.27	64772.93	-	3203.291
46	2341.2	2107.08	73747.8	2141.78	71606.02	-	1241.229
69	2268.7	2041.83	71464.05	2692.29	68771.76	Dominated	-
92	2187.2	1968.48	68896.8	3242.8	65654	Dominated	-

GY = grain yield, AGY=average grain yield, GB = gross benefit, TVC = total variable cost, NB =net benefit, DOM. =dominance and MRR =marginal rate of return

Conclusion and recommendation

The recommendation of the best level of phosphorous nutrients for crops is necessary to attain the optimum yield of field pea. The two-year results indicated that the application of 46 kg ha^{-1} P_2O_5 fertilizer gave the highest grain yield (2371 kg ha^{-1}) with the maximum net benefit. The experiment illustrated that the grain yields and biomass of field pea increased as the phosphorus application rate increased from 0 to 92 kg ha^{-1}. On the other hand, the treatment effect do not clearly indicate the changes in seed per pod, pod per plant, and 100 seed weight. Therefore, based on the partial budget analysis it can be recommend that 46 P_2O_5 kg ha^{-1}fertilizer rate is appropriate and economically feasible to produce field pea around Koga and similar agroecology for the irrigation season.

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Appendeces

Appendix Table 1. Mean squares of analysis of variance for yield and yield components of Field pea in 2014 Irrigation season

Sources	DF	PH	PP	SP	100 seed wt	BY	GY
Treatment	4	289.05*	4.23ns	0.43ns	6.07**	2439778.65*	448440.06**
Replication	3	28.84ns	1.27ns	0.2ns	2.47ns	60221.35ns	120211.17ns
RMSE		8.13	1.78	0.53	0.85	779.4	194.47
CV		7.16	21.58	9.18	4.3	13.8	8.57
R-square		0.7	0.43	0.4	0.84	0.67	0.87

DF=degree of freedom, PH=plant height, PP = pod per plant, seed per pod, BY=biomass yield, GY=grain yield

Appendix Table 2. Mean squares of analysis of variance for yield and yield components of Field pea in 2016 Irrigation season

Sources	DF	PH	PP	SP	100seedwt	BY	GY
Treatment	4	91.34ns	0.57ns	2.7ns	2.7ns	6656555.17**	342769.627**
Replication	2	19.22ns	0.19ns	1.4ns	1.4ns	803954.08ns	39194.351ns
RMSE		8.47	0.7	0.51	0.95	918.3	207.61
CV		9.3	15.21	9.17	5.55	10.68	10.64
R-square		0.33	0.33	0.3	0.58	0.74	0.74

DF=degree of freedom,PH=plant height,PP = pod er plant, seed/pod, BY=biomass yield, GY=grain yield

Appendix Table 3. Mean squares of combined analysis of variance for yield and yield components of Field pea in Irrigation season

Sources	DF	PH	PP	SP	100 seed wt	BY	GY
Treatment	4	317.13^{ns}	3.01^{ns}	0.29^{ns}	6.97**	8215380.8***	734864.7***
Replication	3	118.99^{ns}	0.5^{ns}	0.3^{ns}	3.36ns	5750832.7**	16508.1
Year	1	3962.9***	96.48	0.97	50.7***	59275959.3***	905345.3**
RMSE		8.16	1.24	0.49	1.1	961	224.16
CV		8.11	20.09	8.71	6.04	11.7	10.74
R-square		0.76	0.76	0.32	0.74	0.85	0.75

DF=degree of freedom, PH= plant height, PP = pod per plant, seed per pod, BY=biomass yield, GY=grain yield

Nodulation, Grain Yield and Yield Components of Faba bean (*Vicia fabae* L.) as Influenced by Rhizobium inoculation and Phosphorus fertilization in Moretna Jiru District, Eastern Amhara, Ethiopia

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Abstract

The on-farm experiment was conducted at Moretna Jiru district, Amhara Region, Ethiopia during the main rainy seasons of 2016/17 and 2017/18. The objective of the study was to evaluate the effectiveness of different commercial and new rhizobia strains as well as to evaluate the effect of phosphorus fertilizer on nodulation and grain yield of faba bean in the study area. The experiment comprised of three Rhizobial strain (EAL-110, FB-1035 and FB-1018), one Phosphorus level (10 kg P ha) and control (with-out inoculation and P application) which were laid out in randomized complete block design (RCBD) with three replications. The analysis of variance showed that except nodule size in 2017/18, all the tested nodulation parameters were not affected by the treatments. Plant height which was obtained from both years was significantly affected by the treatments. In 2016/17, significantly the highest plant height (86.4 cm) was observed from combined application of EAL-110 strain with 10 kg P ha^{-1}. The lowest plant height (78.4 cm) was observed with inoculation of the seed of faba bean with strain FB-1018. In 2017/18 the highest plant height (80.0 cm) was observed with sole application of strain FB-1035. In 2016/17, significantly the highest number of pod per plant (21.4) was observed with combined application of strain EAL-110. In 2017/18, significantly the highest number of pods per plant (26.8) was observed with combined application of EAL-110 with 10 kg P. In 2016/17, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of EAL-110 with 10kg P ha^{-1}. The lowest seed yield (1931.6 kg ha^{-1}) was observed from the control plot. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL-110 alone. The partial budget analysis indicated that the highest mean net benefit (43800.7 birr ha^{-1}) was obtained when EAL-110 Rhizobium strain was applied with 10 kg P ha^{-1}. Hence, Rhizobium inoculation of EAL-110 with 10 kg P ha^{-1} could be recommended for faba bean production at the experimental locations in Moretna Jiru district.

Keywords*:*Faba bean, Inoculation, Nodulation, Rhizobium, Yield

Introduction

Faba bean (*Vicia fabae* L.) is a major cool-season food legume that occupies about 34% of the total cultivated land from pulses in Ethiopia (CSA, 2013). Amhara and Oromia regional states are the two favorable areas in Ethiopia where production of faba bean is highest. Those two regions account for 85% of the national faba bean production (IFPRI, 2010). Faba bean is grown in the main season, on both red and black soils.

The crop has been an important protein source for the human diet. The straw of the crop is used as animal food. Faba bean is a legume crop capable of fixing nitrogen by forming an association with root nodulating bacteria group called *Rhizobium leguminosarum* biovar vicia. As a result, it improves the fertility status of the soil and makes N for subsequent crops (Amanuel *et al*., 2000; Habtegebriel *et al*., 2007). Some report indicated faba bean derive the highest percentage of N from the atmosphere (Hardarson *et al*., 1991) and the amount of nitrogen fixed by faba bean have been 240-325 kg ha^{-1} (Somasegaran and Hoben, 1994).

Even though faba bean is of such importance in Ethiopia, the national yield has remained low; and According to Central Statistics Agency of Ethiopia (2012/13), the national average yield of faba bean is 1.5 tones ha^{-1}. Several biotic and abiotic factors contributed to the low productivity of the crop. The major biotic factor includes poor soil fertility and low existence of effective indigenous rhizobia population in the area (Carter *et al*., 1998). The application of chemical fertilizer, particularly phosphorus is needed to improve the production of the crop (Otieno *et al*., 2009). External seed inoculation of rhizobia is one of the practices to increase the nitrogen fixation potential of the faba bean crop and hence the yield of the crops especially in areas where low population of effective indigenous rhizobia or due to higher competitions with non-effective ones (Tolera *et al*., 2009). The objective of this study was therefore to evaluate the effectiveness of different commercial and new rhizobia strains and to evaluate the effect of phosphorus on nodulation and grain yield of faba bean in Moretina Jiru and similar agro-ecologies and soil types areas.

Materials and Methods

Description of the study area On-farm experiment was conducted at Moretna Jiru district, Amhara Region, Ethiopia during the main rainy seasons of 2016 17 and 2017 18. The average annual rainfall from the nearby metrological station (Enewari) is 899.01 mm having a mean minimum and maximum temperature of 21.39 and 9.09°C respectively. Vertisols are the dominant soil type in the areas. The crops widely grown in the study area include wheat, Tef, faba bean and lentil, whereas chickpea, grass pea and others have low area coverage and mostly grow on residual soil moisture at the end of the rainy season. Specifically, the experiment was conducted at 9^{0}52'18.07"N, 39^{0}10'19.34"E (Site 1), 9^{0}52'21.58"N, 39^{0}11'38.36"E (Site 2), 9^{0}50'53.26"N, 39^{0}12'42.58"E (Site 3), 9^{0}49'33.68"N, 39^{0}12'26.19"E (Site 4), 9^{0}54'26.65"N, 39^{0}10'17.54"E (Site 5).

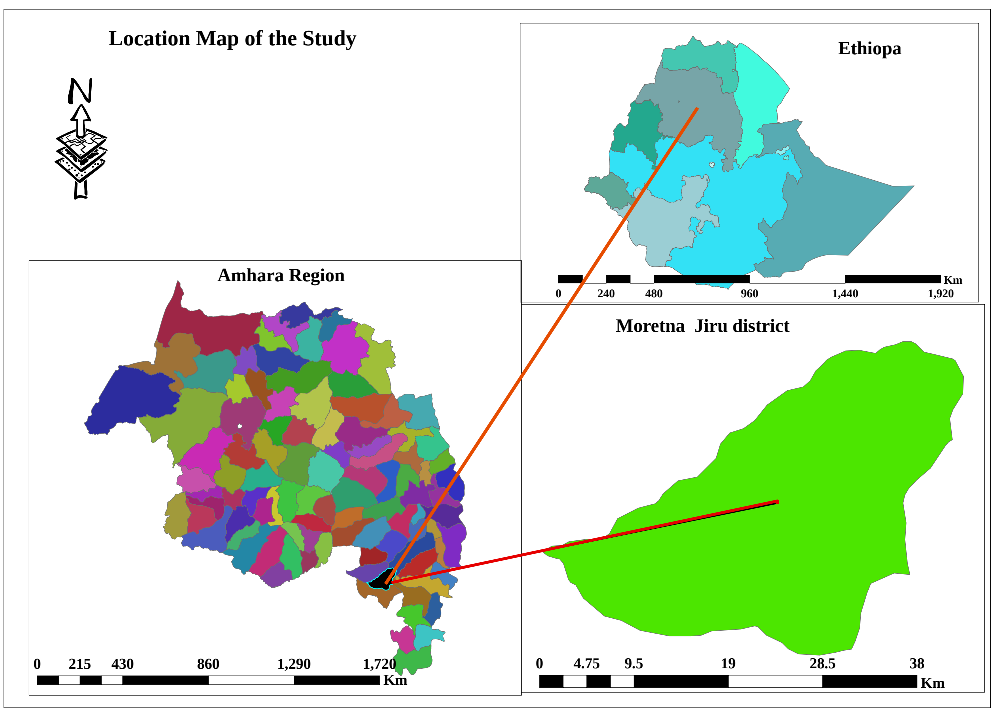

Figure 1. Location Map of the study area

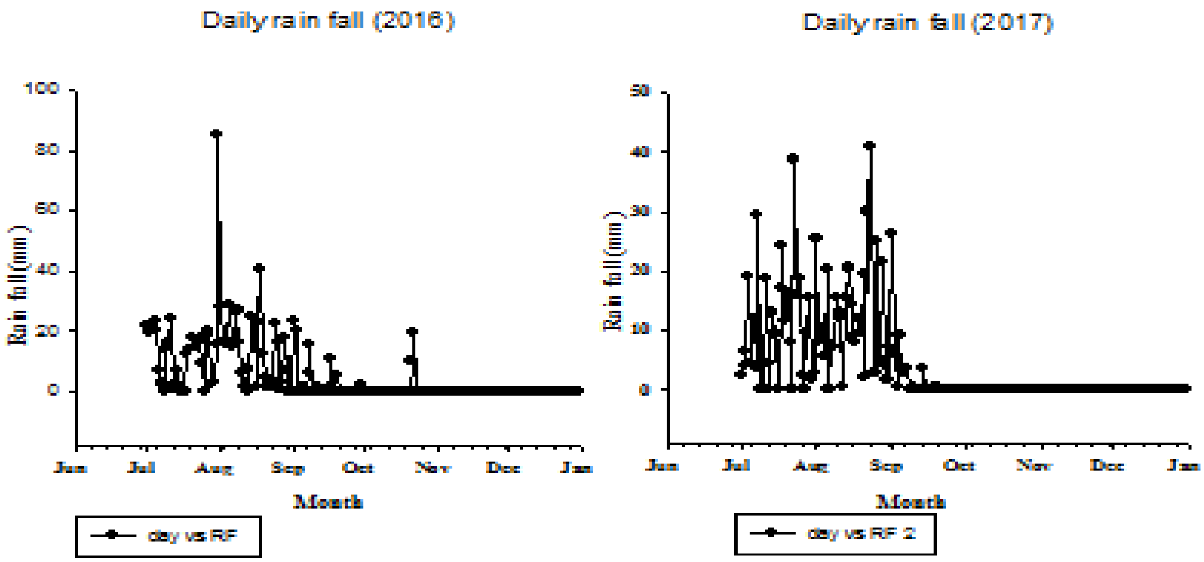

Figure 2. Daily rainfall distribution during the experiment (planting to late pod setting stage)

Experimental detail

Soil sample collection and processing

Before starting the experiment, initial composite soil samples were collected from the experimental plots. The samples were analyzed for texture, pH, Av.P, OC and TN. Soil particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Soil pH was measured with a digital pH meter potentiometrically in supernatant suspension of 1:2.5 soils to distilled water ratio (Van Reeuwijk, 1992). Organic carbon (OC) was determined by the dichromate oxidation method (Walkley and Black, 1934). Total N in the soil was measured by the micro Kjeldahl method (Jackson, 1958). Available P was analyzed by Olsen method (Olsen *et al*., 1954) colorimetrically by the ascorbic acid- molybdate blue method (Watanabe and Olsen, 1965).

Experimental design and treatments

The experiment comprised of seven treatments with three rhizobia strains (EAL-110, strain FB-1035 and strain FB-1018) and a combination of those strains with chemical fertilizer (10 kg P ha^{-1}). The experiment was laid out in a randomized block design with three replications. The plot size was 3.6 m x 3m.

Treatments:

1. Control (No strain and P fertilizer)
2. Strain FB-1035
3. Strain FB-1018
4. Strain EAL-110
5. Strain FB-1035 + 10 kg P ha^{-1}
6. Strain FB-1018 + 10 kg P ha^{-1}
7. Strain EAL-110 + 10 kg P ha^{-1}

Source of rhizobial isolates

Commercially available *Rhizobium* strain EAL-110 was obtained from MBI (Menagesha Biotechnology Industry). While the two available *Rhizobium* strain (FB-1035 and FB-1018) was obtained from Holeta Agricultural Research Center.

Source of improved seeds

The Faba bean variety "Dagem" was used as testing crop for the experiment. The variety was selected based on the recommendation of Debre Birhan Agricultural Research Center for the area.

Method of seed inoculation

Seed inoculation was performed before sowing using the procedure developed by Fatima *et al*. (2007). To ensure the sticking of the applied inoculant to the seeds, the required quantity of seed was suspended in 1:1 ratio in 10% sugar solution. The inoculant was gently mixed with dry seeds at the rate of 10 g per kg of seed. Inoculation was done just before sowing under shade to maintain the viability of cells and allow to air dry for a few minutes and then the inoculated seeds were sown at 40 cm between rows and 10 cm between plants. To avoid contamination, plots with un-inoculated seeds were planted first followed by the inoculated ones.

Data collection

Data collected at the flowering stage

Sampling for nodulation was performed by excavating the roots of plants randomly from two rows next to border rows of each plot at the mid flowering stage of the crop. The plants from each plot were used to record the number of effective nodules, nodule size and nodule volume.

Data collected at early pod setting stage and after harvesting

At early pod setting and after harvesting plant height, number of pod per plant, seed yield, straw yield and 1000 seed weight was determined

Other agronomic management

Disease and pest control: (Redomil) and (Caratin) were sprayed to control faba bean gall disease (*kormed*) and bollworm respectively.

Data analysis

The collected data were subjected to analyses of variance (ANOVA) on the selected parameters using SAS 9.1 statistical software. Where ever the treatment effects were significant, mean separations were made using the least significance (LSD) test at a 5% level of probability (Gomez, 1984).

Economic analysis

Based on the procedure described by CIMMYT (1988), economic analysis was done using partial budget analysis. For partial budget analysis, the variable cost of fertilizer, labor and rhizobial inoculant were taken at the time of planting and during other operations. The price of faba bean grain and straw were considered. The average yield was adjusted downward 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 seed price of faba bean (16.5 Birr kg^{-1} seed), inoculant (240 Birr ha^{-1}), straw (4.00 Birr kg^{-1}), phosphorus fertilizer (9.634 Birr kg^{-1}) and labor cost (100 Birr per person per day) were used for variable cost determination. All input and output cost for economic analysis was based on mean value over location.

Result and Discussion

Selected Physico-chemical Properties of the Soils of the Study Sites

Soil texture is one of the inherent soil properties less affected by management and which determines nutrient status, organic matter content, air circulation and water holding capacity of a given soil. Based on the soil analysis made, the soil texture of the entire site was clay. In agreement with the present study, different scholars reported that the particle size distribution of vertisols of Ethiopia are dominated by clay (Kamara *et al*., 1989; Lemma and Smit, 2008; Debele, 1985 and Tesgaye, 1992).

The results of the selected soil physical and chemical properties are presented in Table 1. The pH of the experimental soils ranged from 6.4 to 6.9. According to Tekalign (1991) all sites are rated as neutral. If all other conditions are constant this soil pH is the most suitable for major field crops including faba bean. This is actually because this pH of the soil has the greatest role in the high population density and presence of persistence rhizobia in the soil (Martyniuk and Oron, 2008). This is primarily because leguminous plants grow less in acid soil than in neutral or slightly alkaline soil which could be due to lowered colonization of *Rhizobium* in the soil and rhizosphere leading to inadequate nodulation. Furthermore, in low pH soils, sensitivity of early nodulation of pasture and grain legumes low content of available phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo) (Rengel, 2002) are common phenomenon. Moreover, low soil pH may have toxic levels of aluminum, all of which can affect the vigor and health of rhizobia (Subba Rao, 1999).

According to Tekalign (1991), the entire site had low OM content (Table 1) and ranged from 0.55 to 1.38. This is because of continuous cultivation without returning residue to the soil. Similarly, different authors reported that vertsols of Ethiopian soil are low in organic matter content (Fassil and Charles, 2009; Kamara and Haque, 1987; Giday *et al*., 2015; Kiflu and Beyene, 2013). According to Asfaw and Aynabeba (1998) low soil organic matter might contribute much to the low population of resident faba bean nodulating rhizobia.

Nitrogen (N) is the fourth plant nutrient taken up by plants in the greatest quantity next to C, O and H, but it is one of the most deficient elements in the tropics for crop production (Mesfin, 1998). According to Giller (2001) the proportion of a legume's N that is derived from N fixation is strongly influenced by the amount of combined N that is available for uptake by the legume and the ability of the plant to capture and utilize that N. Nitrogen (N) derived from N fixation will be smaller when large amount of N is available in the soil.

It has been observed in Table 1, that total N in the study sites varied from 0.06% to 0.14% with a mean value of 0.25%. Based on Tekalign (1991), the total nitrogen content of all sites was low (Table 1). This indicates an external source of N (either from the application of synthetic fertilizer or organic fertilizers including bio-fertilizer) is mandatory for plant growth. In previous work, soil total N was one of the most deficient elements in Ethiopian soil including vertisols (Finck and Venkateswarlu, 1982; Mengel and Kirkby, 1987; Mesfin, 1998; Hillette *et al*., 2015).

Phosphorus deficiency is one of the significant factor that reduces the nodulation since both effective *Rhizobium* bacteria and the host crop requires this nutrient in larger quantity (Getachew and Rezene, 2006). Olsen extractable P content of the soil in the experimental sites ranged from 3.96 to 12.66 mg kg^{-1} with a mean value of 9.47 mg kg^{-1} (Table 1). According to Landon (1991), the available P was rated as low for sites 2, 3, 4 and 5 and very low in site 1. As indicated in table 1, there is variability in the available P content of the soil and the probable reason for this includes the inherent fertility difference among farms and the difference in land management between farms including the difference in fertilizer usage especially P containing fertilizer. Based on this, application of P containing fertilizer is crucial.

Table 10. Selected Physico-chemical properties of the soil

Parameters	**Before planting**					
	Sites					**Mean**
	1^+	**2^+**	**3^+**	**4^***	**5^***	
pH (1:2.5 H_2O)	6.6	6.61	6.4	6.65	6.9	6.63
Organic Carbon (%)	0.7	0.8	0.54	0.55	0.32	0.58
Organic matter (%)	1.20	1.38	0.93	0.95	0.55	1.002
Total N (%)	0.085	0.06	0.14	0.12	0.09	0099
Av. P (mg kg^{-1} soil),	3.96	10.40	8.30	12.66	12.04	9.47
Sand (%)	10	10	12	10	6	
Silt (%)	30	26	18	12	20	
Clay (%)	60	64	70	78	74	
Textural class	Clay	Clay	Clay	Clay	Clay	

$^+$*=indicates farmers field on which the experiment was conducted in 2016/17, * indicates farmers field on which the experiment was conducted in 2017/18*

Nodulation parameters

The competitive ability of the native rhizobia bacteria population could be attributed to the fact that its genetic/physiological adaptation over the introduced inoculant or from a positional advantage. The native rhizobia already occupies the soil along the root zone, whereas the artificially inoculated strains usually remain concentrated around the seeds (López-García *et al*., 2002). Hence, nodule position is one of the most important parameters in assessing the performance of nodules following their ability to fix atmospheric nitrogen. In table 2, the nodule position which was obtained from both years was not significantly influenced by the treatments. This is actually because excavating and uprooting plants from vertisols is resulted in the falling of nodules from their original position for nodulation position scoring.

Many authors have reported that legume nodules having dark pink or red colors due to the presence of leghemoglobin are an indication of the effectiveness of the rhizobial strains used, which is well correlated with nitrogen fixation (Adjei and Chambeiss, 2002; Butler and Evers, 2004). In Table 2, the number of effective nodules was not significantly influenced by the treatment. Moreover, the number of effective nodules observed in the inoculated and un-inoculated plots was comparable to each other indicating the non-effectiveness of inoculated rhizobia or competitiveness of the native rhizobia over the native rhizobia (Table 2).

Nodule volume expressed as ml per plant is also an important parameter to assess inoculation success and for strain selection on a given host legume (Msumali and Kipe-Nolt, 2002). A similar author also indicated that this parameter is less subject to such errors and have a potential to replace nodule dry weight. In Table 2, the nodule volume which was obtained from both years was not significantly influenced by either the sole application of different strains of *Rhizobium* or a combination of different *Rhizobium* with inorganic fertilizer. On the contrary, inoculating grain legumes with efficient strains of rhizobium is widely reported to increase the number, mass and volume of nodules (Shibru and Mitiku, 2000; Nuruzzaman *et al*., 2005).

Table 2. Nodulation parameters of faba bean affected by different strain and inorganic P

Treatments	**2016 17**			**2017 18**		
	NP	**ENN**	**NV(ml)**	**NP**	**ENN**	**NV(ml)**
Control	2.7	8.58	0.92	2.63	53.51	0.79
St.FB-1035	2.6	12.42	0.92	2.67	56.75	0.88
St.FB-1018	2.5	10.08	0.92	2.92	63.21	1.00
St. EAL-110	2.4	10.75	0.93	2.79	57.42	0.81
St.FB-1035+ 10 kg P	2.6	10.50	0.93	3.04	52.12	0.98
St.FB-1018+ 10 kg P	2.4	11.88	0.92	2.96	53.88	0.88
St. EAL-110+ 10 kg P	2.5	12.24	0.95	2.67	50.05	0.85
CV (%)	**12.56**	**22.61**	**2.58**	**15.24**	**19.56**	**12.58**
LSD (0.5)	**ns**	**ns**	**ns**	**ns**	**Ns**	**ns**

Means with the same letter are not significantly different at P<0.05 level of probability following LSD, st.= strain, NP= Nodule Position, ENN=effective Nodule Number, NV= Nodule Volume

Growth parameters

Plant height obtained from both years was significantly affected by the treatment. In 2016/17, significantly the highest plant height (86.4 cm) was observed from the combined application of EAL-110 strain with 10 kg P ha^{-1} (Table 3). The lowest plant height (78.4 cm) was observed with inoculation of the seed of faba bean with strain FB-1018. In 2017/18 the highest plant height was observed with sole application of strain FB-1035. But this treatment was statically as par with sole application of strain FB-1018, combined application of strain FB-1035 with 10 kg P ha^{-1} and combined application of strain FB-1018 with 10 kg P ha^{-1}. The lowest plant height (72.5 cm) was observed from the control in this year. Similar results were reported by Sameh *et al* (2017).

Number of pods per plant responded for the treatment in this study. In 2016/17, significantly the highest number of pods per plant (21.4) was observed with combined application of strain EAL-110. But this treatment is statically as par with the control (Table 3). The lowest number of pods per plant was observed with inoculation of the seed of faba bean with strain FB-1018. In the first year, neither the sole application of *Rhizobium* inoculation nor combined application of *Rhizobium* inoculation with 10 kg P resulted any improvement in numbers of pods per plant (Table 3). In 2017/18, significantly the highest number of pods per plant (26.8) was observed with combined application of EAL-110 with 10 kg P (Table 3). The second year result also demonstrated that number of pods per plant was increased by 1.9 (9.2%) and 4 (19.4%) with sole application of *Rhizobium* inoculation and combined application of both *Rhizobium* and P fertilizer respectively compared with uninoculated and fertilized control plot.

Thousand seed weight was improved by both *Rhizobium* inoculation and P fertilizer application compared with the control check. In 2016/17 thousand seed weight was increased by 10.1 g (3.05%) and 10.6 g (3.2%) with sole application of *Rhizobium* inoculation (St. EAL 110) and combined application of St. EAL 110+ 10 kg P respectively compared with the control. Likewise, in 2017/18, treatments St. FB 1035 and St. EAL 110+ 10 kg increased thousand seed weight by 21.2 g (6.1%) and 22.5 g (6.5%) (Table 3). The probable reason for the maximum thousand seeds weight observed in either sole application of *Rhizobium* inoculation or combined application of *Rhizobium* and P fertilizer attributed to enhanced growth and development of plants that resulted from phosphorus supply and its positive effect on nitrogen fixation. The resulting increased N availability might have promoted the supply of assimilates to seed thereby enabling them to gain more weight. In agreement with the present study, some studies found a positive response of seed weight to inoculation and P application on legumes (Namvar and Sharifi 2011; Ali *et al*. 2004; Yoseph 2011).

The analysis of variance also revealed that thousand seed weight was significantly responded for the treatment only in 2017/18. The highest hundred seed weight (370.1 g) was observed with combined application of EAL-110 strain and 10 kg P ha^{-1}. This treatment combination was found statically as par with a sole application of the three strains and combined application of strain FB-1035 with 10 kg P ha^{-1} (Table 3). While the lowest thousand seed weight (332.3 g) was observed with combined application of FB-1018 with 10 kg P ha^{-1} (Table 3) in this year.

Table 3. Growth and yield-related parameters of faba bean as affected by different strain and inorganic P

Treatments	2016 17			2017 18		
	PH (cm)	Pod per Plant	1000 seed wt (g)	PH (cm)	Pod per Plant	1000 seed wt (g)
Control	80.9[ab]	21.3[a]	331.1	72.5[c]	20.6[b]	347.6[b]
St.FB-1035	79.3[b]	20.5[ab]	329.6	80.0[a]	22.5[b]	368.8[a]
St.FB-1018	78.4[b]	16.1[e]	332.8	76.3[a]	22.1[b]	361.3[a]
St. EAL 110	80.4[ab]	16.9[de]	341.2	77.7[a]	22.9[b]	366.4[a]
St.FB-1035+ 10 kg P	84.0[ab]	18.1[cd]	360.9	76.9[a]	22.8[b]	356.5[a]
St.FB-1018+ 10 kg P	84.3[ab]	19.1[bc]	340.7	76.0[a]	24.2[b]	332.3[b]
St. EAL 110+ 10 kg P	86.4[a]	21.4[a]	341.7	74.6[c]	26.8[a]	370.1[a]
CV (%)	**5.31**	**10.91**	**14.06**	**4.66**	**17.33**	**5.36**
LSD (0.5)	*	*	**Ns**	*	*	*

Means with the same letter are not significantly different at P>0.05 level of probability following LSD, st.= strain, PH=plant height, and p=phosphorus

Seed yield

Seed yield exhibited a significant response to the treatment in each year and combined over locations (Table 4). In 2016/7, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of St. EAL1110 with 10 kg P ha^{-1} (Table 4). The lowest seed yield (1931.6 kg ha^{-1}) was observed with the control plot (Table 4). Nevertheless, this treatment combination was found statically as par with the sole application of strain FB-1018. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL110 alone. However, it also statically as par with the sole application of strain FB-1018 and combined application of these three stains with 10 kg P ha^{-1} (Table 4). Combined over year, the highest mean seed yield which was obtained from the combined application of EAL-110 with 10 kg P ha^{-1} which increase seed yield of faba bean by 20 % (425.1 kg ha^{-1}) over the lowest seed yield (2082.4 kg ha^{-1}) observed from the control plot (Table 4). The result also indicated that the sole application of strain FB-1035, FB-1018 and EAL-110 resulted in a yield advantage of 5, 14 and 14% respectively compared with the un-inoculated and unfertilized control plot. Moreover, the combination of those strains with 10 kg P ha^{-1} resulted in a grain yield advantage of 8, 19 and 20% respectively compared with the control (Table 4).

The present study indicated that, combined application of *Rhizobium* inoculation with P fertilizer is crucial for the study site. For instance, combine application of FB-1035, FB-1018 and EAL-110 with 10 Kg P fertilizer increased seed yield of faba bean by 295.3 kg ha^{-1} (13.5%), 133 kg ha^{-1} (5.9%) and 125.6 kg ha^{-1} (5.3%) respectively, compared with sole application of each respective strain of *Rhizobium* (Table 4). Indicating that P application is crucial for the growth of host plants and effective biological nitrogen fixation. In line with this study Wassie *et al* (2008) reported that inoculation of the seed of faba bean with EAL-110, EAL120 and chemical fertilizer increased grain yield by 61%, 68% and 80%, respectively, over the control. Likewise, the application of 10 kg P ha^{-1} significantly improved grain yield and biological yield of haricot bean planted at Areka research station, SNNPR-Ethiopia (Gidago *et al*. 2012). Similar results also concluded by Negash (2000) Amanuel *et al* (2000), Sameh *et al* (2017), Evans (2005), Carter *et al* (1994). However, Abebe and Tolera reported that the introduction of a new *Rhizobium* strain to Gedo highlands did not significantly increase grain yield.

Straw yield

Straw yield which was obtained from both year and combined over locations was significantly influenced by the treatments (Table 4). Combined over years, significantly the highest straw yield was observed with combined application of EAL-110 with 10 kg P ha^{-1} which would increase straw yield by 283.8 kg (13.5%) compared with the control. Like seed yield, straw yield of faba bean also improved by combined application of *Rhizobium* inoculation and P fertilizer application. For instance, the combined application of FB-1035, FB-1018 and EAL-110 with 10 Kg P fertilizer increased straw yield of faba bean by 44.6 kg ha^{-1} (2.2%), 161.2 kg ha^{-1} (8.5%) and 28.1 kg ha^{-1} (1.4%) respectively, compared with sole application of each respective strain of *Rhizobium* (Table 4).

Table 4. Seed and straw yields of faba bean as affected by different strain and inorganic P

Treatments	Seed Yield			Straw		
	2016/17	2017/18	combined	2016/17	2017/18	combined
Control	1931.6[c]	2233.1[ab]	2082.4[b]	1706.15[c]	1917.2[bc]	1811.7[c]
St.FB-1035	2117.9[bc]	1964.8[b]	2041.35.4[ab]	1909.32[b]	2103.6[bc]	2006.5[b]
St.FB-1018	1974.4[c]	2523.4[a]	2248.9[ab]	1773.45[c]	2001.0[b]	1887.2[bc]
St. EAL-110	2223.2[bc]	2541.7[a]	2382.5[ab]	1985.82[ab]	2149.0[ab]	2067.4[ab]
St.FB-1035+ 10 kg P	2434.1[b]	2539.3[a]	2486.7[a]	1967.89[ab]	2134.4[ab]	2051.1[ab]
St.FB-1018+ 10 kg P	2262.4[bc]	2501.3[a]	2381.9[ab]	1921.81[ab]	2175.0[ab]	2048.4[ab]
St. EAL-110+ 10 kg P	2537.0[a]	2479.2[a]	2508.1[a]	2000.39[a]	2190.6[ab]	2095.5[a]
CV (%)	**7.74**	**13.67**	**14.83**	**8.76**	**13.49**	**14.24**
Sign.	**	*	**	**	*	**

Means with the same letter are not significantly different at P>0.05 level of probability following LSD, st.= strain, PH=plant height

Partial budget analysis

The assumption for partial budget analysis is that the variable cost of the treatment is different. But in our case, the total variable cost of the experiment is categorized into only three groups. With this, the determination of MRR is impossible. In this case, comparison of treatments based on net benefit is mandatory. It is quite evident from table 5, the highest mean total gross benefit (444789.1birr ha^{-1}) and mean net benefit (43800.7birr ha^{-1}) was obtained when EAL-110 *Rhizobium* strain applied with 10 kg P ha^{-1}. The next better net return was 43323.1 ha^{-1} birr which was obtained from the combined application of strain FB-1035 with 10 kg P ha^{-1}. The lowest mean total gross benefit and mean net benefit of 37445.8 birr ha^{-1} was obtained from the control check and found a net benefit penalty of 14.5% (6354.9 birr ha^{-1}).

Table 5. Partial budget Analysis

Treatment	AGY	ASY	GBG	GBS	TGB	TVC	NB
Control	1874.2	1630.5	30923.6	6522	37445.8	0	37445.8
St.FB-1035	1972.3	1805.9	32542.3	7223.4	39765.7	360	39405.7
St.FB-1018	2024	1698.5	33396.2	6793.9	40190.1	360	39830.1
St. EAL-110	2144.3	1860.7	35380	7442.6	42822.8	360	42462.8
St.FB-1035+ 10 kg P	2238	1846	36927.5	7384	44311.5	988.4	43323.1
St.FB-1018+ 10 kg P	2143.7	1843.6	35371	7374	42745.5	988.4	41757.1
St. EAL-110+ 10 kg P	2257.3	1886	37245.3	7544	44789.1	988.4	43800.7

AGY= Adjusted seed yield ((kg ha^{-1}), ASY= Adjusted straw yield (kg ha^{-1}), GBS=gross benefit from straw (ETB ha^{-1}), GBG=gross benefit from grain (ETB ha^{-1}), TGB=total gross benefit (ETB ha^{-1}), TVC=total cost that vary (ETB ha^{-1}), NB=net benefit (ETB ha^{-1}).

Conclusions and Recommendations

N2 fixation by leguminous crops is a relatively low-cost alternative to N fertilizer for small-holder farmers in developing countries. N2 fixation in faba bean (*Vicia faba* L.) is affected by P fertilization and inoculation. The present study was conducted with the objectives of evaluating the effectiveness of different commercial and new rhizobia strains and to evaluate the effect of phosphorus fertilization on nodulation and grain yield of faba bean. The analysis of variance showed that seed yield exhibited a significant response to the treatments. In 2016/7, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of EAL-110 with 10kg ha^{-1}. The lowest seed yield (1931.6 kg ha^{-1}) was observed from the control plot. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL 110 alone. The partial budget analysis indicated that the highest mean net benefit (43800.7 birr ha^{-1}) was obtained when EAL-110 *Rhizobium* strain was applied with 10 kg P ha^{-1}. Hence, *Rhizobium* inoculation with strain EAL-110 with 10 kg P ha^{-1} could be recommended for faba bean production at the experimental locations in Moretna Jiru district.

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On-farm verification of different phosphorus levels for mungbean production in West Gondar Zone Amhara Region.

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Abstract

A field experiment was carried out during the 2018 cropping season at the Metema and Tach Armacheho district, West Gondar zone, Amhara National Regional State (ANRS), to verify the effects of different phosphorus (P) level on the yield and yield-related components of mungbean and validating soil fertility map of lowland areas of the region. The Ethiopian government has launched the 'EthioSIS' project to develop soil fertility maps and generate soil fertility map-based balanced fertilizer recommendations in the country. The map indicates a multi-nutrient deficiency in addition to the conventional N and P nutrients. The map shows seven nutrients (N, P, K, S, B, Zn, and Cu) deficiencies in many cultivated and cultivable areas of Amhara region. *Phosphorus is an essential plant nutrient which involves in all physiological activities of the crop production. The experiment was laid out in a randomized complete block design (RCBD) with three replications and the treatment consisted of one rate of N fertilizer (23 N kgha^{-1}) and four levels of phosphorus fertilizer (20, 28.26, 36.52, and 44.78 kgha^{-1}). The application of different rates of P was significant ($P<0.05$) for grain yield. The highest (1658.1 kg ha $^{-1}$) and lowest (864.7 kg ha^{-1}) mean grain yield was obtained from the application of 36.52 kg P ha $^{-1}$ and the control plots (23 kg N ha $^{-1}$), respectively in Metema. The maximum grain yield (1510.4 kg ha^{-1}) was obtained from the application of 28.26 kg Pha^{-1} (trt 3) while the minimum grain yield (1094.8 kg ha $^{-1}$) of mungbean was recorded from the control plots (23 kg N ha^{-1}) on Tache Armacheho.*

Keywords: Metema, Phosphorus, Soil fertility map, Tache Armacheho

Introduction

Mungbean is a rich source of vegetable protein. It is considered a poor man's meat containing almost triple the amount of protein as compared to rice (ref). It contains 1-3% fat, 50.4% carbohydrates, 3.5-4.5% fibers, and 4.5-5.5% ash, while calcium and phosphorus are 132 and 367 mg per 100 grams of seed, respectively (Frauque, A., *et al*,2000). It is an economically and nutritionally important food and feed legume crop. An important feature of the mungbean crop is its ability to establish a symbiotic partnership with specific bacteria, setting up the biological N_2-fixation in root nodules that supply the plant's needs for N_2 (Mahmood and Athar, 2008; Mandal *et al*., 2009). Mungbean being drought tolerant and short duration can grow well under varied conditions (irrigated and rain-fed). Mungbean has the potential of producing higher seed yield from 1295 to 2961 kg ha^{-1} depending on the genotypes studied (Ullah et al., 2011; Bilal, 1994).

Phosphorus is one of the important plant macronutrients, making up about 0.2% of a plant's dry weight. It is an important component of key molecules such as nucleic acids, phospholipids, and ATP, and consequently, plants cannot grow without a reliable supply of this nutrient. P is also involved in controlling key enzyme reactions and in the regulation of metabolic pathways (Theodorou and Plaxton, 1993). Phosphorus is present in seed and fruit in large quantities and is essential for seed formation. It is known to stimulate root growth and is associated with the early maturity of crops. It not only improves the quality of fruits, forages, vegetables, and grains but also plays a role in disease resistance of plants. (Brady and Weil, 1999). Phosphorus plays a remarkable role in plant physiological processes. Phosphorus is a key constituent of ATP and it plays a significant role in the energy transformation in plants and also essential for energy storage and release in living cells (Sangakara *et a*l, 2001). Legumes require relatively high amounts of phosphorus for nodulation, yield, and high-quality seeds (Ugese and Avan, 2005).
Chemical fertilizers in Ethiopia have contributed to crop yield growth to date, although there is still potential for further improvement. Ethiopia's Growth and Transformation Plan (GTP) recognizes the importance of fertilizer for maintaining soil fertility and maximizing agricultural growth in the country.

However, due to the diverse agro-ecologies (soil and climate) in the country, site-specific and soil-test based fertilizer recommendations are indispensable. Accordingly, the MoANR and ATA have recently completed a detailed soil fertility map for the country. The map shows seven nutrients (N, P, K, S, B, Zn, and Cu) deficiencies in many cultivated and cultivable areas of Amhara region. The new soil fertility map of the Amhara region shows that P is highly deficient (almost 100%) in the soils of the region (ATA and MoANR, 2016). Based on the above facts the present study was aimed to verify the response of mungbean to P application and validating soil fertility map on Metema and Tach Armacheho districts in the lowland areas of Amhara Region

Materials and Methods

Description of Study Area

The experiment was conducted on the farmers' field in Metema and Tache Aremacheho districts in the North Gondar administrative zone in the Amhara National Regional State, Ethiopia. The experimental areas are located at 35.51-37.24 longitude and 12.25-13.14 latitude in metema and 36.62-37.59 and 12.78-13.29 14 longitude and latitude in Tache Armacheho.

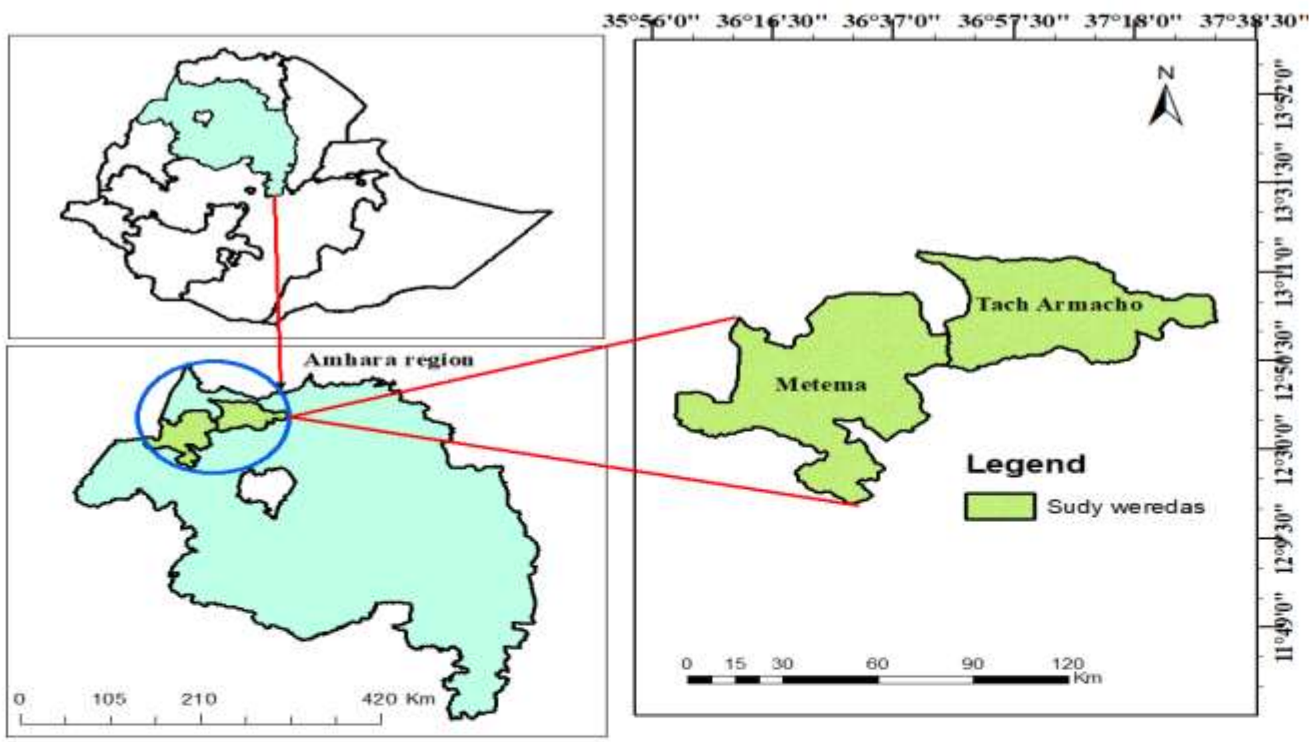

Figure 1. Map of the study areas.

The altitude of the areas ranges from as low as 550 to 1608 m.a.s.l while the minimum annual temperature ranged between 22 ^{0}C and 28 ^{0}C. Daily temperature becomes very high from March to May, where it may get to as high as 43 ^{0}C. Nearly all of the land in the area is in the lowlands except some mountain tops which fall outside. According to the available digital data, the mean annual rainfall for the area ranges from about 850 to around 1100 mm. Based on this digital data, about 90% of the area receives a mean annual rainfall of between 850 and 1000 mm. The rainy months extend from June until the end of September. However, most of the rainfall is received during July and August.

Experimental Research Design and Treatments

The experiment contains five treatments in Randomized Complete Block Design with three replications. The treatments were recommended nitrogen alone (23 kg N ha^{-1}), 20 , 28.26 , 36.52 , and 44.78 kg P ha^{-1} by adjusting the recommendation of N and P of the experimental sites. The old recommendation of fertilizer used 100 kg Dap ha^{-1}. The plot size was 5 m *5 m wide and length. There were 1m, 1.5 m, 40 cm, and 5 cm between plots, replications, rows, and plants respectively.

Soil sampling and preparation

Soil samples were randomly collected in a diagonal pattern before sowing from a depth of 0-20 cm. The soil samples were air-dried and passed through a 2 mm sieve for physicochemical analysis. The soil was analyzed for texture and total nitrogen, available phosphorous, pH, OC, and CEC before sowing. The texture of the soil was determined by the hydrometer method according to (Bouyoucos, 1962). Total N was analyzed by the Kjeldahl digestion method with sulphuric acid (Jackson, 1962). 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, a potentiometer (FAO, 2008). Organic carbon content was determined by the volumetric method (Walkley and Black, 1934). The available phosphorus was determined by the Olsen method (Olsen *et al*; 1954). Exchangeable potassium was extracted by ammonium acetate at pH 7 (Sahalmedhin and Taye, 2000) and determined by an Atomic absorption spectrometer. The cations exchange capacity (CEC) was determined following the 1N ammonium acetate extraction (pH7) method.

Land preparation and sowing

The experimental field was prepared following the conventional tillage practice of the area. It was manually leveled and then divided into blocks and plots; the blocks were separated by a 1.5 meter-wide open space whereas the plots in the block were 1m apart from each other. Each plot consisted of 12 rows of 5 m in length and spaced 0.4 m apart. The selected mungbean variety (Rassa) seeds were sown manually at equal spacing between plants and rows with a seed rate of 20 $kgha^{-1}$ and depth (3-5 cm) mid-way on the row and slightly covered by soil.

Fertilizer use, thinning and weeding.

The full dose of TSP fertilizer was applied during sowing, while urea was applied in split as a 1/3 urea (i.e. as per treatment) was applied uniformly in rows at planting. The remaining 2/3 of each nitrogen fertilizer treatment was side dressed after 45 days from sowing. The weeds observed in the plots were controlled manually at the same time for all treatments. Thinning of seedlings was done three weeks after sowing and the second thinning was also done a week after the first thinning to have 20 cm spacing between plants as recommended and practiced in the area to obtain the recommended stand population. All other typical agronomic practices of the area were performed uniformly to all plots

Statistical analysis

Plant data was recorded on a plot basis and extrapolated on a hectare basis. All parameters were determined and calculated from the middle rows. Analysis of variance and treatment means comparisons for the different measured parameters were carried out using SAS software window 9.0. Mean separation for the recorded plant parameters was made using the Least Significance Difference (at 0.05 significance level).

Economic analysis

Economic analysis was conducted using partial budget analysis as described by CIMMYT (1988) to find the best treatment which has an economic benefit. The following equations were used:

$$\text{Gross benefit} = \text{economical yield return} * \text{price (birr kg}^{-1}\text{)}$$

$$\text{Net profit} = \text{gross benefit} - \text{total cost that varies.}$$

To identify the best treatments from the experiment the dominance analysis was used. The marginal rate of return (MRR) was calculated by considering a pair of non-dominated treatments listed. MRR denotes the return per unit of investment for the different managements tested in the field. Following the analysis, treatments with the highest MRR were recommended to farmers.

MRR =change in NB/change in TCV

Where MRR is the marginal rate of return, NB is net benefit ha^{-1} for each treatment, and TCV is the total variable costs ha^{-1} for each treatment.

Results and Discussion

Selected physical and chemical properties of soils before planting

The PH value ranged from 6.4-7.3 which indicated that slightly acidic to neutral. As per the classification set by London (1991), the organic contents of all the study sites rated under very low. The reasons for the very low content of OC could be intensive cultivation of the land and the total removal of crop residues for animal feed and source of energy. Moreover, there is no practice of the addition of organic fertilizers, such as farmyard manure and green manure that would have contributed to the soil OC pool in the study area. The available P content of the composite surface soil sample of the experimental sites could be rated as low. Generally, the existence of low contents of available P is a common characteristic of most soils in Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002 ;). The exchangeable potassium of the soil was optimum (Berhanu Debele, 2008). According to Murphy (2007) the cation exchange capacity of the soil was very high.

Table 1. Physical and chemical properties of soil used on Metema and Tache armacheho district.

Site	Parameters					
Metema	PH (H_2O)	OC	Ava. P (p/ppm)	CEC (cmol/k)	Exch.k^+ (cmol/kg)	Textural class
	6.7	1.3	3.8	69.8	0.7	Clay
	7	1.5	3.7	63.1	0.6	Clay
	6.4	1.5	1.9	70.2	0.4	Clay
Tach-Armacheho						
	7.2	1.3	3.9	74.9	1.5	Clay
	7.3	1.6	3.2	44.1	0.7	Sandy clay
	6.9	1.5	3.5	58.9	0.9	Clay
	6.7	1.4	4.5	74.2	0.9	Clay
	6.9	1.4	2.5	62.6	0.7	Silt clay

Yield and yield-related components

The responses of plant height, hundred seed weight, and number of pod per plant, number of seed per pod, grain yield, and straw yield of mungbean to phosphorus fertilization of the combined data of over three Metema experiment sites are demonstrated in Table 2. The effect of applied fertilizers on plant height was found significant ($P < 0.05$). As indicated in Table 2 the minimum (49.0 cm) and maximum (61.5 cm) plant height were obtained from the application of no phosphorus and 36.52 kg P ha^{-1} respectively. These results showed that, plant height was gradually increased due to the increase in phosphorus doses up to 36.52 kg P $ha^{-1,}$ and thereafter it was decreased. Almost similar results were found by Rahman *et al*. (2008), Bhuiyan *et al*. (2004) and Akter et al, (2019).

Similarly, the number of pod per plant was significantly affected ($P \leq 0.05$) by phosphorus application. The maximum number of pod per plant (9.1) was obtained from the application of 36.52 kg P ha^{-1}, while the lowest (7.6) from the control treatment 23 kg N ha^{-1} alone Muhammad et al (2017), reported that the maximum and minimum number of pods per plant was recorded in 39-52 kg P ha^{-1} and the control plots where no phosphorus was applied respectively.

The application of different rates of phosphorus fertilizer show a significant ($P > 0.05$) effect on a hundred seed weight at both experimental sites. The maximum (5.1 gm) and minimum (4.7 gm) hundred seed weight was recorded on treatment 4 (36.52 kg P ha^{-1}) and treatment 1 (23 kg N ha-^{1}) respectively. On Tache Armacheho the highest (5.6 gm) hundred seed weight was obtained on treatment 3 (28.26 kg P ha^{-1}).

Table 2. Effects of phosphorus levels on yield and yield components of mungbean

	Metema					Tache Armacheho	
Treatments	PH (cm)	NPP (No.)	HSW (gm)	GY (kg)	STR	HSW (gm)	GY (kg)
23 N	49.0[b]	7.6[b]	4.7[b]	864.7[b]	911.4[b]	5.3[b]	1094.8[b]
20 P	58.2[a]	9.1[a]	4.9[ab]	1617.2[a]	1560.0[a]	5.4[b]	1402.6[a]
28.26 P	59.4[a]	9.0[a]	5.0[ab]	1553.2[a]	1528.6[a]	5.6[a]	1510.4[a]
36.52 P	*61.5[a]*	9.1[a]	5.1[a]	1658.1[a]	1447.6[a]	5.3[b]	1422.7[a]
44.78 P	58.4[a]	9.0[a]	4.9[ab]	1581.3[a]	1402.6[a]	5.3[b]	1436.6[a]
CV (%)	6.7	14.2	4.6	16.9	21.7	4.5	13.0
LSD (5%)	7.1	1.4	0.3	342.5	325.4	0.2	148.9

*NB: Plant height(PH),No. of pod/plant(NPP),No. seed/pod(NSP) , 100 seed weight(TSW), Grain yield(GY),and Straw yield(STR). * Significant*

The application of different rates of P was significant ($P<0.05$) for grain yield. As shown in Table 2 the highest (1658.1 kg ha $^{-1}$) and lowest (864.7 kg ha^{-1}) mean grain yield was obtained from the application of 36.52 kg P ha $^{-1}$ and the control plots (23 kg N ha $^{-1}$) on Metema respectively. Ali et al., 2010 reported that all the levels of phosphatic fertilizer showed a significant impact on the mungbean crop compared to the control plotseventhough the treatment of phosphatic fertilizer with the rate of 84 P_2O_5kg ha-1 out yielded the rest of the treatments In Pakistan. Similar results obtained by Emsley. (2000), showed that phosphatic fertilization has an increasing influence on growth and yield. Also on Tache Armacheho the maximum (1510.4 kg ha^{-1}) and minimum (1094.8 kg ha $^{-1}$) grain yield of mungbean was obtained from the application of 28.26 kg P ha^{-} and the control plots (23 kg N ha^{-1}) respectively. According to Rahman *et al* (2015), the minimum significant seed yield (1.11 t ha^{-1}) was obtained with the treatment 0 kg P ha^{-1} which was in line with our research finding.

The highest (1560 kg ha $^{-1}$) and the lowest (911.4 kg ha $^{-1}$) straw yield was obtained from the application of 20 kg P ha^{-1}and 0 kg P ha^{-1} respectively. As phosphorus rate increased, straw yield also correspondingly increased up to 28.26 kg ha^{-1} P levels and then declined. This result was in conformity with Hamaz et al, (2016), who reported highest stover yield (2.86 t ha^{-1}) using 40 kg

P_2O_5 ha^{-1} which was statistically similar to 60 kg P_2O_5 ha^{-1}. Straw yield of mungbean increased with an increase rate of phosphorus fertilizer

Partial budget analysis

The result of the partial budget analysis revealed that the economically feasible fertilizer application rate varies. Since mung bean yield is the major worry of this experiment, the economic application rates within the acceptable level of mung bean yield was necessary. Tables 3 & 4 showed an economically feasible application rate at 20 kg P ha^{-1} due to its high marginal rate of return. The other treatments were eliminated by the concept of dominance analysis since the net benefit incurred decreased as the cost increased. The highest MRR (514 and 151 birr) was obtained from 20 kg P ha^{-1} resulting in a yield of 1617.2 and 1402.6 kg grain yield ha^{-1} (Table 3 & 4) on Metema and Tache Armacheho respectively. This indicates that farmers can obtain 514 & 151 birr extra by investing one birr buying fertilizer to apply 20 kg P ha^{-1}. The farmers should apply 100 kg DAP to obtain 20 kg P ha^{-1}. The application of phosphorus fertilizer above 20 kg P ha^{-1} is not economically beneficial for both districts

Table 3. Partial budget analysis of mungbean produced by applying phosphorus (Metema).

No.	Treatment (TSP)	Total Revenue	TVC	Net Revenue	MRR (%)
	(kg)	(birr)	(birr)	(birr)	(birr)
1	0	11673.45	0	11673.45	_
2	20	21832.2	1652	20180.2	514.9
3	28..3	20968.2	2334	18634.2	-66.2
4	36.5	22384.35	3017	19367.35	24.3
5	44.8	21347.55	3899	17448.55	-49.2

TVC; Total vary cost, MRR; Marginal rate of return

Table 4. Partial budget analysis of mungbean produced by applying phosphorus (Tache Armacheho).

No.	Treatment (TSP) (kg)	Total Revenue (birr)	TVC (birr)	Net Revenue (birr)	MRR (%) (birr)
1	0	14780	0	14780	_
2	**20**	18935.1	1652	17283.1	151.5
3	28..3	20390.4	2334	18056.4	33.1
4	36.5	19206.5	3017	16189.5	-61.8
5	44.8	19394.1	3899	15495.1	-17.8

TVC; Total vary cost, MRR; Marginal rate of return

Conclusion and Recommendation

The result obtained from this study showed that different applications rates of phosphorus fertilizers significantly improved mungbean growth and yield as compared to the control. It can be observed that the number of pods and seeds per plant tended to increase as the phosphorus rate increased in all Metema experimental sites. The maximum plant height were produced with the application rate of 23 kg N ha^{-1} + 36.52 kg P ha^{-1} in both districts. This can be attributed to the promoted vegetative growth of mungbean due to phosphorus fertilizer. There was an increase in hundred seed weight, grain yield, and straw yield with an increasing rate of phosphorus fertilizer. Fertilizer rate of 23 kg N ha^{-1} + 36.52 kg Pha^{-1} and 23 kg Nha^{-1} + 28.26 kg Pha^{-1} also appeared to give a higher grain yield compared to the rest of the treatments in Metema and Tach Armacheho respectively. The lowest yield was obtained on 23 kg N ha^{-1} alone on both districts. This might be due to a limitation or low amount of available phosphorus in the soil. Based on the partial budget analysis result of the experiment, it is possible to recommend the application of fertilizer with rates of 20 kg P and 23 kg N ha^{-1} for both Metema and Tache Armacheho because of economically optimum and acceptable rates for mungbean production.

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Optimization of Fertilizer Recommendations for Chickpea at Sayadeberena Wayu District North Shewa, Amhara Region, Ethiopia

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Abstract

Chickpea is one of the most important pulse crops in Ethiopia in general and Sayadeberena Wayu district in particular. However, there is no updated fertilizer sources and rate recommendation sofar for this crop in the above mentioned district. Therefore, an experiment was conducted to select fertilizer utilization options for better yield production of chickpea in the Sayadeberena Wayu district of Amhara Regional State of Ethiopia for the last two consecutive years (2016/17 and 2017/18). The treatments included twelve different types of nutrient sources; control (T1), inoculant-CP11(T2), 10 kg ha^{-1} P (T3), 20 kg ha^{-1} P (T4), 30 kg ha^{-1} P (T5), 0/20 kg ha^{-1} P/K_2O (T6), 10/20 kg ha^{-1} P/K_2O (T7), 20/20 kg ha^{-1} P/K_2O (T8), 30/20 kg ha^{-1} P/K2O (T9), 20/10 kg ha^{-1} P/K_2O (T10), 20/20/5/1/5/0.5 kg ha^{-1} P/K_2O/S/Zn/Mg/B (T11) and 20/30 kg ha^{-1} P/K_2O (T12). The experiment was laid out on a randomized complete block design with farmers as replications. Results showed that seed and straw yield were significantly affected by the application of different inorganic fertilizer sources. The highest chickpea seed yield (2435.6 kg ha^{-1}) and straw yield (1957 kg ha^{-1}) were obtained from the applications of 20 kg P ha^{-1} followed by that obtained from 30 kg P ha^{-1} (2411.3 kg ha^{-1}seed yield and 1981.2 kg ha^{-1}straw yield) even though statistically no significant differences among treatments. The result also showed that the highest net return was obtained from the application of 20 kg P ha^{-1} followed by 10 kg P ha^{-1}, which were economically feasible, high rate of marginal return and can be recommended as alternative P rate for chickpea production in the study area and similar agro-ecologies.

Keywords: Chickpea, inorganic fertilizer, phosphorus, pulse crop, seed yield

Introduction

Chickpea (Cicer arietinum L.) is one of the most important pulse crops in Ethiopia. It is an important legume crop in reducing poverty and hunger, improving human health and nutrition, improving incomes especially to smallholder women farmers, and enhancing ecosystem balance. Chickpea is grown in over 50 countries and is third in production after a dry bean and field pea in the world (FAOSTAT, 2014). Africa accounts for 5% of the world's chickpea production, mostly from Ethiopia, Malawi, Tanzania, and Kenya in Eastern Africa and Morocco in North Africa. Ethiopia is among the top five world producers of chickpea and is the largest producer of chickpea in Africa, accounting for about 60% of the continent's production in 2014. During 2016/17, Ethiopia produced 499,925.55 tons of chickpea from an area of 242,703.3 ha with average productivity of 2.06 ton ha^{-1} (CSA, 2017) which is less than half of the global chickpea production potential (5 ton ha^{-1}). In most chickpea growing areas of the world, the main constraints reported to affect chickpea production are lack of high yielding varieties, limited use of fertilizers, abiotic and biotic stresses (Upadhyaya et al., 2011). From these constraints, lack of high yielding varieties and limited use of fertilizers (especially phosphorus fertilizer) are the major limiting factors of chickpea in the study area.

Although many factors contribute towards the low productivity of chickpea, the major reasons for its low yield are diseases, insect pests, limited use of modern inputs, and inappropriate agronomic practices like inadequate or imbalanced fertilizer application. Nitrogen (N) and phosphorus (P) are the two most yield-limiting nutrients in sub-Saharan Africa, including Ethiopia. Phosphorus is the second most critical plant nutrient overall, but for pulses it assumes primary importance owing to its important role in root proliferation and atmospheric nitrogen fixation. However, information is lacking on the effect of different fertilizer sources and rates on chickpea growth and productivity in Ethiopia. Therefore, the objective of this experiment was to select the optimum fertilizer source and recommendations for chickpea.

Materials and Method

Description of study area

The experiment was conducted at Sayadeberena Wayu district, North Shewa Zone of Amhara Regional State for two consecutive years (2016/17 and 2017/18). Geographically, the experimental site is located at a range of 090 8' to 090 9'N and 380 8' to 380 9'E and a mean altitude of 2644 m.a.s.l at a distance of about 125 km north of Addis Ababa.

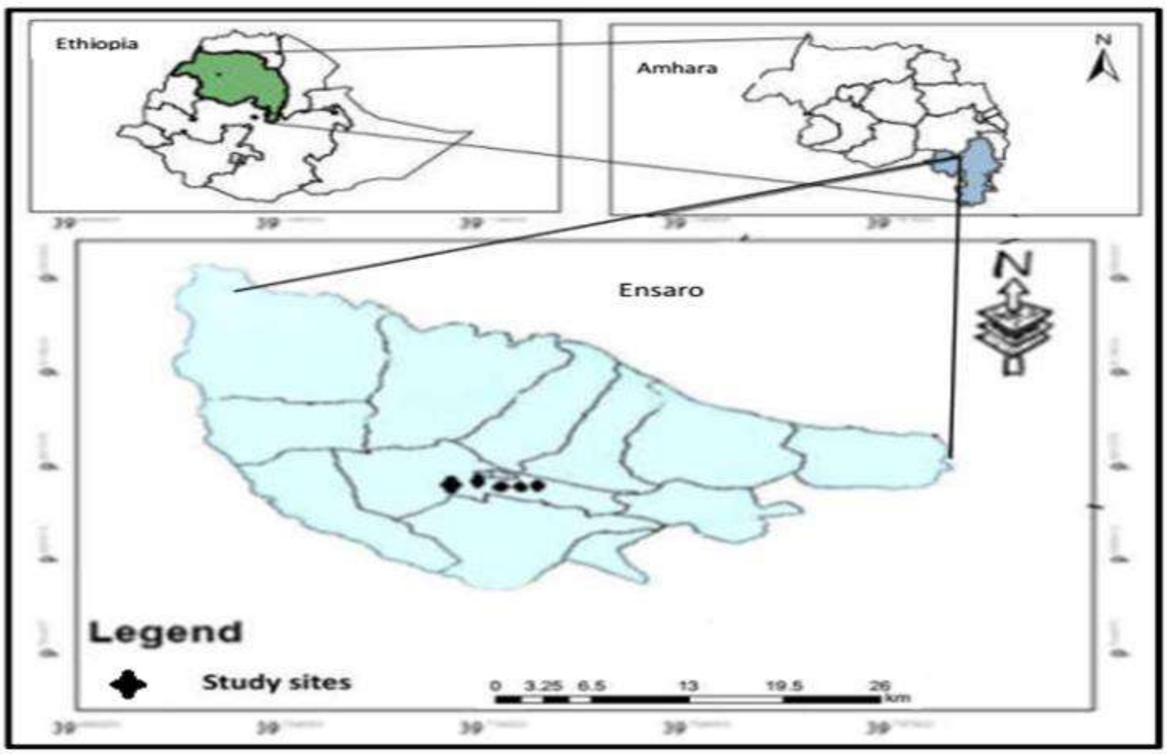

Figure 1. Map of the study area (Ensaro which is Sayadeberan Wayu)

The area is characterized by a unimodal rainfall pattern and receives an average annual rainfall of 926.3 mm, about 85% of which is received from June to September. The annual average minimum and maximum air temperatures are 11.7 and 26.7°C, respectively. Vertisols are the dominant soil type in this district. The crops widely grown in the study area include tef, wheat, lentil chickpea, faba bean and others. Chickpea is mostly grown on residual soil moisture at the end of the rainy season from mid-August to early September. The experiment was laid out in randomized complete block design with farmers as replications and unit plot size was 3.2 m x 3.8m (two BBF 1.2 x 3.8 m size 8 rows per plot) The seed was sown in rows with 30cm spacing between rows and 10cm between plants. Prior to planting, one composite soil sample (0 - 20 cm) was taken from each experimental site for the determination of some selected soil properties. The samples were taken randomly across each experimental field using a soil auger and then air-dried, thoroughly mixed and ground to pass through a 2-mm mesh sieve and packed for laboratory analysis. Soil particle size distribution was analyzed using the Bouyoucos hydrometer method (Bouyoucos, 1962) after destroying organic matter (OM) using hydrogen peroxide (H_2O_2) and dispersed the soils with sodium hexametaphosphate ($NaPO_3$).

The soil samples were analyzed for pH in a 1:2.5 soil-water suspension using a glass electrode as described by van Reeuwijk (1992), organic carbon using wet oxidation methods of Walkley and Black (1934) and total nitrogen by Kjeldahl procedure of Bremner and Mulvaney (1982), available phosphorus by Olsen method (Olsen et al. 1954), exchangeable potassium was determined by extracting potassium with 1 N NH_4OA and determined with a flame photometer. The treatments used in the experiment were control (T1), inoculant-CP11(T2), 10 kg ha^{-1} P (T3), 20 kg ha^{-1} P (T4), 30 kg ha^{-1} P (T5), 0/20 kg ha^{-1} P/K2O (T6), 10/20 kg ha^{-1} P/K2O (T7), 20/20 kg ha^{-1} P/K2O (T8), 30/20 kg ha^{-1} P/K2O (T9), 20/10 kg ha^{-1} P/K2O (T10), 20/20/5/1/5/0.5 kg ha^{-1} P/K2O/S/Zn/Mg/B (T11) and 20/30 kg ha^{-1} P/K2O (T12). The chickpea lignite-based rhizobial inoculant, CP11, obtained from Holeta Agricultural Research Center was used. Triple superphosphate, gypsum and KCl fertilizer sources were applied at planting with respective treatment rates as nutrient sources of phosphorus, sulfur and potassium. The test crop was chickpea variety Mastawal. Plant yield components such as seed and straw yield were collected. Disease and pest control activities were carried out (application of pesticides like deyazenol to control cutworm with recommended rate and time of application).

Statistical analysis

The agronomic data were analyzed using the general linear model (GLM) procedures of the SAS statistical software (2002) to evaluate the effect of different fertilizer treatments. Duncan multiples range test (DMRT) at 5% probability level was used to separate means whenever there were significant differences among different treatments.

Economic analysis

Partial budget analysis was done to examine different fertilizer application effects on the yield of chickpea. Maximum net benefit from the application of different nutrient sources, dominance, and marginal analysis criteria were undertaken to see the economic feasibility of different nutrient sources and rates. To minimize the over estimate of the experimental plot, yield was adjusted to 10 percent that reflected the actual field condition according to the manual of CIMMYT (1988). The two years average farm get price of chickpea seed (19 Birr kg^{-1}) and straw (2 Birr kg^{-1}) and KCl (11.45 ETB kg^{-1}), P (9.364 ETB kg^{-1}), S (12.20 ETB kg^{-1}), B (12.20 ETB kg^{-1}), Mg (12.20 ETB kg^{-1}) and Zn (15.00 ETB kg^{-1}) were used for partial budget analysis.

Result and Discussion

Selected soil physical and chemical properties

The selected soil properties of study sites were presented in Table 1. The textural class of the soil is clay. The average pH value of soils of the study area is 6.76, rated as neutral according to Tekalegn (1991). Generally, the experimental fields are low in soil organic carbon, medium in total nitrogen, very low in available P and high in exchangeable K (Landon, 1991).

Table1. Selected physicochemical properties of the experimental soil at Sayadeberena Wayu District

Year	pH (1:2.5)	OC (%)	TN (%)	Exch.K (cmol (+) kg^{-1})	Av.P (ppm)	Clay (%)	Silt (%)	Sand (%)	Tex. Class
2017	6.66	0.85	0.13	1.66	4.27	58.00	27.00	15.00	Clay
2018	6.86	0.54	0.10	2.25	6.81	70.00	20.0	10.00	Clay
Mean	6.76	0.69	0.12	1.96	5.54	64.00	23.50	12.50	Clay

Effects of different treatment application on chickpea yield

The seed yield of chickpea did not exhibit significant variation because of the application of different treatments (Table 2). Even though there is no significant difference with the control, the highest seed yield (2435 kg ha^{-1}) was obtained with the application of 20 kg ha^{-1} P as compared to control (2231.4 kg ha^{-1}). The application of 20 kg ha^{-1} P increased the grain yield of chickpea by 9.2% as compared to the control treatment, although it is statistically at par. This study did not reveal that applications of inorganic and organic nutrient sources, especially P fertilizer, had a significant effect on seed and straw yield of chickpea.

The analysis of variance of straw yield showed significant differences among the treatment means. The maximum straw yield was recorded in the treatment of 20 kg ha^{-1} P as compared to control (1981.2 kg ha^{-1}) and a minimum amount of yield (1316.7 kg ha^{-1}) was recorded in sole application of potassium at 20 kg ha^{-1} K.

Table 2. Response of chick pea for different fertilizer treatments

Treatments	Seed Yield kg ha^{-1}	Straw Yield kg ha^{-1}
1. Control	2231.4abc	1713.0abc
2. Inoculant (CP11)	1967.1bcd	1535.4bcd
3. 10P	2336.1ab	1961.4a
4. 20P	2435.6a	1957.8a
5. 30P	2411.3a	1981.2d
6. 0P20K	1775.0d	1316.7d
7. 10P20K	1853.0cd	1499.7bdc
8. 20P20K	2247.9abc	1784.3ab
9. 30P20K	2315.4ab	1961.5a
10. 20P10K	2297.7ab	1771.1ab
11. 20P20K 5S 1Zn 5Mg 0.5B	2094.9abcd	1613.6bc
12. 20P30K	1946.0bcd	1460.1cd
CV (%)	13.57	12.04
Sign	**	**

Economic analysis

The highest net return of 44049.0 Ethiopian Birr with MRR value of 250.0 was obtained from the application of 20 kg ha-1 P followed by 10 kg ha^{-1} P with a net return of 42916.0 ETB and MRR 298.3 (Table 3). According to the CIMMYT (1988) manual that showed the minimum rate of return acceptable to farmers would be between 50-100%. Therefore, treatments that have the highest marginal rate of return (MRR %) are optional sources of nutrients for the study area.

Table 3. Partial budget and marginal analyses of different fertilizer application on chickpea

No	Treatments	SY (kg ha-1)	StY (kg ha-1)	GB (ETB ha-1)	TVC (ETB ha-1)	NB (ETB ha-1)	MRR (%)
1	Control	2008	1541.7	41240	0	41240	
2	Inoculant (CP11)	1770	1381.9	36401	440	35961D	-
3	10P	2102	1765.3	43478	562	42916	298.3
4	20P	2192	1762.0	45173	1124	44049	250.0
5	30P	2170	1783.1	44799	1686	43114	111.2
6	0P20K	1598	1185.0	32723	417	32306D	-
7	10P20K	1668	1349.7	34386	979	33407D	-
8	20P20K	2023	1605.9	41651	1541	40110D	-
9	30P20K	2084	1765.4	43124	2103	41022D	-
10	20P10K	2068	1594.0	42479	1332	41146D	-
11	20P20K5S1Zn5Mg0.5B	1885	1452.2	38727	1941	36787D	-
12	20P30K	1751	1310.5	35898	1749	34148D	-

SY= Seed Yield, StY=straw yield,GB=Gross benefit, TVC=Total Variable Cost, NB=Net Benefit

Conclusions and Recommendations

This study explored the potential use of different sources of fertilizer to select economically viable nutrient sources to increase chickpea yield. Results showed that there is no significant difference for seed and straw yield of chickpea among applied treatments as compared to the control. Also, the application of organic sources of fertilizer (inoculants) did not bring outsmart results as compared to the non-fertilizer source treated plots. Based on this finding, application of both sources of fertilizer did not improve the yield components of chickpea. However, as soil maintenance and future sustainable production, application of 10 kg ha-1 of phosphorus had brought comparable seed yield with a high marginal rate of return with a higher net benefit. Further verification and demonstration of this technology at the study and similar agroecology is necessary.

Acknowledgments

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Refining of recommended fertilizer rates for teff production systems in Takusa district, Northern Ethiopia

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Abstract

In Ethiopia, including Takusa district appropriate fertilizer management was the major problem accounted for low productivity of teff. Therefore, a field experiment was conducted with the objective of investigating the effect of nitrogen, phosphorus, potassium and sulfur levels on yield and related components of teff at Takusa district, Northern Ethiopia during the rainy seasons of 2014 and 2015. The treatments consisted of 8 rates of Nitrogen (0, 23,46, 69, 92,115, 138 and 161 kg ha^{-1} N), 6 rates of Phosphorus (0, 11, 22, 33, 44 and 55 kg ha^{-1} P), 6 rates of Potassium (0, 15, 30, 45, 60 and 75 kg ha^{-1} K) and 6 rates of sulfur (0, 10, 20, 30, 40 and 50 kg ha^{-1} S) arranged in randomized complete block design for each experiment. Other non-experimental elements (N, P, K, S, Zn and B) were applied to the same amount as basal fertilizer application. The result revealed that the effect of nitrogen fertilizer have significant effect on combined average value of plant height, panicle length, number of effective tiller per plant, above ground biomass and grain yield of teff. Besides, the effect of Phosphorus fertilizer have significant effect only on combined average value of above ground biomass and grain yield of teff. However, all collected parameters didn't respond for applied K and S fertilizers. As a result, the maximum average biological grain yield of 1.89 ton ha^{-1} was harvested at 161 kg ha^{-1} N, and 1.74 ton ha^{-1} was harvested at 44 kg ha^{-1} P application. Finally, based on partial budget analysis, application of 69 kg ha^{-1} N and 22 kg ha^{-1} P are optimum rates for teff (Quncho variety) production. Therefore, it is indispensable to use this recommendation for Takusa area and similar agroecologies.

Key words: Nitrogen, phosphorus, potassium, quncho, sulfur,

Introduction

Teff [Eragrostis tef (Zucc.) Trotter] is a cereal crop resilient to adverse climatic and soil conditions, It grows with varying annual rainfall of 750-850 mm and temperatures between 10 and 27^{o}C (Seyfu, 1993). Interestingly, teff can thrive well in both waterlogged and drought conditions. It is occupying about 22.6% of the cultivated land from the total area of cereals (86.06%) with accounting 16% of the grain production in Ethiopia (CSA, 2012).

Despite its versatility in adapting to extreme environmental conditions, the productivity of teff is very low with the national average standing at 1.5 ton ha^{-1} (CSA, 2014). Which could be the result of a decline in the soil fertility due to high soil erosion and others, and unbalanced chemical fertilizer application. Currently a large portion of Ethiopian Institute of Agricultural Research (EIAR) resources is focused on testing crop yield response to N and P fertilizers, and regional tailoring of DAP and Urea fertilizer recommendations, as these were the priorities identified from the Murphy studies in the 1950s-60s (Gete *et al*., 2010) or more often, a single recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0). This blanket recommendation often fails to take into consideration differences in resource endowment (soil type, labor capacity, climate risk) or make allowances for dramatic changes in input/output price ratio, thereby discouraging farmers from fertilizer application.

Moreover, the nutrients in the blanket recommendation are not well balanced agronomically and its continued use will gradually exhaust soil nutrient reserves. Therefore neither yields nor profits can be sustained using imbalanced application of fertilizers, as the practice results in accelerating deficiencies of other soil nutrients. This could explain, in part, the modest crop yield improvements observed over the last few decades in contrast to significant increases in fertilizer use and investment made in the country. Today, in addition to N and P, S, B and Zn deficiencies are widespread in Ethiopian soils, while some soils are also deficient in K, Cu, Mn and Fe (Ethio SIS, 2014). To overcome the constraint of low nutrient recovery and optimize fertilizer use, there is a need to replace such general and over-simplistic fertilizer recommendations with those that are rationally differentiated according to agro-ecological zones (soils and climate), crop types, nutrient uptake requirements and socio-economic circumstances of farmers. Better matching fertilizer application recommendations to local climate, soil, and management practices helps ensure that production can be intensified in a cost-effective and sustainable way and, thereby, enhance regional food security. The objective of this study was therefore to determine soil- crop specific optimum N, P, K and S fertilizer rates for teff.

Materials and Methods

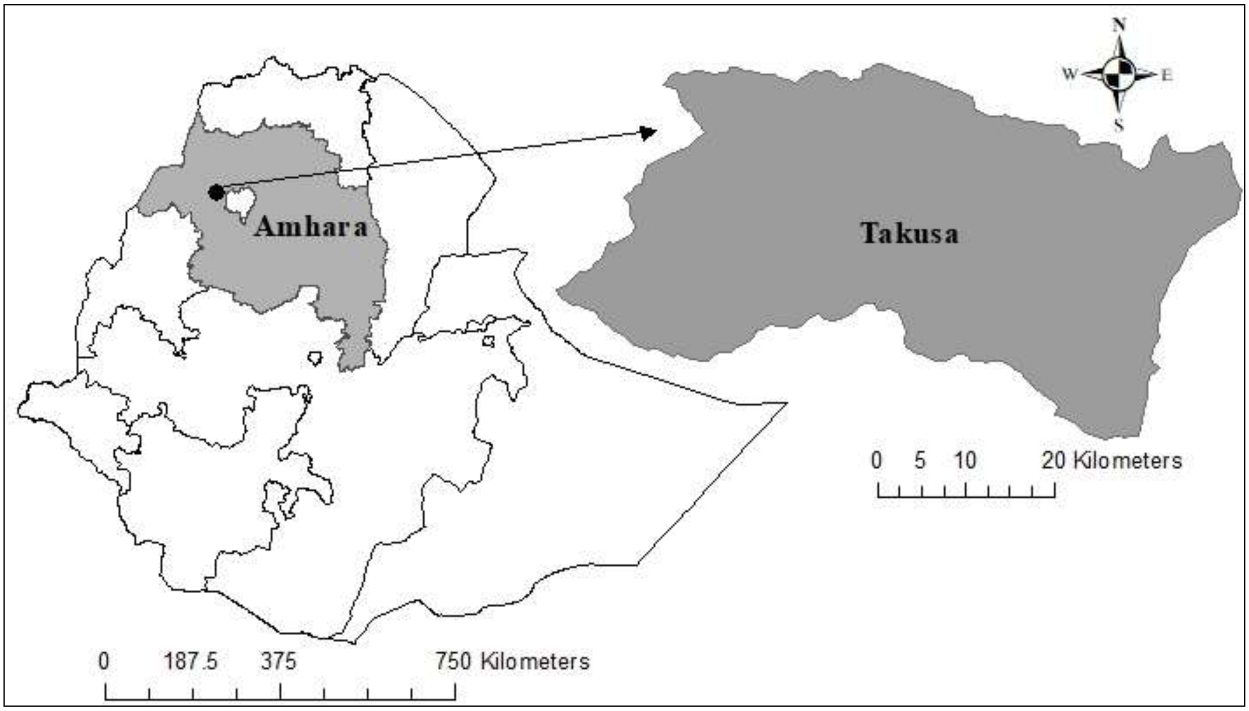
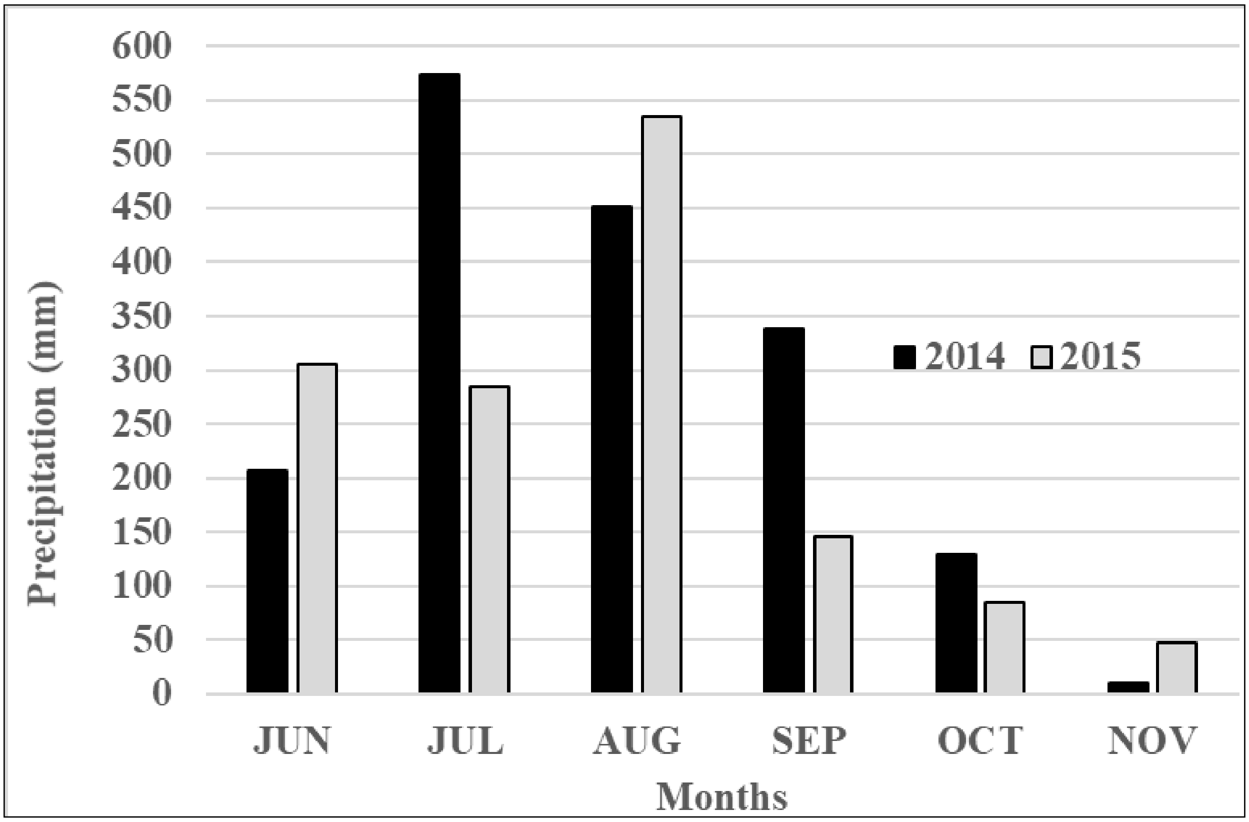


Figure 1. Location map of the Takusa district

The experiment was conducted on farm under rain fed conditions in the 2014 and 2015 cropping seasons at Takusa district located at 12°I0' N and 37°01' E with an altitude of 1780 m a.s.l. (Figure 1). The dominant soil type of the district is vertisol. The area received an annual rain fall of 2051.22 mm, minimum temperature of 16.41° C and maximum temperature of 25.86° C during the year 2014. It also received an annual rain fall of 1560.51 mm, minimum temperature of 17.02° C and maximum temperature of 27.07° C in 2015. The area received the highest rainfall in july 2014 (572.83 mm) and august 2015 (535.25 mm) cropping seasons (Figure 2).

The trial considered four independent set of experiments in each site. Hence, at each location the different rates of N, P, K and S (but not as a factorial) with three replications having sufficiently large amounts of basal fertilizer application for the other three nutrients (Table 1) were considered. All fertilizer treatment combinations were laid out in Randomized Complete Block Design (RCBD) with three replications per site and also replicated across three farmers' fields. The plot size was 3m x3m with 1.5m in between blocks and 1m in between plots. Quncho variety was planted in rows at seed rates of 25 kg ha^{-1} and 20 cm space in between rows. Other agronomic practices were considered as recommended to the area. The collected data were analyzed using the SAS (2002) and Statistix (2013) statistical software. Analyses of variance (ANOVA) were performed to evaluate the effects of treatments (N, P, K and S rates),

Figure 2. Rainfall in 2014 and 2015 cropping season at Takusa district (Source:



https://power.larc.nasa.gov)

experimental sites, years, and their interactions on plant characteristics and yield parameters. Comparisons among treatment means were made using the LSD tests.

For economic analysis, the variable cost of fertilizer were taken at the time of planting and during other operations. Price of teff grain and straw were considered. Yield from experimental plots was adjusted downwards by 10% for management difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Accordingly, the economic response of teff for fertilizer treatments were subjected to partial budget analysis using the procedures outlined by CIMMYT (1988). In this study, 100% return to the investments was used as reasonable minimum acceptable rate of return.

Table1. Treatment and basal fertilizer application rates

Nitrogen rates (N kg ha^{-1}) (Experiment1)	Basal application (kg ha^{-1})				
	P_2O_5	K_2O	S	Zn	B
0, 23,46, 69, 92,115, 138,161	69	80	30	5	1
Phosphorus rates (P kg ha^{-1}) (Experiment 2)	Basal application (kg ha^{-1})				
	N	K_2O	S	Zn	B
0,11,22,33,44,55	92	80	30	5	1
Potassium rates (K kg ha^{-1}) (Experiment 3)	Basal application (kg ha^{-1})				
	N	P_2O_5	S	Zn	B
0,15,30,45,60,75	92	69	30	5	1
Sulfur rates (S kg ha^{-1}) (Experiment 4)	Basal application (kg ha^{-1})				
	N	P_2O_5	K_2O	Zn	B
0,10,20,30,40, 50	92	69	80	5	1

Source: P=TSP, K= KCl, S= CaSO4, Zn=ZnSO4, B = Borax

Results and Discussions

Response of Teff to N

The two years combined analysis of variance (ANOVA) result showed that the effect of different N rates significantly affected plant height, panicle length, number of effective tiller per plant, above ground biomass and grain yield of teff (Appendix Table 1). In addition, the ANOVA result for each year indicated that there was significant plant height, above ground biomass and grain yield difference among the nitrogen fertilizer rates (Appendix Table 1).

The combined analysis showed that maximum plant height (123.59 cm) was recorded at 138 kg ha^{-1} of N; while the lowest plant height (81.44 cm) was recorded in the control plots (no nitrogen fertilizer). The maximum number of effective tiller per plant was recorded at 161 kg ha^{-1} of N, but the maximum panicle length (cm) and biomass (ton ha^{-1}) was recorded at 138 kg ha^{-1} of N respectively; and the minimum was recorded in the control plots. Increase of grain yield was observed as the N fertilizers application increased. Application of 161 kg ha^{-1} N fertilizer resulted in the highest biological grain yield of teff, 1.89 ton ha^{-1}, with a yield advantage of 923.48 kg ha^{-1} over N unfertilized treatment (0.97 ton ha^{-1}) (Table 2). These results concurred with the study of Temesgen (2001) who observed a significant biomass and yield response to N on vertisols in the central highlands of Ethiopia.

Table 2. Effect of Nitrogen rates on the grain yield and yield components of teff at Takusa district.

Rates of N (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	81.53^{e}	34.56	1.69	2.69^{c}	1.06^{e}
23	101.24^{cde}	40.18	2.27	4.52^{b}	1.47^{d}
46	99.40^{de}	35.36	2.11	5.73^{b}	1.72^{c}
69	117.18^{bcd}	41.16	2.11	8.90^{a}	2.11^{b}
92	122.11^{bc}	42.29	2.07	8.43^{a}	2.01^{b}
115	119.62^{bcd}	40.76	2.27	8.35^{a}	2.09^{b}
138	148.18^{a}	43.11	2.73	9.80^{a}	2.00^{b}
161	124.27^{b}	42.20	2.76	8.71^{a}	2.41^{a}
LSD (0.05)	22.65	7.18	0.78	1.80	0.24
CV (%)	20.90	18.95	36.65	26.55	13.36
Year 2015					
0	81.36^{c}	32.10^{c}	1.47	3.04^{c}	0.87^{d}
23	89.96^{b}	35.63^{b}	1.48	3.46^{c}	0.99^{cd}
46	97.53^{ab}	37.86^{ab}	1.61	4.63^{b}	1.25^{ab}
69	99.43^{a}	39.06^{a}	1.61	5.29^{b}	1.34^{ab}
92	102.17^{a}	37.26^{ab}	1.74	4.65^{b}	1.15^{bc}
115	100.36^{a}	37.81^{ab}	1.62	6.43^{a}	1.43^{a}
138	99.00^{a}	36.9^{ab}	1.71	7.13^{a}	1.45^{a}
161	101.73^{a}	37.19^{ab}	1.66	6.61^{a}	1.36^{a}
LSD (0.05)	7.74	3.07	0.25	0.76	0.20
CV (%)	8.46	8.82	16.65	15.62	16.93
Combined					
0	81.44^{e}	33.33^{b}	1.58^{b}	2.87^{f}	0.97^{f}
23	95.60^{d}	37.91^{a}	1.87^{ab}	3.99^{e}	1.23^{e}
46	98.47^{cd}	36.61^{ab}	1.86^{ab}	5.18^{d}	1.49^{d}
69	108.31^{bc}	40.11^{a}	1.86^{ab}	7.09^{bc}	1.73^{bc}
92	112.14^{ab}	39.77^{a}	1.91^{ab}	6.54^{c}	1.58^{cd}
115	109.99^{bc}	39.28^{a}	1.94^{ab}	7.39^{bc}	1.76^{ab}
138	123.59^{a}	40.01^{a}	2.22^{a}	8.46^{a}	1.73^{bc}
161	113.00^{ab}	39.69^{a}	2.21^{a}	7.66^{ab}	1.89^{a}
LSD (0.05)	11.77	3.85	0.43	0.97	0.16
CV (%)	16.89	15.18	33.97	23.76	15.42

Response of Teff to phosphorus

The combined analysis of variance (ANOVA) result showed that the effect of different P rates significantly affected above ground biomass and grain yield of teff, however plant height, panicle length and number of effective tiller per plant didn't respond for applied P fertilizer (Appendix Table 2).

The maximum combined mean value of above ground biomass (6.86 ton ha^{-1}) was obtained from plots that was treated with 33 kg ha^{-1} P, which was statistically par from plots that was treated with 11, 22, 44 and 55 kg ha^{-1} P (Table 3). The lowest value for above ground biomass (5.65 ton ha^{-1}) was obtained from not P fertilized plots. The maximum combined mean value of grain yield (1.74 ton ha^{-1}) was obtained from plots that was treated with 44 kg ha^{-1} P, The lowest value for grain yield (1.36 ton ha^{-1}) was obtained from plots that received 11 kg ha^{-1} P, which was statistically par from plots that was not P fertilized (1.51 ton ha^{-1}) (Table 3). Consistent with these results, Temesgen (2012) reported significantly higher number of tillers, plant height, and panicle length in response to the application of high N rate in teff but not for P.

Table 3. Effect of Phosphorus rate on the grain yield and yield components of teff at Takusa

Rates of P (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	118.8	39.82	1.84	7.67	2.07^{a}
11	123.56	43.09	1.87	8.04	1.58^{b}
22	121.58	44.60	2.18	7.89	1.98^{a}
33	115.27	38.38	1.84	8.21	2.06^{a}
44	119.4	41.07	1.64	8.41	2.20^{a}
55	120.67	44.49	1.87	8.35	2.03^{a}
LSD (0.05)	9.78	5.36	0.50	1.10	0.33
CV (%)	8.52	13.36	27.7	14.19	17.47
Year 2015					
0	87.86^{c}	34.50	1.27^{b}	3.63^{b}	0.95^{b}
11	91.92^{bc}	35.64	1.31^{b}	4.73^{ab}	1.13^{ab}
22	101.58^{ab}	38.38	1.74^{a}	5.28^{a}	1.34^{a}
33	100.01^{ab}	38.19	1.67^{a}	5.50^{a}	1.26^{a}
44	101.74^{a}	38.12	1.70^{a}	5.20^{a}	1.29^{a}
55	100.74^{ab}	38.26	1.53^{ab}	5.01^{a}	1.22^{a}
LSD (0.05)	9.81	3.81	0.30	1.18	0.24
CV (%)	10.52	10.69	20.45	25.2	20.73
Combined					
0	103.33	37.16	1.56	5.65^{b}	1.51^{bc}
11	107.74	39.37	1.59	6.39^{ab}	1.36^{c}
22	111.58	41.49	1.96	6.58^{a}	1.66^{ab}
33	107.64	38.28	1.76	6.86^{a}	1.66^{ab}
44	110.57	39.59	1.67	6.80^{a}	1.74^{a}
55	110.71	41.37	1.70	6.68^{a}	1.63^{ab}
LSD (0.05)	6.70	3.19	0.30	0.80	0.20
CV (%)	9.28	12.12	26.65	18.48	18.68

Response of Teff to K

The two consecutive years of combined ANOVA result indicated that the different K fertilizer rates did not significantly affected plant height, panicle length, number of effective tillers per plant, above ground biomass and grain yield of teff (Appendix Table 3).

The combined mean value of grain yield obtained from plots that was not treated with K (1.75 ton ha^{-1}) was statistically par from plots that was treated with 15, 30, 45, 60 and 75 kg ha^{-1} K (Table 4). The result contradicts the research findings of Yohannes *et al*. (2019) who reported plant height, panicle length, number of effective tillers, dry matter and grain yield of teff increased significantly with applied K on vertisols of East Gojjam. On the other way, the present result contradicts the findings of Dagne (2016) and Fayera *et al*. (2014) whom recommended to include potassium in blended fertilizers.

Table 4. Effect of Potassium rate on the grain yield and yield components of teff (quncho variety) at Takusa area

Rates of K (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	114.36	38.13	1.89[a]	8.13	2.12
15	115.62	39.91	2.04[a]	7.77	2.12
30	140.07	39.82	1.64[ab]	7.99	2.14
45	115.82	39.02	1.44[b]	8.15	2.05
60	124.84	41.96	1.67[ab]	8.40	2.14
75	122.84	42.71	1.98[a]	8.32	2.24
LSD (0.05)	27.34	5.48	0.42	1.32	0.30
CV (%)	23.34	14.2	24.38	16.89	14.61
Year 2015					
0	100.37	39.33	1.61	5.70	1.39
15	97.08	38.97	1.62	5.25	1.29
30	95.96	36.44	1.86	5.59	1.31
45	96.49	36.43	1.60	5.43	1.28
60	100.96	39.17	1.98	5.97	1.38
75	93.78	35.98	1.70	5.69	1.30
LSD (0.05)	7.07	3.24	0.38	0.54	0.18
CV (%)	7.57	8.97	23.05	10.13	14.55
Combined					
0	107.36	38.73	1.75	6.92	1.75
15	106.35	39.44	1.83	6.51	1.70
30	118.01	38.13	1.75	6.79	1.72
45	106.16	37.73	1.52	6.79	1.67
60	112.90	40.56	1.82	7.18	1.76
75	108.31	39.34	1.84	7.01	1.77
LSD (0.05)	13.92	3.09	0.27	0.72	0.19
CV (%)	19.06	11.93	23.49	15.68	16.2

Response of Teff to S

Like K fertilizer application, combined ANOVA result indicated that the different S fertilizer rates did not significantly affected plant height, panicle length, number of effective tiller, above ground biomass and grain yield of teff (Appendix Table 4).

The combined mean value of grain yield obtained from plots that was not treated with S (1.67 ton ha^{-1}) was statistically par from plots that was treated with 10, 20, 30, 40 and 50 kg ha^{-1} S

(Table 5). In contrast to the present result, Habtegebrial and Singh, (2006) were reported that the grain yield of teff was improved with S fertilization which is a 33% increase, compared with those treatments without S at Tigray national regional state, Ethiopia.

Table 5. Effect of Sulfur rate on the grain yield and yield components of teff (quncho variety) at Takusa

Rates of S (kg ha^{-1})	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014					
0	115.73	41.22	1.92	7.47	1.91
10	121.71	39.80	2.20	8.12	1.99
20	120.64	39.89	1.76	7.56	1.98
30	117.36	36.98	1.62	7.90	2.00
40	116.36	39.51	1.80	7.82	2.07
50	120.51	42.51	2.09	8.31	2.05
LSD (0.05)	10.04	5.53	0.59	1.04	0.28
CV (%)	8.83	14.43	30.9	13.81	14.47
Year 2015					
0	94.98	36.18	1.78	5.52	1.43
10	98.19	38.42	1.68	4.97	1.31
20	98.36	38.64	1.74	5.49	1.36
30	96.69	37.32	1.77	5.51	1.42
40	103.68	36.68	1.89	5.78	1.50
50	107.54	36.84	1.82	5.73	1.45
LSD (0.05)	14.63	3.68	0.33	0.53	0.16
CV (%)	15.29	10.3	19.26	9.98	11.48
Combined					
0	105.36	38.70	1.84	6.49	1.67
10	109.95	39.11	1.94	6.54	1.65
20	109.50	39.27	1.75	6.53	1.67
30	107.02	37.15	1.69	6.70	1.71
40	110.02	38.09	1.84	6.80	1.79
50	114.03	39.68	1.96	7.02	1.75
LSD (0.05)	8.89	3.23	0.33	0.57	0.15
CV (%)	12.24	12.56	26.05	12.92	13.59

Economic Analysis

The result of this trial encourages to recommend N and P fertilizers, but the need of K and S fertilizers are rejected through statistical evidences. Morover, the partial budget analysis of the present experiment showed that the maximum net benefit of 15734.75 ETB ha^{-1} and marginal rate of return (MRR) of 561.74% were obtained from application of 69 kg ha^{-1} N. The maximum net benefit of 14761.80 ETB ha^{-1} with MRR value of 79.86% (which is below 100%) were obtained from application of 44 kg ha^{-1} P, but the second large and un-dominated net benefit of 14291.40 ETB ha^{-1} with the MRR value of 280.79% was obtained from application of 22 kg ha^{-1} P. Therefore, for every 1.0 ETB invested in N application farmers can expect to recover their 1.0 ETB, and obtain an additional 5.6 ETB; and for every 1.0 ETB invested in P application farmers can expect to recover their 1.0 ETB and obtain an additional 2.8 ETB in teff production at Takusa area.

Table 6. The partial budget analysis

Fertilizer rate (kg ha^{-1})	Adjusted yield (ton ha^{-1})	Straw (ton ha^{-1})	Total Revenue (ETB ha^{-1})	Production costs (ETB ha^{-1})	total costs (ETB ha^{-1})	Gross field benefit (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Total costs that vary (ETB ha^{-1})	D	Marginal cost (ETB ha^{-1})	Marginal net benefit (ETB ha^{-1})	MRR (%)
Nitrogen												
0	0.92	1.95	12953.75	6629	6629	6324.75	6324.75	0				
23	1.17	2.82	16601.25	6629	7204	9972.25	9397.25	575		575.0	3072.5	534.35
46	1.42	3.76	20283.75	6629	7779	13654.75	12504.75	1150		575.0	3107.5	540.43
69	1.64	5.45	24088.75	6629	8354	17459.75	15734.75	1725		575.0	3230.0	561.74
92	1.50	5.04	22032.50	6629	8929	15403.50	13103.50	2300	D			
115	1.67	5.72	24595.00	6629	9504	17966.00	15091.00	2875	D			
138	1.64	6.82	24773.75	6629	10079	18144.75	14694.75	3450	D			
161	1.80	5.86	26273.75	6629	10654	19644.75	15619.75	4025	D			
Phosphorus												
0	1.43	4.22	20756.25	8121.5	8122	12634.75	12634.75	0				
11	1.29	5.10	19345.00	8121.5	8416	11223.50	10928.70	295	D			
22	1.58	5.00	23002.50	8121.5	8711	14881.00	14291.40	590		590	1656.6	280.79
33	1.58	5.28	23142.50	8121.5	9006	15021.00	14136.60	884	D			
44	1.65	5.15	24062.50	8121.5	9301	15941.00	14761.80	1179		589	470.4	79.86
55	1.55	5.13	22696.25	8121.5	9596	14574.75	13100.75	1474	D			

Conclusion and Recommendation

A field experiment was conducted with the obejective of refining the current fertilizer rate and to check whether additional nutreints such as K and S would be important for teff production in Takusa district. The result revealed that the two major macro nutreints are most necessary to apply as fertilizer sources in the studz areas. Hence, maximum average biological grain yield (1.89 ton ha^{-1}) was harvested by applying 161 kg ha^{-1} N application. Similarly, application of 44 kg ha^{-1} P gave a grain yield of 1.74 ton ha^{-1}. Howver, application of K and S fertilizers did not provided significant biomasss and grain field on teff crop in the study sites. Therefore, based on partial budget analysis of the present finding, its is possible to recommend for Takusa district and othe similar agro-ecologies two types of major nutrients namely N and P with a rate 69 kg ha^{-1} N and 22 kg ha^{-1} P respectively for teff production.

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Appendix

Appendix Table 1. Combined mean squares for teff yield and yield components by Nitrogen treatment in 2014, 2015 and over the two years

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	300.43	111.882	11.805	18.0061	1.53354**
Rep	2	551.36	47.922	4.5717**	2.1059	0.18033
N	7	3613.73**	93.714	1.1273	57.0967**	1.63006**
Site*N	14	385.46	23.063	0.6552	2.2302	0.04596
Error	46	569.6	57.286	0.6801	3.5944	0.06166
Year 2015						
Site	2	4376.49**	908.555**	0.72792**	5.1035**	2.29636**
Rep	2	3.55	8.39	0.10792	1.2898	0.06968
N	7	466**	39.856**	0.08808	19.9716**	0.4001**
Site*N	14	102.74	14.369	0.16522*	2.0317**	0.09239*
Error	46	66.61	10.497	0.07212	0.6478	0.04355
Combined						
Year	1	11342.3**	374.423**	14.6306**	142.168**	14.0938**
Site	2	1402*	823.476**	9.014**	12.804**	3.2941**
Rep	2	319.9	24.484	1.7502*	0.667	0.0144
N	7	3038**	100.25**	0.7689*	68.422**	1.7188**
Site*N	14	210.4	15.142	0.2625	2.083	0.0693
year *N	7	1041.8**	33.319	0.4465	8.65**	0.3152**
year *Site*N	16	652.5*	44.125	0.9281*	3.195	0.1275**
Error	94	316.3	33.848	0.4304	2.133	0.0568

**, ** =significant at 0.05 and 0.01 levels respectively*

Appendix Table2. Combined means squares for teff yield and yield components by Phosphorus treatment in 2014, 2015 and over the two years

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	298.282	92.0541	6.04741**	82.7793**	2.36914**
Rep	2	33.087	8.3163	1.17852*	1.4245	0.18001
P	5	71.443	59.0816	0.2643	0.719	0.3961*
Site*P	10	138.441	25.6674	0.15674	1.8412	0.15431
Error	34	104.249	31.3445	0.2695	1.3196	0.12039
Year 2015						
Site	2	658.032**	304.711**	0.02574	3.55767	0.55337**
Rep	2	67.869	27.146	0.12963	1.10312	0.1668
P	5	315.692*	25.267	0.37896**	4.02504*	0.17611*
Site*P	10	57.472	8.787	0.11396	0.70558	0.03005
Error	34	104.817	15.789	0.09885	1.51765	0.06181
Combined						
Year	1	13752.1**	603.028**	3.06704**	277.858**	16.6852**
Site	2	754.4**	362.126**	3.08694**	35.669**	1.9513**
Rep	2	97.6	32.622	0.34111	0.361	0.346*
P	5	167.9	51.935	0.37822	3.559*	0.3416**
Site*P	10	120.8	18.89	0.15017	1.512	0.0764
year *P	5	219.2	32.414	0.26504	1.185	0.2312*
year *Site*P	12	96.3	18.743	0.59815**	9.307**	0.253**
Error	70	101.6	22.975	0.20654	1.44	0.0886

*, ** =significant at 0.05 and 0.01 levels respectively

Appendix Table 3. Mean squares for teff yield and yield components for six Potassium rates (K) at three sites, 2014 and 2015.

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	361.17	5.3719	0.50667	94.1989**	5.83061**
Rep	2	652.39	3.1763	0.04667	2.2617	0.44321*
K	5	849.75	27.4519	0.47644*	0.4677	0.03264
Site*K	10	1118.87	22.4074	0.21778	1.7403	0.09634
Error	34	814.3	32.7041	0.18784	1.8849	0.09714
Year 2015						
Site	2	25.4585	47.1669*	0.46167	8.03003**	1.39092**
Rep	2	93.1746	4.8802	0.00722	0.92041	0.10898
K	5	67.6363	22.622	0.21722	0.5511	0.02063
Site*K	10	46.9594	12.8951	0.18922	0.30013	0.04252
Error	34	54.4072	11.4486	0.15859	0.32243	0.03705
Combined						
Year	1	16635.9**	174.041**	0.0675	171.588**	17.7471**
Site	2	268.1	34.021	0.14083	24.315**	3.4338**
Rep	2	166	1.671	0.01194	0.159	0.0892
K	5	397.3	18.679	0.25883	0.943	0.0275
Site*K	10	693.7	24.768	0.2235	0.637	0.0489
year *K	5	520.1	31.395	0.43483*	0.075	0.0258
year *Site*K	12	413.2	11.865	0.29083	14.155**	0.7063**
Error	70	438.5	21.628	0.16947	1.159	0.0784

*, ** =significant at 0.05 and 0.01 levels respectively

Appendix Table 4. Mean squares for teff yield and yield components for six Sulfur rates (S) at three sites, 2014 and 2015.

Source of variation	Df	Plant height (cm)	Panicle length (cm)	Number of effective tiller per plant	Above ground biomass (ton ha^{-1})	Grain yield (ton ha^{-1})
Year 2014						
Site	2	727.15**	119.825*	0.73461	19.9432**	0.40361*
Rep	2	240.927	21.379	0.6235	1.5911	0.02336
S	5	58.015	31.002	0.42092	0.9137	0.02912
Site*S	10	104.583	22.901	0.39419	0.6974	0.06641
Error	34	109.917	33.302	0.34363	1.1797	0.08381
Year 2015						
Site	2	404.712	98.8119**	1.47241**	11.2732**	0.45772**
Rep	2	469.054	3.3557	0.01907	0.3027	0.03218
S	5	202.611	8.8336	0.04596	0.7422	0.03941
Site*S	10	319.792	13.8323	0.03796	0.2585	0.03435
Error	34	233.29	14.8103	0.11751	0.3012	0.02625
Combined						
Year	1	9556.04**	187.757**	0.35611	150.781**	9.35745**
Site	2	993.85**	201.818**	1.49549**	0.659	0.30623**
Rep	2	279.24	16.8	0.40771	0.97	0.04621
S	5	158.67	15.151	0.18864	0.74	0.04922
Site*S	10	294.44	25.402	0.25923	0.31	0.0486
year *S	5	101.96	24.684	0.27778	0.916	0.01931
year *Site*S	12	131.28	12.246	0.27935	5.631**	0.13598**
Error	70	179.01	23.596	0.22905	0.746	0.05373

*, ** =significant at 0.05 and 0.01 levels respectively

Response of soybean (*Glycine max* L.) to inoculation and phosphorus in West Gondar Zone, Ethiopia

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Abstract

Sub-Saharan Africa (SSA) accounts for about 9% of the global population threatened by food and nutritional insecurity. This threat is partly due to poor soil fertility and low crop diversification. The nitrogen reserves of arable soils must be replenished periodically to maintain an adequate level for crop production. This replenishment of soil nitrogen is accomplished through the application of mineral fertilizer, or management of biological nitrogen fixation. To find out possible correction measures of soil fertility depletion, a field experiment was carried out on-farm, during 2015and 2016 growing season, at Metema and Tach-Armachiho, West Gondar adminster zone, Ethiopia. The aimed of this experiment was to evaluate the *response of soybean (Glycine max L.) to inoculation and phosphorus fertilizer application in farmers' fields. The experiment included seven treatments; three strains of Bradyrhizobium japonicum (*MAR-1495, SB- 12, TAL- 379) *with and without phosphorus fertilizer (10 kg P ha^{-1}) along with one (Un inoculated and unfertilized control). The treatments were arranged in a randomized complete block design with three replications. The effect of the use of rhizobia strains and P fertilizer on nodulation, yield and yield components of soybean was found statistically significant ($P<0.05$). The highest grain and dry matter yields of 2.7 and 6.4 t ha^{-1}, respectively, were obtained from SB-12+P which was statistically at par with the yields obtained from SB-12 alone. A grain yield advantage of 30.8% over the control treatment was found from the use of SB-12 alone. Similarly, the maximum number of effective nodules (15.1) per plant was recorded from SB-12+P which was statistically at par with the number of effective nodules (11.8) per plant counted from SB-12 inoculated treatment. Therefore, inoculation with the strain SB-12 was found the most effective for improved soybean production in the study districts and similar agro-ecologies.*

Keywords*:* Bradyrhizobium, Grain yield, Inoculation, Soybean

Introduction

Sub-Saharan Africa (SSA) accounts for about 9% of the global population threatened by food and nutritional insecurity. This threat is partly due to poor soil fertility and low crop diversification (Sanchez and Swaminathan, 2005). The nitrogen reserves of arable soils must be replenished periodically to maintain an adequate level for crop production. This replenishment of soil nitrogen is accomplished through the application of mineral fertilizer, or management of biological nitrogen fixation (BNF) (Bekunda *et al*., 2010).

Nitrogen is one of the most abundant elements on earth which constitutes about 78% of the earth's atmosphere, but its availability often limits plant growth and crop production. This situation arises because the N_2 molecule is very stable chemically and is unusable by most biological organisms. It must be "fixed" before it can be assimilated (Fisher and Newton, 2002). Nitrogen can be utilized when it is reduced to ammonia by fixation. It can be reduced by chemical fixation through industrial production and/or biological fixation involving microorganisms. Most plants utilize nitrogen in its ionic forms ammonium (NH_4^+) and nitrate (NO_3^-) from soil (Li *et al*.,2013).

The increasing cost of fertilizers and their impact on the environment have forced people to look for other possible sources of plant nutrients. In this regard, nitrogen fixation which is a process by which elemental atmospheric nitrogen is changed to organic forms by biological nitrogen fixation both by symbiotic and asymbiotic microorganisms in soil has drawn much attention (Kumari and Sinha, 2011). The symbiotic nitrogen fixation is used to maximum advantage in the case of leguminous crops. There is no doubt that specificity exists between rhizobia- strain and the legume, and compatibility between the two is essential for successful nodulation. This necessitates using specific cultures for different legumes. When growing a new legume species on soil, it is necessary practice that the appropriate rhizobia culture is applied (Solomon *et al.*, 2012).

It is therefore important to inoculate seeds with relevant strains of rhizobia before sowing especially if the crop is to be grown for the first time on the land. Inoculation responses are associated primarily with the first planting of a legume in soil having no prior history of the crop (Zerpa *et al*., 2013). The use of commercial rhizobial inoculants in the establishment of soybean has been widely recognized, especially in areas where indigenous nodulation is inadequate. It has been reported that soybean inoculated with different rhizobial strains react differently in the growth, yield and nitrogen fixation (Mmbaga *et al*., 2014).

Previous studies conducted in Ethiopia showed that the response of soybean to rhizobia inoculation is promising but variable depending on the inherent field variability, difference in environmental and edaphic factors. However, such information is scanty in the study area. Therefore, this study is geared towards the evaluation of different rhizobia strains under different phosphorus supply for improving nodulation and yield of soybean.

Materials and methods

Experimental site

The study was carried out on the farmer's field in 2015 and 2016 at Metema and Tache Aremacheho districts which is located in the North Gondar zone, Amhara Regional State in Ethiopia (Fig.1) The area has a mean elevation of 1080 m.a.s.l, with a maximum of 1608 m a.s.l. and a minimum of 550 m a.s.l. The mean annual rainfall for the area ranges from about 850 to around 1100 mm and the rainy months extend from June to the end of September. However, maximum rainfall is received during July and August respectively. The average annual temperature of the study area ranged between 22 ^{0}C and 28 ^{0}C. The maximum temperature was recorded during March to May. Nearly all of the land in the area is in the lowlands except some mountain tops which fall outside. The major crops grown in the area are sorghum, cotton, sesame and teff. One variety of soybean (Ethio-Yugoslavia) was tested. This variety was obtained from Adet Agricultural Center and its potential grain yield is from 2.5 to 3 t. ha^{-1}. Three strains of soybean rhizobia (Strain MAR-1495, Strain SB- 12, TAL -379) were obtained from Holeta Microbiology Laboratory (Ethiopia).

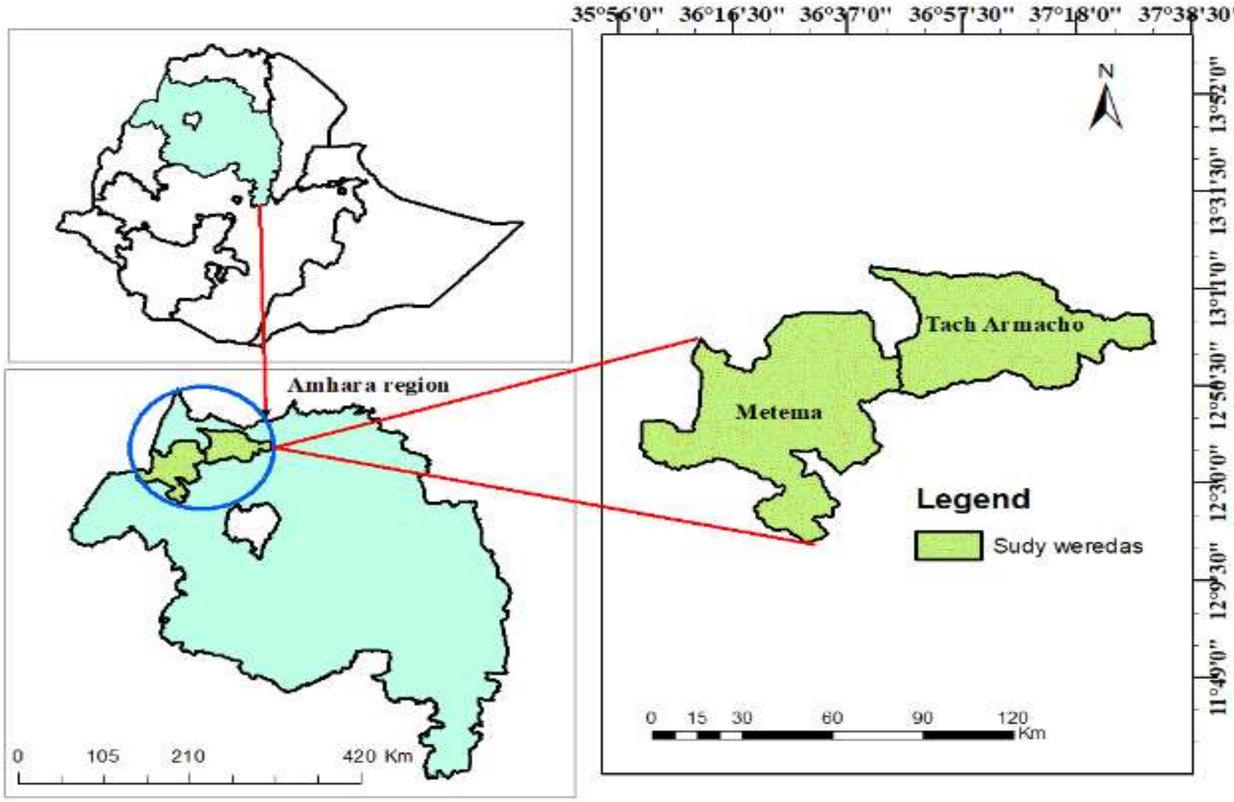

Figure1. Map of the study area

Experimental design

In each district, the experiments were conducted on farmer's fields where sorghum was grown in the previous season to reduce soil nitrogen effects and soil heterogeneity factor.

The experiment was designed in a randomized complete block design (RCBD) with three replications. The experiment included seven treatments of which three strains of *Bradyrhizobium japonicum* (MAR-1495, SB-12, TAL-379) combined with and without phosphorus fertilizer (10 kg P ha^{-1}) along with one (un inoculated and unfertilized control). Gross plot size was 12 m^2 (4 m x 3 m) and spaced 1 m and 1.5 m between plots and blocks, respectively. The net harvestable area was 6.25 m^2 (2.5 m x 2.5 m). Three seeds were sown per hill, which were later thinned to one after germination, with spacing of 5 cm between plants and 60 cm between rows.

Physico-chemical analysis of Soil

Experimental soils were sampled for their Physico-chemical properties analysis from one representative composite sample which were taken 0 to 20 cm depth from the entire field before planting. Similarly, soil samples were collected at each plot after harvest. Sampleswere analyzed for the following parameters viz., pH, organic carbon, cation exchange capacity, and available P from the representative bulk soil sample before planting and at harvest. soil pH was estimated by potentiometric method at soil: water ratio of 1:2.5 (Van Reeuwijk, 1992). Cation exchange capacity was determined by 1M ammonium acetate method at pH 7 (Chapman, 1965) whereas organic carbon was determined by the dichromate oxidation method (Walkley and Black, 1934) and available P was analyzed by Olsen method (Olsen *et al*., 1954) and determined colorimetrically by the ascorbic acid- molybdate blue method (Watanabe and Olsen, 1965). Ca^{++} and Mg^{++} values were found out from Atomic Absorption. Spectrophotometer reading while Na^{+} and K^{+} was determined using flame photometer.

Seed Inoculation

The lignite -based inoculants were added to the soybean seeds in a container after moistening the seeds. The inoculants and the seeds were mixed thoroughly until the seeds were adequately coated with the inoculants and allowed to air-dry in the shade for 30 minutes after which they were planted on the ridges.

Data collection

Nodule Data Collection

Four plants were sampled randomly from the second border rows of each plot at mid-flowering. The whole plant was carefully uprooted using a spade to obtain intact roots and nodules. Uprooting was done by exposing the whole-root system to avoid loss of nodules. The adhering soil was removed by washing the roots with intact nodules gently with water. The number of nodules per plant was determined by counting the number of nodules from all the four uprooted plants per plot and then averaged as per plant.

Crop Yield and Agronomic Data Collection

Five plants were sampled randomly at maturity from each plot, pods were counted for all the five plants, and the average value was reported as the number of pods per plant. The number of seeds per pod was determined from five pods randomly sampled, and the average was reported as a number of seeds per pod. The number of plants per plot was recorded at harvesting from the central four rows, and the mean was computed and used for the analysis of the final plant stand. Soybean plants were harvested from each plot at physiological maturity leaving the border rows and 0.5m row length on every end of each row. Seed yield was obtained by adjusting the moisture level to 10% according to the formula indicated by Abebe (1979) as follows and converted into kg ha $^{-1}$:

$\text{Adj. grain yield (kg ha}-^{1}) = \frac{100-\text{M.C}}{100-\text{SMC}} \text{ X Plot yield (g)x} \frac{10}{\text{Net plot size (m2)}}$, where Adj. grain yield (kg/ha) = adjusted grain yield in kg ha $^{-1}$, M.C = the % moisture content of the seed sample, Plot yield (g) = unadjusted grain yield in gram, SMC= % standard moisture content (which is 10 for soybean), Net plot size = Area harvested (plot size) in m^2.

or

$\text{Adj. grain yield (per plot)} = \frac{100-\text{M.C}}{100-10} \text{ X Plot yield (g)}$, where 10 is the SMC; then convert this into ha basis.

where MC is moisture content of soybean seeds at the time of measurement, and 10 is the standard moisture content of soybean seeds at harvest in percent. The weights of hundred seeds randomly counted from the seeds of each plot maintaining the seed moisture content at 10% were reported as hundred seeds weight.

Statistical analysis

All statistical analysis was carried out using SAS software version 10. One-way analysis of variance (ANOVA) was performed to determine the statistical differences. When significant differences (p < 0.05) were noticed, all treatment means were compared using the Least Significant Difference (LSD) at a 5% level of significance.

Results and discussion

Selected Soil Physical and Chemical Properties before planting

The soil analysis results of the pre-sowing selected physical and chemical properties of the experimental sites are presented in Table 1. Soil analysis of the experimental field has shown that the soil had a pH of 6.84 to 7.93, which was rated as moderately alkaline (Tekalign, 1991). Soil organic matter of the experimental site was high (4.8%) (Tekalign, 1991). The analysis further indicated that the soil had low available phosphorus (4.5 to 7.01 ppm) (Table 1) according to the ratings of Marx *et al*. (1996). Besides, the cation exchange capacity (CEC) of the soil was rated in the range of very high as reported by Landon (1991).

Table 1. Intial soil chemical properties of Metema and Tach-Armachiho sites (2015).

Sites	pH (H_2O)	EC (ms/cm)	Available P (ppm)	OC (%)	CEC (cmol(+)/kg)
Metema -1	7.93	0.09	5.15	0.83	57.46
Metema -2	7.14	0.06	4.25	0.88	61.59
T/Armachiho- 1	7.45	0.06	7.01	0.83	29.23
T/Armachiho- 2	6.84	0.08	4.25	1.17	57.57

Table 2. Chemical properties of the soil after harvesting of the experiment in Metema (2015).

Treatment	PH (H_2O)	EC (ms/cm)	Availabel P (ppm)	OC (%)	CEC (cmol(+)/kg)
1	6.8	0.07	3.3	0.9	52.4
2	6.9	0.07	3	1	54.6
3	6.9	0.07	3.1	1.3	54.5
4	6.8	0.07	4	0.8	52.4
5	6.9	0.06	3.6	1.1	51.5
6	6.8	0.07	3.3	0.8	53.3
7	6.7	0.07	3.8	1	53.5

Table 3. Soil chemical properties after harvesting at Tach-Armachiho (2015).

Treatment	PH (H2O)	EC(ms/cm)	AVAILABLE P (ppm)	OC (%)	CEC (cmol(+)/kg)
1	8	0.08	4.55	0.7	53.23
2	7.9	0.07	4.17	0.92	53.46
3	7.7	0.08	3.27	25.6	53.09
4	7.8	0.07	3.71	0.85	52.29
5	7.7	0.07	4.49	0.97	56.25
6	7.8	0.08	5.75	1.1	51.83
7	7.8	0.09	3.29	0.84	53.91

Where: OC: Organic content; P: Phosphorus; CEC: Cation Exchange Capacity.

Effect of rhizobia inoculation and P fertilizer on dry matter yield and yield components

There was a significant ($P<0.05$) effect of rhizobia strains and P fertilizer on the grain and dry matter yields of soybean at two testing sites in the first experimental year (Table 4).The maximum grain and dry matter yields were obtained from inoculation alone with the strain SB-12 followed with insignificant ($P>0.05$) difference by the yields obtained from inoculation alone with the strain MAR-1495. However, there was insignificant ($P>0.05$) difference among plant height due to the effect of the treatments at all testing sites.

Table 4. Mean yield and yield components of soybean influenced by rhizobia strains and P at Metema and Tach armachiho in 2015

		Metema			Tach armachiho	
Treatment*	PH (cm)	GY (kg ha^{-1})	DM (kg ha^{-1})	PH (cm)	GY (kg ha^{-1})	DM (kg ha^{-1})
Control.	61.6	1543.8	4354.4	79.7	2235.5	6420.3
SB-12	72.6	2638.9	6625.2	86.7	3031.3	7469.1
MAR-1495	69.8	2372.4	6080	79.4	3137.8	7481.1
TAL-379	68.3	1834.5	5135.6	78.6	1981.5	5615.1
SB-12+P	73.2	2606.7	6521	92.6	3371.6	8427.3
MAR-1495+P	72.6	2471.6	6368.2	80.8	2571.5	6890.9
TAL-379+P	69	1679.6	5340.4	89.4	2551.6	7323.1
CV (%)	6.9	15.3	10.3	9.2	14.9	7.1
LSD (5%)	ns	588.7	1062.6	ns	740.6	935.6

*PH = Plant height (cm), GY = Grain yield (kg ha^{-1}), DM = dry matter yield (kg ha^{-1}). *Means within a column followed by the same letter are not significantly different at < 0.05 significance level; ns = non-significant at P = 0.05.*

The pooled analysis over the testing sites revealed a statistically significant ($P<0.05$) difference among plant height, hundred seed weight (HSW), grain and dry matter yields due to the effect of treatments (Table 5). The maximum plant height of 85.1 cm, HSW of 15.9 g, grain yield of 3.0 t ha^{-1} and dry matter yield of 7.5 t ha^{-1} were obtained from the use of SB-12+P followed with insignificant difference (P>0.05) by the yield and yield components obtained from the use of SB-12 alone. Phosphorus treated plots exhibited the maximum HSW as compared to inoculated alone treatments. Though the treatment by site interaction effect on the grain and dry matter yields was significant (P<0.05), the effects of SB-12+P, SB-12 and MAR-1495 alone were found uniformly dominant across all testing sites.

Table 5. Effect of P and rhizobia on the yield and yield components of soybean pooled over the two testing sites in 2015

Treatment*	PH (cm)	PN per plant	SN per pod	100SW (g)	GY (kg ha^{-1})	DM (kg ha^{-1})
1. Control	76.1	31.4	2.8	14.1	2268.6	6032.3
2. SB-12	80.6	28.6	2.7	15.3	2924.2	7011.3
3. MAR-1495	77.7	32.9	3.6	15	2804.5	6717.3
4. TAL-379	75.9	27.8	3.3	14.4	2252.3	5855.2
5. SB-12 + P	85.1	29.3	2.8	15.9	3034.9	7524
6. MAR-1495 + P	80.8	27.2	2.6	15.8	2716.8	6870.6
7. TAL-379 + P	82.6	29.6	3.0	14.9	2487.7	6622.3
Mean	79.8	29.5	2.9	15.1	2638.6	6661
CV (%)	7.4	18.6	39.6	6.6	13.8	8.6
LSD (5%)	5.8	ns	ns	1.05	350.1	554.9
Loc*Trt	ns	ns	ns	ns	*	**

**Means within a column followed by the same letter are not significantly different at < 0.05 significance level; ns = non-significant at P = 0.05; * and ** = significant at 5 and 1% probability level, respectively. PH; plant height, PN ; pod number, SN ; seed number, 100SW; 100 seed weight, GY; grain yield, DM; dry matter.*

The second year data analysis results also indicated that grain and dry matter yields were significantly (P<0.05) affected by the effect of rhizobial inoculation and addition of P fertilizer. (Table 6). However, other yield component parameters such as plant height and pod number per plant were not significantly (P>0.05) affected by the effect of treatments. At Metema, the highest grain yield of 2.6 t ha^{-1} was measured from MAR-1495+P and SB-12+P being statistically at par with the yields obtained from SB-12 alone. However, at Tach Armachiho, except the control treatment, there was no significant (P>0.05) yield difference among treatments. The lowest yield at both testing sites was recorded from the control treatment. The combined analysis over the two testing sites showed that rhizobial inoculation with P fertilizer had significant (P<0.05) effect on the yield of soybean (Table 6). Inoculation alone with the strains MAR-1495 and SB-12 gave statistically similar grain and dry matter yields with their combined use along with P (Table 6).

Table 6. Effect of rhizobial and P on the yield and yield components of soybean at Metema and Tach Armachiho in 2016

Treatment*	Metema				Tach Armachiho			
	PH (cm)	PNPP	GY (kg ha^{-1})	DM (kg ha^{-1})	PH (cm)	PNPP	GY (kg ha^{-1})	DM (kg ha^{-1})
1. Control	69.6	27.7	1996.3	3869	56	20	899.2	2224.6
2. SB-12	63	28.2	2383.5	4514.9	61.2	23.8	1539.4	3346.5
3. MAR-1495	69.5	26.6	2085.6	5538.7	60.2	23.6	1469.3	3178.1
4. TAL-379	65	29.8	1926.4	4126	57.4	20.1	1615.5	3518.3
5. SB-12 + P	74.1	27.3	2578.3	5021.8	66.9	25.3	1573.6	3310
6. MAR-1495 + P	76.8	33.8	2625.6	5136.4	59.6	25.2	1307.6	3018.3
7. TAL-379 + P	67	33.4	2183.2	4271.8	63	27.3	1324.5	3063.5
Mean	69.3	29.5	2254.1	4639.8	60.6	23.6	1371.7	3062.8
CV (%)	8.4	12.9	9.6	10.0	11.5	10.3	14.9	13.9
LSD (5%)	ns	ns	385.6	826.5	ns	ns	416.3	873.3

*PH = plant height (cm), PNPP = pod no per plant, GY = Grain yield (kg ha^{-1}), DM = dry matter yield (kg ha^{-1}). *Means followed by the same letters are not significantly different at 5% level of probability: ns = Non-significant at 5% significance level.*

Table 7. Mean yield and yield components of soybean affected by rhizobia and P fertilizer pooled over the two testing sites in 2016.

Treatment*	PH (cm)	PNPP	GY (kg ha^{-1})	DM (kg ha^{-1})

1. Control	65.3	26.3	1450.3	3049.3
2. SB-12	64.6	28.5	1964.0	3933.2
3. MAR-1495	67.4	27.6	1779.9	4360.9
4. TAL-379	63.7	27.5	1804.5	3885.4
5. SB-12 + P	73.0	28.8	2179.0	4339.6
6. MAR-1495 + P	70.7	31.9	2100.9	4291.7
7. TAL-379 + P	67.5	32.9	1756.3	3670.1
Mean	67.4	29.1	1849.3	3914.5
CV (%)	10.1	12.7	12.4	11.6
LSD (5%)	ns	4.4	286.1	567.4
Loc*trt	ns	ns	*	Ns

PH = Plant height (cm), GY = Grain yield (kg ha^{-1}), DM = dry matter yield (kg ha^{-1}).

**Means followed by the same letter/s are not significantly different at 5% level of probability: ns = Non-significant at P = 0.05.*

The combined analysis result over the two experimental years and over all testing sites indicated that there was a highly significant effect of treatments on the plant height, grain and dry matter yields of soybean (Table 8). However, pod number per plant and seed number per pod were not significantly affected by the effects of treatments. The combined use of SB-12 with P gave the highest grain and dry matter yields of 2.7 and 6.4 t ha^{-1}, respectively which are statistically at par with the yields recorded from SB-12 alone. Inoculation with the strain SB-12 alone had a 30.8% yield advantage over the yield obtained from the control treatment. Inoculation of soybean with the strain MAR-1495 had also statistically comparable yield advantage with the strain SB-12 and had 21.8% yield advantage over the yield obtained from the control treatment. The finding in this paper is supported, who concluded that the strain SB-12 was the best strain among the strains evaluated in their study in increasing the yield of soybean.

Table 8. Mean yield and yield components of soybean affected by rhizobia strains and P combined over locations and years

Treatment*	PH (cm)	PNPP	SNPPD	GY (kg ha^{-1})	DM (kg ha^{-1})
1. Control	69.7	26.3	2.9	1939.2	4837

2. SB-12	72.1	25.5	2.8	2538	5777.9
3. MAR-1495	71.5	27.8	3.4	2363.2	5705.2
4. TAL-379	68.9	24.6	3.2	2090.3	5149.7
5. SB-12+P	78.1	26.1	2.9	2727.2	6384.6
6. MAR-1495+P	74.7	26.1	2.8	2494.8	5947.5
7. TAL-379+P	74.4	27.9	3.0	2193.1	5439.4
Mean	72.7	26.3	2.9	2331.8	5598.4
CV (%)	8.6	16.7	31.1	13.6	9.6
LSD (5%)	4.8	ns	ns	236.2	401.4
Loc*Trt	ns	ns	ns	ns	ns

**Means followed by the same letter/s are not significantly different at 5% level of probability; ns = Non-significant at P = 0.05. PH = plant height, PNPP = pod no per plant, SNPPD=seed number per pod, GY = Grain yield (kg ha^{-1}), DM = dry matter*

Effect of rhizobial inoculation and P fertilizer on root nodule formation

The maximum number of effective nodules per plant (NENP) at Mtema was recorded from TAL-379+P statistically at par with the NENP recorded from MAR-1495 and SB-12. While at Tach Armachiho, the maximum NENP was recorded from SB-12+P statistically at par with the NENP recorded from MAR-1495 and SB-12 alone. The combined analysis over the two testing sites indicated that the maximum average NENP (15.1) was recorded from the use of SB-12+P which was statistically at par with the average NENP (11.8) recorded from the use of the strain SB-12 alone (Table 9).

Although the effect of treatment by site interaction on nodulation was significant, use of the strains MAR-1495 and SB-12 alone was found to perform uniformly better than the other treatments in producing effective nodules.

Table 9. Effect of inoculation with rhizobia strains and P fertilizer on root nodulation of soybean in 2016

Treatment*	Number of effective nodules per plant

	Metema	Tach Armachiho	Combined
1. Control	0.6	1.8	1.2
2. SB-12	5.2	18.3	11.8
3. MAR-1495	4.4	13.1	9.6
4. TAL-379	1.5	8.5	6.1
5. SB-12 + P	4.8	20.4	15.1
6. MAR-1495 + P	6.4	16.1	10.3
7. TAL-379 + P	6.8	11.5	9.1
CV (%)	40.7	34.2	48.9
LSD (5%)	3.4	7.7	5.12
Trt*Loc	-	-	**

**Means followed by the same letter/s are not significantly different at 5% level of probability; ** = significant at 1% significance level.*

Conclusion

The result in this study indicated that the combined use of the rhizobia strains SB-12 and MAR-1495 were found to increase yield of soybean significantly as compared to the control treatment. However, the sole use of the rhizobia strain SB-12 had statistically similar yield advantage with its combined use with P fertilizer.Thus, inoculation of soybean seeds with SB-12 primarily and MAR-1495 alternatively prior to planting can be recommended for improved soybean production in Metema and Tach Armachiho districts and similar agro-ecologies.

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Response of Tef (*Eragrostis Tef*) to Different Rates of Nitrogen and Phosphorous in Gumara Maksegnit Watershed

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Abstract

Nitrogen, phosphorous and potassium are the essential elements required for plant growth in relatively large amounts. However, deficiencies of nitrogen and phosphorus are common. Soil nutrients become depleted due to leaching of nitrogen, fixation of phosphorous, soil erosion, and removal by crops. To maintain a high crop production level, the nutrient status of the soil has to be maintained through crop rotation, addition of manures or application of inorganic fertilizers). Synthetic fertilizers are important inputs in agricultural production system because they supply the required nutrients in a readily available form for immediate plant use. An experiment was conducted in Gondar Zuria district, Abakaloye and Dinzaz villages, Gumara-Maksegnit watershed with the objective of determining biologically and economically optimum level of N and P rates for tef production. The experiment was carried in two groups of homogeneous sites Vertisols (heavy soil) and Cambisols of the area. Four levels of nitrogen (0, 46, 69 and 92 kg N ha^{-1}) and four levels of phosphorus fertilizer (0, 20, 30 and 40 kg P ha^{-1}) combined factorially. A randomized complete block design with three replications was used. Growth and yield parameters were collected and analyzed using SAS computer software. The results showed that there was a statistically significant difference among treatments in both biomass and grain yield ($p < 0.05$). Application of 20 kg P ha^{-1} *and 46 kg N* ha^{-1} *significantly increased grain yield and biomass yield. Therefore, 20 kg P* ha^{-1} *and 46 kg N* ha^{-1} *are recommended to tef production.*

Keywords*:* Gonder-Zuria, nutrient, tef production, vertisols, yield

Introduction

Nitrogen, phosphorous and potassium are the essential elements required for plant growth in relatively large amounts. However, deficiencies of nitrogen and phosphorus are common. Soil nutrients become depleted due to leaching of nitrogen, fixation of phosphorous, soil erosion, and removal of nutrients by crops (Oldeman *et al.,1993)*. To maintain a high crop production level, the nutrient status of the soil has to be maintained through crop rotation, addition of manures and /or application of inorganic fertilizers (WRI, 1997). Synthetic fertilizers are important inputs because they supply the required nutrients in a readily available form for immediate plant use.

Tef is the most important cereal crop and serving millions of people as a staple food in Ethiopia. (Chibo et al., 2002) reported that tef contains 11% protein and is an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods. Tef contains more lysine than barley, millet, and wheat and slightly less than rice or oats. They further mentioned that tef is also an excellent source of fiber and iron, and has many times the amount of calcium, potassium and other essential minerals found in an equal amount of other grains. They also noted that tef is nearly gluten-free and alternative grain for persons with gluten sensitivity. Tef may also have applications for persons with Celiac Disease. It contains 11% total carbohydrates, 24% dietary fiber, 10% thiamine, 2% riboflavin, 4% niacin, 8% calcium and 20% iron and is free from saturated fat, sugar and cholesterol (Purcell Mountain Farms, 2008). Gilbert (1997) indicated that tef straw from threshed grains is considered to be excellent forage, superior to straws from other cereal species. Tef straw provides an excellent nutritional product in comparison to other animal feed and is also utilized to reinforce mud or plasters used in the construction of buildings (Doris, 2010). Although tef is adapted to a wide range of environments and diverse agro-climatic conditions, it performs excellently at an altitude of 1800-2100 m a s l, annual rainfall of 750-850 mm, growing season rainfall of 450-550 mm, and a temperature of 10 0^{C}-27 0^{C} (Seifu Ketema, 1993). It does well on clay loam and clay soils, which retain moisture during growing seasons. Tef is well suited on soils with a moderate fertility level and can tolerate moderate waterlogged conditions (National Soil Service, 1994). It is also widely grown in the Southern Region of Ethiopia, where early varieties like Dhabi and Bunigne are commonly produced during belg (March-June) rainy season, whereas medium to late varieties are dominantly produced during the main rain/meher (July- October) season According to CSA

(1999), tef, covers the largest cultivated land as compared to cereals, pulses and oils, with an average annual production of 1.87 million tonnes. Out of the estimated total cultivated land (8.216 million ha), it covered 31% in 1996/1997, 32% in 1997/1998 (CSA1999), and 25.84% in 2000/01 (CSA, 2002). From the figures above one can understand that, although the percentage of land under tef gradually decreases, the total area is continued to increase still as a result of more and more new land is being cleared and put under cultivation each year. Despite the large-scale production and various merits, tef production and productivity have been far below the potential. Currently, the average national productivity is 0.92 t ha^{-1}, which is very low as compared to other small grain cereals grown in Ethiopia. Tef is produced in large plots, which is difficult for farmers to apply organic fertilizers to improve soil fertility. To feed the ever-increasing population and generate income, continuous cultivation of land became a common practice in major tef producing areas, which eventually led to soil fertility decline and subsequent reduction of crop yields. Thus, as noted by Mwangi (1995) the use of synthetic fertilizer is critical to increase crop yield. In many cases, farmers are being forced to either not use or use low rates of fertilizer due to high fertilizer costs. Use of fertilizers recommendation rate irrespective of soil variations is one of the discouraging factors to farmers. Thus, cost-effective use of fertilizers in Ethiopia is very crucial. Fertilizer recommendations are site, crop and soil specific; hence fertilizer rates should also be established for each crop.

Soil fertility studies and crop improvement have brought remarkable changes in crop production, particularly in tef. Decreases in soil status decreases productivities of various cultivars in which their nutritional demand is dife erent and increasing. Dubale (2019) elucidates that fertilizer rate studies are dynamic and increasing from time to time. Fertilizer rate recommendations need to be soil test based and should be done repeatedly for any cultivar to maximize the inherent potential yield of the crop (Dubale, 2019). However, 100 kg DAP ha^{-1} and 100 kg urea ha^{-1} were set by the Ministry of Agriculture and Rural Development later (Kenea *et al.*, 2001). Therefore, this research was carried out for two consecutive years to assess the economic and biological optimum rates of NP levels for the production of tef.

Materials and methods

Description of the study area

The study area is located between 37° 33’ to 37° 30’ North latitude and 12° 23’ to 12° 30’ East longitude (figure 1) in Gondar zuria District, North Gondar administrative zone, Amhara National Regional State of Ethiopia.

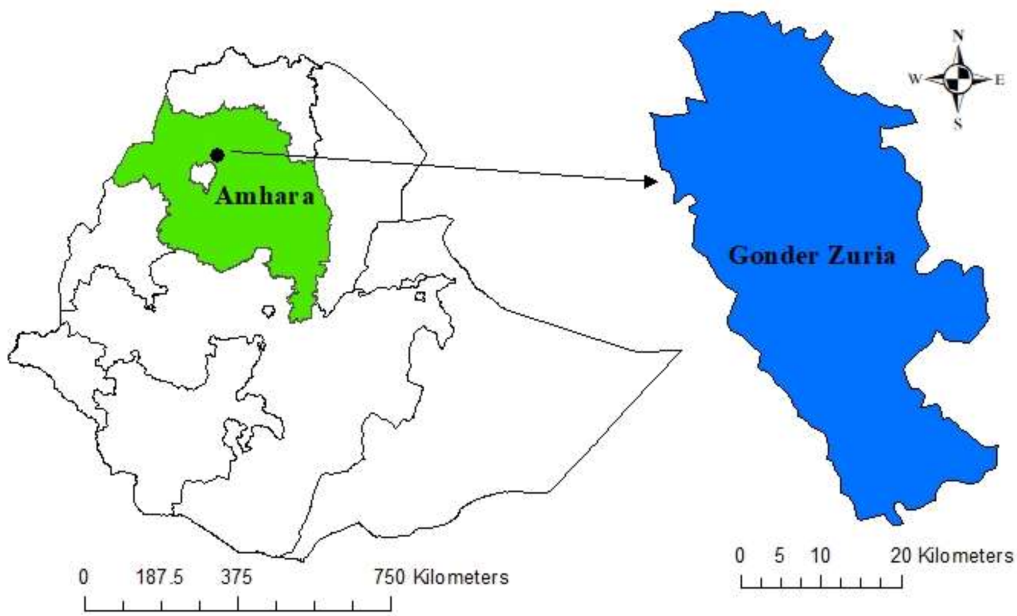

Figure 5. Map of the **s**tudy area

The Altitude of the area ranges from 1920 to 2400 m a.s.l (Woina Dega (cool semi-humid) and Dega zones (cool, above 2,400 m.a.s.l). The annual rainfall is 1052 mm with a variation between 758 mm and 1440 mm and has a monomodal pattern. Rainfall starts in June and ends in mid-September. The annual temperature varies from a minimum of 13.3 o C to a maximum of 28.5o C. Based on rainfall and PET calculations, the length of the growing period (LGP) is expected to vary from 110 to 120 days. The major soil type is Vertisol according to USDA soil classification.

Experimental design and procedures

The study was carried out during two cropping seasons (2014 and 2015). The field studies were carried on a farmer’s field with two locations using factorial combinations of nitrogen and phosphorous fertilizers. Urea (46% N, TSP (46% P2O5) and NPS (19-38-7) were used as a source of nitrogen and phosphorus nutrients. Quncho variety (DZ-Cr-387-RIL 355), which is a high-yielding white-seeded cultivar adapted to a wide range of altitudes was used for the experiment. The treatments were a factorial combinations of four levels of nitrogen (0, 46, 69 and 92 kg N ha-1), and four levels of phosphorus (0, 20, 30 and 40 kg P ha-1). The experiment was laid in a randomized complete block design (RCBD) with three replications. The size of each experimental plot was 3 m by 3 m. Distance between plots and blocks were 0.5 and 1.5 m, respectively as well as 20 cm between rows. Experimental plots were kept weed-free uniformly.

Data Collection

Plant height was measured at physiological maturity from the ground level to the tip of the panicle from ten randomly selected plants in each plot. While panicle length which is the length of the panicle from the node where the first panicle branches emerge to the tip of the panicle was determined from an average of ten selected plants per plot. Furthermore, grain yield was measured by harvesting the crop from the net middle plot area of 2.5 x 2.5 m to avoid border effects. At maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area were harvested and after drying, the biomass was measured. Straw yield was calculated after threshing and measuring the grain yield, the straw yield was obtained by subtracting the grain yield from the total above-ground biomass. Finally, harvest index was calculated by dividing grain yield by the total above-ground air-dry biomass yield.

Soil Sampling and Analysis

Soils were sampled from experimental sites for their Physico-chemical properties analysis from one representative composite sample which were taken 0 to 20 cm depth from the entire field before planting and after harvest from each plot. Samples were analyzed for the following parameters viz., pH, organic carbon, cation exchange capacity, and available P from the representative bulk soil sample before planting. Soil pH was estimated by potentiometric method at soil: water ratio of 1:2.5 (Van Reeuwijk, 1992). Cation exchange capacity was determined by 1M ammonium acetate method at pH 7 (Chapman, 1965) whereas organic carbon was determined by the dichromate oxidation method (Walkley and Black, 1934) and available P was analyzed by Olsen method (Olsen et al., 1954) and determined colorimetrically by the ascorbic acid- molybdate blue method (Watanabe and Olsen, 1965). Ca++ and Mg++ values were found out from Atomic Absorption Spectrophotometer reading while Na+ and K+ were determined using flame photometer.

Data analysis

The data collected on different parameters were subjected to statistical analysis using PROC ANOVA function of SAS program. After performing ANOVA, the differences between the treatment means were compared by LSD test at 5% level of significance.

Results and discussion

Intial soil properties of the study sites

The soil pH analysisresult showed that the soil was slightly acidic to neutral . According to Tekalign (1991), the experimental areas were low in total Nitrogen and available Phosphorus () (Table 1). This result indicated that both nitrogen and phosphorus nutrients may be a yield-limited factor in the area for Tef production.

Table 1. Soil analysis result before planting

Soil properties	Results
pH (H_2O)	6.58
Total Nitrogen (%)Kjeldhal	0.07
Available P (PPM)	7.43
OC (%)Walkely	1.2
Soil texture	Sandy clay

Table 2. Soil analysis result after harvesting

Treatments (P2O5, N) (kg/ha)	PH H_2O	EC ms/cm	TN (%) Kjeldhal	Available P PPM	OC (%) Walkely
(0,0)	6.97	0.04	0.07	8.05	1.94
(46,0)	6.97	0.03	0.07	12	2.25
(69,0)	6.98	0.03	0.07	17	1.92
(92,0)	6.98	0.03	0.08	21.5	2.35
(0,46)	7	0.03	0.06	7.18	1.92
(46,46)	6.95	0.03	0.07	7.61	2.28
(69,46)	6.97	0.04	0.08	10.5	1.58
(92,46)	6.88	0.04	0.08	16.2	2.52
(0,69)	6.97	0.04	0.08	12.5	2.11
(46,69)	6.94	0.04	0.07	6.32	1.97
(69,69)	6.91	0.03	0.07	10.6	2.3
(92,69)	7.01	0.03	0.07	16	2.47
(0,92)	6.88	0.07	0.08	6	1.94
(46,92)	6.95	0.04	0.07	7.49	2.06
(69,92)	6.89	0.04	0.08	9.81	2.04
(46,92)	6.97	0.03	0.07	13.1	1.14
(69,92)	6.96	0.04	0.07	12.5	1.94

The soil analysis result after harvest indicated that (Table 2) the availability of P increasing with an increasing effect of phosphorus fertilizer application and while there was no significant change in soil pH . This might be because of the soil fertilizer application and the organic matter content was affected by the treatment.

Straw yield

Straw yield was significantly ($P \leq 0.05$) affected by the main effect of N and P application as well as their interaction. Generally, the combined application of N and P resulted in increased straw yields (Table 3). Thus, the application of 46 kg N ha-1 and 20 kg P ha-1 provided the highest (3135.4 kg ha-1) straw yield, with the yield increment of 129% compared to the control. In contrast, the lowest (1396.4 kg ha-1) straw yield was recorded from the control treatment (unfertilized plot). Consistent with this finding, Melesse (2007) reported that wheat cultivars produced higher straw yields in response to the combined application of higher rates of N and P. The increased straw yield might be due to the effect of high N application on the production of effective large numbers of tillers, increased plant height, and panicle length (provid the yield component data here; plant height, panicle length). Temesgen (2012), Haftom et al., (2009) and Mitiku (2008) indicated that the highest straw yield was obtained in response to the application of higher rates of N application, which enhanced the production of significantly longer panicle sizes and taller plants, and as a result greater biomass yield.

Table 3. Straw yield (kg ha^{-1}) of tef as affected by N*P interaction at Gondar Zuria, 2014 – 2015

N (kg ha^{-1})	P (kg ha^{-1})				
	0	20	30	40	Mean
0	1396.4i	2106.4ef	2266.2de	2294.6de	2015.9
46	1716.8fghi	3135.4a	2505.4bcd	2468.1cde	2456.4
69	1597.9hi	2286.4de	2436.5cde	2468.7cde	2197.4
92	1708.6ghi	2600.4bcd	2367.2cde	2089.0efg	2191.3
Mean	1604.9	2532.2	2393.8	2330.1	
N *P , LSD(5%)=201.1			CV (%) =18.75		

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 analysis of variance showed that the grain yield of tef was significantly ($P \leq 0.05$) influenced by the main effect of N and P fertilizer rate as well as by the interaction of N and P rates (Table 4).

The maximum grain yield (1681.1 kg ha-1) was obtained from the application of 46 kg N ha-1and 20 kg P ha-1while the minimum grain yield of tef was recorded from the unfertilized plots. Grain yield significantly increased ($P \leq 0.05$) from 708.6 to 1681.1 kg ha-1with the increase in the levels of N/P from the control (0/0 N/P) to 46 kg N ha-1along with 20 kg P ha-1, but decreased with further increase in applied N and P fertilizer. The magnitude of increase in grain yield due to application of 46 kg N ha-1and 20 kg P ha-1was higher by 137 % than the control. This might be due to the uptake of balanced amounts of nitrogen by plants throughout the major growth stages; enhanced synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone in sufficient amounts. Temesgen (2001) reported that the application of different levels of N significantly affected grain yield of tef on the farmer's field. In this experiment, the reduction in grain yield with higher N and P levels beyond 46 kg N and 20 kg P ha-1might be mainly related to the reductions observed in the yield components and thereby decreased grain yield. Consistent with this suggestion, Reinke et al. (1994) indicated that where the grain yield response is negative, yield reduction is primarily caused by a reduction in the proportion of the number of filled spikelets per panicle. Singh et al. (1995) also reported a decrease in grain yield of rice with an application of high doses of N fertilizer.

Table 4. Grain yield (kg ha^{-1}) of tef as affected by N*P interaction at Gondar Zuria, 2014 – 2015.

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	20	30	40	Mean
0	708.6h	1005.8de	1257.2bc	1179.4cd	1037.8
46	832.6fgh	1681.1a	1142.0cd	1312.0b	1241.9
69	966.1efg	1039.0de	1015.8ef	1105.3cde	1031.6
92	921.3efg	1079.6de	1042.4de	947.5efg	997.7
Mean	857.2	1201.4	1114.4	1136.1	
N *P , LSD(5%)= 99.8			CV (%) =18.53		

Effects of NP fertilizer on economic feasibility of tef production

The higher net return EB 19043.8 Birr ha-1 with a marginal rate of return of 1221% was obtained with the application of 46/20 kg N/P ha-1. Thus, 46 kg N ha-1 combined with 20 kg P ha-1 fertilizer rate application are the most economically feasible for tef growers compared to the other levels.

Table 5. Effects of NP rates on economic feasibility of tef production of at Gondar Zuria.

N (kgha^{-1})	P (kgha^{-1})	AGYT (kgha^{-1})	TVC (Birr)	Revenue (Birr)	Net benefit (Birr)	Value to cost ratio	Marginal rate of return (%)
0	0	637.7	9885	2085	7800	3.7	
0	20	905.2	14031	3022.5	11008.4	3.6	1000
46	0	749.3	11615	3470	8144.8D	2.3	
0	30	1131.5	17538	3960	13577.9	3.4	111
69	0	869.5	13477	4162.5	9314.6D	2.2	
46	20	1513	23451	4407.5	19043.8	4.3	1221
92	0	829.2	12852	4855	7997.1D	1.6	
0	40	1061.5	16453	4897.5	11555.1D	2.4	
69	20	935.1	14494	5100	9394.1D	1.8	
46	30	1027.8	15931	5345	10585.9D	2	
92	20	971.6	15060	5792.5	9967.9D	2	
69	30	914.2	14170	6037.5	8132.9D	1.3	
46	40	1180.8	18302	6282.5	12019.9D	1.9	
92	30	937.8	14536	6730	8505.9D	1.4	
69	40	994.8	15419	6975	8443.9D	1.2	
92	40	852.8	13218	7667.5	6250.1D	0.9	

** Price of Urea =13.85 Birr/kg, TSP=18.75 Birr/kg, DAP=14.35 Birr/kg, Price of tef=15.50 Birr/kg and price of tef for seed=20 Birr/kg, AGYT= Adjusted grain yield of tef and D=Dominated*

Conclusion and recommendation

Application of 20 kg ha-1P and 46 kg ha-1N significantly increased grain yield and biomass yield. The results showed that there was a statistically significant difference among treatments in both biomass and grain yield ($p < 0.05$). The treatment with better grain yield was found economically optimal. Therefore, 20 kg ha-1P and 46 kg ha-1N are recommended to tef production.

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Optimization of P and K fertilizer recommendations for soybean in Ethiopia: the case of JabiTehnan District

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Abstract

*Ethiopian soils are reported to exhibit multi-nutrient deficiency addition to nitrogen (N) and phosphorus (P). Legume crops including soybean can satisfy their N demand through biological N fixation. However, P and potassium (K) nutrients should be supplied in optimal amount. Thus, taking the aforementioned premises in account, a study was conducted in Jabitehnan district of West Gojam Zone of Amhara region in 2015 and 2016 aimed at optimizing P and K fertilizer recommendations for soybean. Four levels of P (*0, 10, 20, 30 P kg ha^{-1}*) and four levels of K (0, 10, 20 and 30 K kg ha^{-1}) were combined in incomplete factorial arrangement with a diagnostic satellite treatment comprising S, Zn, Mg and B. The treatments were laid in RCBD with three replications. Phosphorus, K, S and Mg fertilizers were applied as basal application in the form of triple super phosphate (TSP), KCl, CaSO4 and MgO, respectively. While, the micronutrients Zn and B were applied as foliar application 45 days after planting. The agronomic data analysis results collected in both experimental years indicated that there was no significant yield response both to the application of P and K fertilizers and addition of other macro and micronutrients (S, Mg, Zn and B). However, it was observed that inoculation of soybean with TAL-379 gave a better yield return compared to the control (non-inoculated) treatment with a yield advantage of 39.6%. Therefore, it can be concluded that application of P and K did not significantly affect soybean yield in Jabi-Tehnan district. While, the strain TAL-379 can be used as an alternative rhizobia inoculant to improve yields of soybean in the mentioned district. However, further investigation on the status of P and K availability on the surface soil of the present study area and selection of the right source of P and K fertilizers need to be done to improve the productivity of soybean in the area.*

Keywords: Inoculation, nodule, rhizobia, strain, yield

Introduction

Soybean (*Glycine max* L.) is now produced in larger quantities than any other legume crop in the world and is certainly the most important source of vegetable oil, processed in a wide variety of ways to produce soya milk, bean curd, flour and fermented products. The seed (bean) contains about 18% oil and 38% protein and the extraction residue represents more than 40% of the utilization value of the plant (Asiedu, 1989). Soybean fixes up to 200 kg N ha^{-1} $year^{-1}$ when in symbiotic association with *Bradyrhizobium japonicum* (Zhange et al., 2002) reducing the need for potentially environmental damaging N fertilizer (Asiedu, 1989). Nitrogen and phosphorus have been the two major nutrients that largely limit plant growth in smallholder farms in Africa. However, nutrient mining due to sub optimal fertilizer use in one hand and unbalanced fertilizer uses on other have favored the emergence of multi nutrient deficiency in Ethiopian soils (Abyie *et al.,* 2003; Wassie *et al.,* 2011) that in part may contributed to fertilizer factor productivity decline experienced over recent past.

Different research reports indicate that nutrients like K, S, Ca, Mg and all micro-nutrients except Fe are becoming depleted and deficiency symptoms are being observed on major crops in different areas of the country (Wassie *et al.,* 2011; Asgelil *et al.,* 2009; Abyie *et al.,* 2003). Recently acquired detail soil survey data from EthioSIS (Ethiopian Soil Information System) revealed that in addition to nitrogen and phosphorus, K is reported to be deficient in most of the cultivated land in the country. Legume crops including soybean can satisfy their N demand through biological N fixation if there is effective indigenous rhizobia strain or artificially inoculated with effective rhizobia inoculants. However, P and K nutrients should be supplied optimal in the form of fertilizer to meet the crop demand. This research was therefore conducted with the objective of optimizing P and K fertilizer recommendations for soybean.

Materials and Methods

Study Site Description

This study was conducted in Jabi-Tehnan District of West Gojam Zone of Amhara region for three years from 2014 to 2016. The study district is geographically located at coordinates of $10^o40'41''$ northern latitude and $37^o16'23''$ eastern longitude with altitudinal ranges of 1500-2500 masl. The dominant soil type in the study site is Rhodic Nitisols. The mean annual rainfall and mean minimum and maximum temperatures of the study district are 1250 mm, 14 and 32 ^oC, respectively. The soil physico-chemical characteristics of surface soils of the study district are given below (Table 1).

Table 1. Some physico-chemical characteristics of surface soils of the study district

Soil parameter	Value
Organic carbon (%)	0.55-3.10
Total nitrogen (%)	0.044-0.136
Cation exchange capacity CEC (meq 100 gm^{-1})	14.8-22.6
Base saturation (%)	36-55
Texture	Clay

Experimental Procedure and Treatments

The field was ploughed and prepared with oxen-drawn traditional *Maresha*. The experimental field was then divided in to experimental plots which had an area of 3 m * 3 m. The space between each plot and block was 1 m. An improved variety of soybean *Gishama 335* was planted in a row with 40 cm and 10 cm spacing between rows and plants, respectively. Phosphorus, K, S and Mg fertilizers were all applied as basal application in the form of triple superphosphate (TSP), KCl, $CaSO_4$ and MgO, respectively. While, Zn and B were applied as foliar application 45 days after planting. Soybean seeds were moistened with water soaked with table sugar and inoculated with the strain under a shade immediately before planting. Composite surface (0-20 cm) soil samples were collected at planting for the determination of pH, texture, OC, TN and available P analysis.

Four levels of K (0, 10, 20 and 30 K kg ha^{-1}) and four levels of phosphorus (0, 10, 20 and 30 P kg ha^{-1}) were combined in incomplete factorial arrangement. There was also a diagnostic satellite treatment comprised of N, P, K, S, Mg, Zn and B (23N, 20P, 20K, 5S, 5Mg, 1Zn and 0.5B) in both experimental years. Except the control treatment (non-fertilized), all the rest treatments were inoculated with the rhizobia strain TAL-379. The treatments were laid in RCBD with three replications.

Data Collection and Analysis

The inner rows excluding the boarder were harvested at maturity and yield and yield related parameters were measured. The grain yield measured was adjusted to 14% moisture content. Composite surface soil (0-20 cm) samples were collected before planting for pH, OC, TN, available P and CEC analysis. The agronomic data collected were subjected to analysis of variance (ANOVA) using SAS statistical software version 9.0 (SAS, 2009). Mean separation was made by using Duncan's Multiple Range Test Method (DMRT) at 5% level.

Results and Discussion

Effect of P and K fertilizers on the yield of soybean

The data analysis in the first and second experimental years (Table 2, 3 and 4) indicated that except from the control treatment, there was no statistically significant grain and dry biomass yield differences among the other treatments. The lowest yield was obtained from the control treatment in both experimental years. The result revealed that inoculation of soybean with TAL-379 rhizobia strain gave significantly higher grain and biomass yields than the control treatment. This indicates the need for inoculation of soybean with effective commercial rhizobia strains for improved production. The result is supported by Tesfaye *et.al.* (2010), who reported indigenous rhizobia bacteria in the present study area were not found effective and competitive as compared to a commercial rhizobia strain like TAL 379 in increasing yield.

However, application of P and K were not found to have significant effect on the yield of soybean in the study. In contrast with this result, Isreal 1987 indicated that legume plants that depend on biological N-fixation require more P and other macro and micronutrients than plants receiving fertilizer N since the reduction of atmospheric N by the nitrogenous system is a very energy consuming process and more P and other nutrients are needed for symbiotic N-fixation than for general plant metabolism. But, other completed research on the effect of different rhizobia strains on the yield of soybean in the present study area revealed that inoculation alone without P fertilizer could give comparable yield with the treatments which received P fertilizer (Abebe et al. 2018, unpublished).

Table 2. Effect of P and K fertilizer application on the yield (kg ha^{-1}) of soybean at site 1 and site 2 in 2015

	Site 1		**Site 2**		**Combined**	
Treatment*	**Grain yield (kg ha^{-1})**	**Biomass (kg ha^{-1})**	**Grain yield (kg ha^{-1})**	**Biomass (kg ha^{-1})**	**Grain yield (kg ha^{-1})**	**Biomass (kg ha^{-1})**
1. Control	1954.0b	5072.9b	2509.9	5354.2	2232.0b	5213.5
2. Inoculation alone	2755.1a	6503.5a	2473.0	5222.2	2614.0a	5862.8
3. 10P + Inoc.	2854.3a	6534.7a	2863.4	5958.3	2858.9a	6246.5
4. 20P + Inoc	2804.3a	6465.3a	2735.9	5951.4	2770.1a	6208.3
5. 30P Inoc.	2935.5a	6566.0a	2627.0	5798.6	2781.3a	6182.3
6. 0P20K + Inoc.	2791.5a	6475.7a	2724.2	5725.7	2757.9a	6100.7
7. 10P20K + Inoc	2802.9a	6503.5a	2792.8	5607.6	2797.8a	6055.6
8. 20P20K + Inoc.	2723.2a	6295.1a	2885.6	5868.1	2804.4a	6081.6
9. 30P20K + Inoc.	2735.8a	6232.6a	2848.3	5916.7	2792.0a	6074.7
10. 20P10K + Inoc.	2830.7a	6503.5a	2942.1	6034.7	2886.4a	6269.1
11. 20P20K 5S 1Zn 0.5B + Inoc.	2752.1a	6291.7a	2572.2	5878.5	2662.2a	6085.1
12. 20P30K + Inoc.	2788.4a	6215.3a	2762.9	5885.4	2775.6a	6050.3
Mean	2727.3	6304.9	2728.1	5766.8	2727.7	6035.9
CV (%)	5.6	7.4	10.7	11.3	8.7	9.2

**Mean separation made by DMRT at 5% level. Means without a letter or followed by the same letter within a column are not significantly ($p \geq 0.05$) different.*

Table 3. Effect of P and K fertilizer application on the yield (kg ha^{-1}) of soybean at site 3 and site 4 in 2016

Treatment*	Site 3		Site 4		Comb	
	Grain yield	**Biomass yield**	**Grain yield**	**Biomass yield**	**Grain yield**	**Biomass yield**
1. Control	1236.6b	2810.2b	866.2b	2226.9b	1051.4c	2518.5b
2. Inoculation alone	2035.9a	4282.4a	1904.1a	4069.4a	1970.0ab	4175.9a
3. 10P + Inoc.	2201.7a	4444.4a	1561.9a	3268.5ab	1881.8ab	3856.5a
4. 20P + Inoc.	2379.6a	4745.4a	1976.3a	4194.4a	2178.0a	4469.9a
5. 30P + Inoc.	2271.4a	4833.3a	1483.0a	3314.8ab	1877.2ab	4074.1a
6. 0P20K + Inoc.	1920.8a	4037.0a	1491.7a	3324.1ab	1706.3b	3680.6a
7. 10P20K + Inoc.	2158.9a	4245.4a	1713.2a	3731.5a	1936.0ab	3988.4a
8. 20P20K + Inoc.	2094.3a	4384.3a	2043.0a	4421.3a	2068.7ab	4402.8a
9. 30P20K + Inoc.	2213.4a	4606.5a	1981.3a	3833.3a	2097.3ab	4219.9a
10. 20P10K + Inoc.	2306.1a	4763.9a	1849.5a	3884.3a	2077.8ab	4324.1a
11.20P20K5S1Zn 0.5B + Ino.	2275.5a	4768.5a	1695.5a	3736.1a	1985.5ab	4252.3a
12. 20P30K + Inoc.	2044.5a	4097.2a	1475.9a	3231.5ab	1760.2ab	3664.4a
Mean	2094.9	4334.9	1670.1	3603	1882.5	3968.9
CV (%)	14.5	13.2	19.4	17.7	16.8	15.2

**Mean separation made by DMRT at 5% level. Means without a letter or followed by the same letter within a column are not statistically significantly ($p \geq 0.05$) different.*

Table 4. Effect of P and K fertilizer application on the yield of soybean pooled over years and testing sites

Treatment*	Grain yield (kg ha^{-1})	Biomass (kg ha^{-1})	Plant height (cm)	Pod per plant
1. Control	1641.7b	3866.0b	70.8b	27.9
2. Inoculation alone	2292.0a	5019.4a	78.3a	30.4
3. 10P + Inoc.	2370.3a	5051.5a	81.0a	33.7
4. 20P + Inoc.	2474.0a	5339.1a	81.5a	33.6
5. 30P + Inoc.	2329.2a	5128.2a	77.8a	32.9
6. 0P20K + Inoc.	2232.1a	4890.6a	80.1a	33.3
7. 10P20K + Inoc.	2366.9a	5022.0a	78.9a	33.8
8. 20P20K + Inoc.	2436.5a	5242.2a	79.6a	33.2
9. 30P20K + Inoc.	2444.7a	5147.3a	80.3a	33.5
10. 20P10K + Inoc.	2482.1a	5296.6a	80.9a	32.5
11.20P20K5S1Zn0.5B + Inoc.	2323.8a	5168.7a	83.1a	32.7
12. 20P30K + Inoc.	2267.9a	4857.3a	79.4a	31.8
Mean	2305.1	5002.4	79.3	32.4
CV (%)	12.2	11.7	7.8	15.6

**Mean separation made by DMRT at 5% level. Means without a letter or followed by the same letter within a column are not statistically significantly ($p \geq 0.05$) different.*

Conclusion and Recommendation

The study results indicated that there was no significant difference between inoculation alone and inoculation with application of P and K fertilizers on the yield of Soybean. However, it was found that inoculation of soybean with the strain TAL-379 gave significantly higher yield than the control treatment. Therefore, the rhizobium inoculum TAL-379 can be used as alternative inoculants for soybean. However, further investigation on the status of P and K availability on the surface soil of the present study area and selection of the right source of P and K fertilizers need to be done to improve productivity soybean in the area.

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Evaluation of different doses of lime applied in rows at planting on bread wheat yield in West Amhara, Ethiopia

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Abstract

The need for the application of high amount of lime per hectare due to high soil acidity hindered wider dissemination of liming by the smallholder farmers in Ethiopia in general and in Amhara region inparticular due to high transportation cost. Therefore, a field experiment was conducted to evaluate the effect of row application of different doses of lime at planting on bread wheat yield in the acidic soils of Gozamin and Banja districts, west Amhara. The experiment was comprised of nine treatments including (5, 10, 12.5, 20, 25, 100, 150% of the full dose of lime calculated based 1.5x exchangeable acidity, 2 tons of lime and control (without lime). The treartments were arranged in a randomized complete block design with three replications. The 5-25% of the full dose of lime were applied in rows by drilling at planting. While 100, 150% and 2 tons of lime per hectare were applied by broadcasting at planting. The recommended DAP and half of urea were applied at planting to all treaments uniformily. While half of the recommended urea was applied at tillering. All soil and agronomic data were collected following the standard procedures. All collected data were subjected to GLM using SAS software and significant mean differences were computed by least significant difference at 5% level of significance. The statistical analysis showed that application of 25% and 20% of the full dose of lime with recommended fertilizer gave 1087.9 and 972.2 kg ha^{-1} grain yield difference compared to the recommended fertilizer alone respectively at Gozamen. Similarly, the yield difference between the application of 25% and 20% of the full dose of lime with recommended fertilizer compared to the recommended fertilizer alone was 1317.6 and 827.4 kg ha^{-1} respectively at Banja. The soil pH was increased from 4.48 to 5.32 due to the application of 25% of the full dose of lime and from 4.48 to 5.22 due to the application of 20% of the full dose of lime. The exchangeable acidity was also decreased from 1.59 to 0.04 due to the application of 25% of the full dose of lime and from 1.59 to 0.65 due to the application of 20% of the full dose of lime at both locations. Application of 25% of the full dose of lime will benefit the smallholder farmers by reducing the cost of lime and its transportation. Hence, 25% of the full dose of lime with the recommended fertilizers is recommended for Banja, Gozamen and similar agroecologies to reclaim acidic soils.

Key words: Acidic soil, Banja, Gozamen, liming, micro dozing

Introduction

The success in soil management to maintain soil quality depends on an understanding of how soils respond to agricultural practices over time. However, land degradation is one of the challenges facing Ethiopian agriculture. Among the land degradations soil erosion and soil fertility depletion are current problems hindering crop production in Ethiopia. One of the soil chemical degradation challenging the Ethiopian highland soils is soil acidity which can be caused by leaching and plant uptake of basic cations (Ca and Mg), production of organic acids from organic matter decomposition, and application of acidifying N fertilizers (Ammonium/ammonia N sources including products like urea) (Bierman and Carl, 2005). Acid soils are rampant and occupy about 40.9 percent of the country (Mesfine A., 2007; Schlede, H., 1989). They extend from south-west to north-west with east-west distribution (Mesfine A., 2007). They are concentrated mainly in the western part of the country including the lowlands but are limited by the eastern escarpments of the Rift Valley (Mesfine A., 2007). Out of the 40.9 percent total coverage, 27.7 percent are moderate to weakly acidic (pH of 5.5 - 6.7); 13.2 percent are strong to moderately acidic (pH< 5.5) and nearly one-third have aluminum toxicity problem (Schlede, H., 1989). From the soil analysis result by Bahir Dar, Debremarkos and Gonder soil laboratories indicate that north west Ethiopia especially the highlands of Gojam and Gonder are dominated by soil acidity problems (unpublished data).Soil acidity affects productivity of the soil through its effect on nutrient availability and toxicity by some elements like aluminum and manganese; most plant nutrients become more limited in supply, and a few micronutrients become more soluble and toxic. These problems are particularly acute in humid tropical regions that have been highly weathered (Harter, 2002).As soils become more acid, particularly when pH drops below 4.5, it becomes increasingly difficult to produce food crops. Aluminum and manganese become more soluble (i.e. more of the solid form of these elements will dissolve in water when the soil is acid) and toxic to plants, most plant nutrients become more limited in supply, and a few micronutrients become more soluble and toxic. The ideal soil pH for most crops is slightly acidic to neutral (pH in water 6-7). Favorable soil pH in water for wheat production is 5.5 -7 below this pH ranges especially below 5.1- 5.5 wheat production is severely affected due to toxicity of aluminum and unavailability of macronutrients (Fenton and Helyar, 2007). The critical aluminum level extracted by $CaCl_2$ solution for wheat production is 0.4-0.8 ppm in which aluminum toxicity will affect wheat production (Fenton and Helyar, 2007). High levels of soil acidity (low soil pH) can cause reduction of root growth, nutrient availability, affect crop protecting activity (Douglas, 2001), reduction and total failure of crop yields and deterioration of soil physical properties. In general it affects the biological, chemical and physical properties of soil, which in turn affect the sustainability of crop production in both managed and natural ecosystem.

Reclamation and maintenance of soil acidity is very important soil management practices for crop production. Lime is the major means of ameliorating soil acidity (Anetor and Ezekiel, 2007); because it has very strong acid neutralizing capacity and can effectively remove existing acid. Liming increases the uptake of nutrients, stimulate biological activity and reduce toxicity of heavy metals. Liming raises the soil pH and causes the aluminum and manganese to go from the soil solution back into solid (non-toxic) chemical forms. Regular applications of lime are required on many soils to maintain soil pH in the desired range, because soil acidification is an ongoing process (Bierman and Carl, 2005). Limestone is the most commonly used material to increase soil pH. However, for most efficient crop production on acid soils, application of both lime and fertilizer are required. Since lime make minerals more available to plants, liming without fertilizers application results in soil fertility decline that might lead to serious problem of production. Therefore, applying fertilizer to correct nutrient constraints caused by acidity is necessary. Lime and fertilizer management practices are primary important for proper management of acid soils. Research attempts are made at different parts of the country (Agumas et al, 2016a; 2016b; Agegnehu et al 2017; Abay A. 2011; Chimeda et al. 2012), to look for viable solutions for acidic soil for small holder farmers. According to Agumas et al. (2016a), the amount of lime applied to reclaim acidic soil was 1.5x exchangeable acidity of that specific soil. According to Mosisa (2018), 5-16.5 t ha^{-1} lime rates are recommended depending on the extent of soil acidity. However, smallholder farmers are complaining the current lime rate because of very high cost and beyond their purchasing capacity. Due to this challenge, lime application did not expand as expected and only 6% of the agricultural lands are receiving lime and only 7% of targeted farmers are applying lime nationwide (Gurmessa, 2020). Therefore, this experiment was designed to evaluate cost effective and affordable lime application techniques to improve crop production and reclaim acidic soil in Amhara region in particular and in Ethiopia in general.

Material and methods

Description of the Study Area

The experiment was conducted on farmers' field at Enerata Kebele of Gozamen district and Akayita Kebele of Banja district from 2012-2013 cropping season on permanent plots for two consecutive years. Gozamen district is located in East Gojam administrative Zone of Amhara National Regional State. Enerata Kebele is traversed by a gravel road that passes from Debremarkos town to Sinan district i.e about 7 km from Debremarkos town. Geographically, the kebele is located at 37^0 44' 03'' East longitude and $10^0$24'41" North latitude. Akayita kebele is located on Banja district of Awi administrative zone. The Kebele is around three kilometer from Injibara town to the way to Addis Abeba city. The areas are situated within the Abay basine.

Experimental procedure and treatment set up

From farmers' field, composite soil samples were collected from 0 – 15 cm depth and analyzed for exchangeable acidity and pH prior to planting. For the second and third times soil samples were collected during harvesting. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+1} of each site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The amount of lime required per hectare (full dose) was calculated based on the following formula.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.\,(Mg/m^3) * 1000}{2000} * 1.5 \qquad \text{-Eq-1}$$

The full dose of lime was applied at once in the first year by broadcasting during planting. The recommended N and P were applied uniformly to all treatments. For the broadcast application, lime was broadcasted uniformly by hand and incorporated into the soil during planting while for the row application lime was applied at planting in rows in each year. Urea and DAP was used as the source of N and P, respectively. Application of urea was applied in two splits, while the entire rate of phosphorus was applied at planting. Improved wheat variety (TAY) was used as a test crop. During the second year those plots which received full dose of lime did not get lime while those plots which received lime on row application also received lime again for the second year according to the treatment set up. For the second year land preparation was done using man power to restrict mixup of different plots. The experiment was laidout in RCBD with three replications. Weeding and frequent follow up was conducted as per visual observations and there was no crop rotation that was wheat after wheat for the second year. Gross and net plot size were 1.6mX3m = 4.8m^2 and 1.2mX3m= 3.6m^2 respectively.

treatments:

1. 25% of full dose of lime calculated based on equation-1 applied in row
2. 20% of full dose of lime calculated based on equation-1 applied in row
3. 12.5% of full dose of lime calculated based on equation-1 applied in row
4. 10% of full dose of lime calculated based on equation-1 applied in row
5. 5% of full dose of lime calculated based on equation-1 applied in row
6. 100% of full dose of lime calculated based on equation-1applied in broadcasting
7. 150% of full dose of lime calculated based on equation-1applied in broadcasting
8. 2 tons of lime per hectare (recommended by regional soil laboratory)
9. Control no lime with recommended urea and DAP.

Table 1. Initial soil physico-chemical properties and lime calculated for each site

Woreda	pH	BD	Ex. Al	Ex. H	Ex. acidity	OM	Texture	Lime kg ha^{-1}	Lime Kg ha^{-1} (1.5x)
Gozamen	5.28	1.67	0.90	1.09	2.0	3.36	Heavy clay	2508.7	3763
Banja	4.47	1.15	2.29	1.28	3.22	5.21	Silt clay	2783.6	4175.3

BD; bulk density, Ex.Al; exchangeable aluminium, Ex.H; exchangeable hydrogen, Ex.acidity; exchangeable acidity

Results and discussion

Response of bread wheat yield to different lime amount and application methods

The statistical analysis at Gozamen indicated that there was significant variation among treatments in grain yield at $p<0.05$. The maximum grain yield (3125 kg ha^{-1}) was obtained from 2 t lime ha^{-1} combined over years (Table 2) and it was at par with the yield obtained from 25% (2847 kg ha^{-1}), 150% (2800 kg ha^{-1}), 20% (2731 kg ha^{-1}), and 100% (2581 kg ha^{-1}) of the full dose of lime. However, there was no significant difference among different doses of lime except with 5%, 10% of the full dose of lime and the control (Table 2). There was 61.9% yield advantage of applying 25% of full dose of lime with the recommended fertilizer rate over the recommended fertilizer rate alone at Gozamin.

Similarly, combined over years, the statistical analysis at Banja showed significant difference in grain yield among the treatments (Table 3). The maximum grain yield (3455 kg ha^{-1}) was obtained from the application of 25% of the full dose of lime. But, there was no statistically significant difference among treatments except with the lower lime doses (5%, 10% and the control) (Table 3).

The result indicated that 25% of the full dose of lime calculated based on 1.5x exchangeable acidity could be enough to neutralize the effect of soil acidity in the root zone for Gozamen and Banja districts and similar agroecologies. Hence, the result has great implication for the smallholder farmers in the region for it reduces the lime cost per hectare per year to $1/4^{th}$ with no yield reduction. In addition, application of 25% of the full dose of lime in row at planting each year (for consecutive four years) didn't reduce wheat yield. This is because, every year the lime neutralizes the root zone as contrary to the application of full dose of lime. Even though the maximum yield was recorded in the combined analysis using the blanket recommendation at Gozamen, the yield of the second year indicates that one fourth of lime was high (Table 2). Demonstration studies by Demil et al., 2020 showed an advantage of mean grain yield 4525 kg ha^{-1} and marginal rate of return 252% using 25% of full recommended lime as compared to without using lime. Therefore, applying 25% of the full dose of lime applied in rows during planting calculated based on exchangeable acidity might enhance the promotion of liming in Amhara Region in particular and in Ethiopia in general.

Table 2. Influence of lime amount and application methods on yield of bread wheat at Gozamen (kg ha^{-1})

Lime amount and application method	2012	2013	Combined
25% of the full dose of lime calculated based on equation-1 applied in row	3611.1ab	2083.3a	2847.2ab
20% of the full dose of lime calculated based on equation-1 applied in row	3472.2ab	1990.7a	2731.5abc
12.5% of the full dose of lime calculated based on equation-1 applied in row	3148.2ab	1805.6ab	2476.9bc
10% of the full dose of lime calculated based on equation-1 applied in row	3009.3b	1435.2b	2222.2bcd
5% of the full dose of lime calculated based on equation-1 applied in row	2847.2b	1435.2b	2141.2dc
100% of the full dose of lime calculated based on equation-1 applied by broadcasting	3402.8ab	1759.3ab	2581.0abc
150% of the full dose of lime calculated based on equation-1 applied by broadcasting	3842.6ab	1759.3ab	2800.9ab
2 ton of lime per hectare recommended by regional soil laboratory	4305.6a	1944.4a	3125.0a
Control (no lime. With recommended urea and DAP alone)	2685.2b	833.3c	1759.3d
CV (%)	21.81	13.30	21.32
LSD (0.05)	1271.9	385	630.59

Table 3. Influence of lime amount and application methods on yield of bread wheat at Banja woreda (kgha^{-1})

Lime amount and application method	2012	2013	combined
25% of the full dose of lime calculated based on equation-1 applied in row	4418.5a	2490.7a	3454.6a
20% of the full dose of lime calculated based on equation-1 applied in row	4112.0ab	1816.7ab	2964.4ab
12.5% of the full dose of lime calculated based on equation-1 applied in row	3718.5ab	1737.5ab	2728.0abc
10% of the full dose of lime calculated based on equation-1 applied in row	3452.8ab	1342.6b	2397.7bc
5% of the full dose of lime calculated based on equation-1 applied in row	3249.0ab	1241.7b	2245.4bc
100% of lime calculated based on equation-1applied by broadcasting	4525.9a	1973.1a	3249.5a
150% of lime calculated based on equation-1 applied by broadcasting	4574.1a	1964.8a	3269.4a
2 ton of lime per hectare recommended by regional soil laboratory	4376.8ab	2292.6a	3334.7a
Control (nolime. With recommended urea and DAP alone)	3060.2b	1213.9b	2137.0c
CV (%)	19.45	25.52	21.85
LSD (0.05)	1327.3	789	734.53

Influence of lime dose and application methods on soil pH and exchangeable acidity at Banja and Gozamen districts, Ethiopia

The soil analysis result showed that the two locations are different in exchangeable acidity, organic matter content and texture (Table 1) which were resulted different doses of lime. According to Hazelton and Murph (2007), suitable pH for wheat production is 5.5 to 7; below which wheat production is severely affected by aluminum toxicity and unavailability of macronutrients (Fenton and Helyar, 2007). From the soil data, the pH of the testing sites were below 5.5 which means wheat production has been greatly affected by soil acidity. Similarly, the critical aluminum level extracted by $CaCl_2$ solution for wheat is 0.4 to 0.8 ppm, above this range aluminum toxicity will affect wheat production (Fenton and Helyar, 2007). The soil analysis result showed that aluminum content of the soil was greater than the critical level at Gozamen (2.0 ppm) and Banja (3.22 ppm) (Table 1).

In the first year, an increased pH was recorded by applying different lime amount in row application at Gozamen (Table 4). The maximum pH increment and minimum exchangeable acidity were recorded from 1.5x exchangeable acidity in broadcast application in the same location. Exchangeable acidity was decreased from 1.41 to 0.78 and similarly exchangeable aluminum was reduced from 0.94 to 0.47 in the first year by applying 25% of the amount of lime in row at the same research site. In the second year, the pH increased from 4.48 to 5.32 while the amount of exchangeable acidity decreased from 1.59 to 0.04 by applying 25% of the amount of lime calculated based on the above equation in row at Gozamen. Maximum increment of pH and minimum exchangeable acidity were recorded by applying maximum dose of lime. However, there was no significant difference in wheat grain yield between full dose, 1.5x full dose, 2 tone kg ha^{-1} limes, 25% and 20% of the full dose of lime.

Table 4. Effect of lime amount and application methods on pH and Exchangeable acidity of soil at Gozamen districts

Lime amount and application method	After a year of lime application (2013)				After two years of lime application (2014)			
	pH	Ex. acidity	Ex. Al	EX. H	pH	Ex. Acidity	Ex. Al	EX. H
25% of full dose of lime calculated based on equation-1 applied in row	4.87	0.78	0.47	0.31	5.32	0.04	0	0.04
20% of full dose of lime calculated based on equation-1 applied in row	4.97	1.2	0.67	0.53	5.22	0.96	0.13	0.84
12.5% of full dose of lime calculated based on equation-1 applied in row	4.97	1.25	0.79	0.46	5.33	0.03	0	0.03
10 of full dose of lime calculated based on equation-1 applied in row	5.05	1.37	0.83	0.54	5.36	0.28	0.14	0.14
5% of full dose of lime calculated based on equation-1 applied in row	5.03	1.27	0.75	0.52	5.36	0.84	0.26	0.58
100% of full dose of lime calculated based on equation-1applied by broadcasting	5.08	0.38	0.32	0.06	5.35	0.04	0	0.04
150% of full dose of lime calculated based on equation-1 applied by broadcasting	5.31	0.23	0.09	0.14	5.47	0.09	0	0.09
2 ton per hectare recommended by regional soil laboratory	5.13	0.98	0.49	0.49	5.37	0.31	0	0.31
Control no (lime with recommended urea and DAP)	4.35	1.41	0.94	0.47	4.48	1.59	1.07	0.52

Table 5. Effect of lime amount and application methods on pH and Exchangeable acidity of soil at BanjaWoredas

Lime amount and application method	After a year of lime application (2013)				After two years of lime application (2014)			
	pH	Ex. Acidity	Ex. Al	EX. H	pH	Ex. Acidity	Ex. Al	EX. H
25% of full dose of lime calculated based on equation 1 applied in row	4.90	2.32	1.24	0.84	5.77	1.00	0.89	0.11
20% of full dose of lime calculated based on equation 1 applied in row	4.85	2.48	2.08	0.40	5.82	2.18	1.64	0.54
12.5% of full dose of lime calculated based on equation 1 applied in row	4.73	2.84	2.09	0.76	5.68	2.34	2.00	0.35
10% of full dose of lime calculated based on equation 1 applied in row	4.71	3.16	2.31	0.85	5.85	2.42	1.90	0.52
5% of full dose of lime calculated based on equation 1 applied in row	4.74	2.84	2.20	0.74	5.53	2.34	1.77	0.57
100% of full dose of lime calculated based on equation-1applied by broadcasting	4.86	1.78	1.33	0.70	5.72	1.26	0.86	0.40
150% of full dose of lime calculated based on equation-1 applied by broadcasting	5.01	1.37	0.52	0.38	5.76	2.21	1.63	0.58
2 ton per hectare recommended by regional soil laboratory	4.89	1.73	1.10	0.64	5.83	2.01	1.34	0.68
Control no (lime with recommended urea and DAP)	4.68	3.22	2.29	1.28	5.53	2.53	1.92	0.61

At Banja, even though soil pH was below 5.5 after lime application in the first year it increased from 4.68 to 4.90 and 4.85 and exchangeable acidity was reduced from 3.22 to 2.32 and 2.48 when 25% and 20% of full dose of lime applied in rows respectively. Exchangeable aluminum concentration was reduced from 2.29 to 1.24 and 2.08 in the first year and from 1.92-to 0.89 and 1.64 in the second year by applying 25% and 20% of the full dose of lime. However, higher soil pH was recorded and increased from 5.53 to 5.77 to 5.82 at Banja in the second year. This might be due to sampling season variation in which the first year was during planting and in the second year at harvest which results great variation in the pH at both sites. Soil samples collected during rainy season has lower pH compared to those samples collected during dry season. Because during rainy season, there is leaching of cations and leads to reduced pH. From the result of both sites it was noticed that, there was no significant yield variation between full dose of lime and 20-25% of the full dose of lime while exchangeable acidity and aluminum were significantly reduced. Hence, instead of applying full dose of lime at once, application of 1/4 of the full dose of lime calculated based on 1.5x exchangeable acidity might be enough to increase wheat yield by reducing root zone acidity. This might be due to the neutralizing effect of lime in the root zone even though further investigation might be necessary in the future. In general, application of lime using micro dozing technique increased soil pH and reduces exchangeable aluminum and hydrogen which leads to increased wheat grain yield (Table 2-5). The amount of lime required in Banja was higher compared to Gozamen due to variation in soil buffering capacity of the two sites (Table 1). Generally, the buffering capacity of soil which is governed by texture, cation exchange capacity and organic matter determines the amount of lime required. The textural class of soils at Banja was silt clay and had very high aluminum concentration and the organic matter content was higher than at Gozamen which might also attributed to more lime requirement. This result was confirmed by Demil et al., 2020 who reported that applying only 25% of the full recommended rate of lime provided an advantage of mean grain yield of 4525 kg ha^{-1} and marginal rate of return of 252% compared to without lime.

Conclusion and recommendation

From the agronomic and soil data analysis results, it is possible to conclude that the contribution of lime application in micro dozing (in row) for acid soil rehabilitation was beneficial and an innovative approach. The result also confirmed that lime has great influence on grain yield as well as improving soil properties. Row application of 25% of the full dose of lime at planting also reduces the complaints of farmers by saving 3/4th of cost to be incurred by the smallholder famrers per hectare per year. However, lime application is not well practiced yet by the smallholder farmers in the region as well as in the country to curbe the effect of expanding soil acidification due to its bulkiness and difficulty for transportation. Hence, for bread wheat production application 25% of the full dose of lime calculated based on 1.5x exchangeable acidity in rows at planting is recommended for Gozamen and Banja districts and similar agroecologies. This finding should be further refined for different soil types, crops types and agro-ecologies in the future integrated with other soil acidity amelioration technologies.

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II Agricultural Water Management

Effect of Irrigation Regimes on Tuber Yield and Water Use Efficiency of Potato in Efratanagidiem District, North Shewa

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Abstract

The right water management practice is important to enhance water productivity without having a yield penalty and it is a viable way to improve sustainable crop production and productivity in water-scarce areas. Effective water management is not a simple short-term exercise; rather it needs great effort continuously. Many irrigation projects have the potential to degrade the land, the soil, and pollute the water source if they are mismanaged. The study was conducted at lowlands of North showa, Efratanagidiem woreda at FTC site, to determine the effects of different irrigation depths and intervals on tuber yield and water use efficiency of potato. The analysis was based on agronomic parameters collected during two years of fieldwork. The statistical analysis was performed using SAS statistical software. Potato (Solanum tuberosum L) was grown with treatments consisted of 15 irrigation regimes. The treatments have 5 irrigation depths (50%,75%,100%, 125%, 150% of CROPWAT generated depth) and 9 days, 12 days, and 15 days interval. The irrigation treatments were laid out in a randomized complete block design with 3 replications. The best combination for the Yimllow site for better production with limited water resources is the application of 22.00 mm (75% of model generated depth) with 9 day gives 29.180 t/ha total yield and 89 kg/mm^{-1}ha^{-1}.

Keywords: Crop water requirement, irrigation water requirement, scheduling, water productivity potato

Introduction

Ethiopia has the greatest potential for potato production as 70% of its arable land mainly in highland areas with altitudes greater than 1,500 m above sea level is considered suitable for potato (Yilma S ,1991). In a natural environment, plants are subjected to many stresses that have a great impact on the growth, development and finally yield of crops. These factors could be drought and nutrients -sub-optimal use, excess water and water stress are major abiotic factors that limit crop production (Reddy AR, *et al,* 2004).

Studies show that water is the most important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing season for efficient use of water (Panigrahi B, *et al,* 2001). The most important requirmentto avoid water shortage and over-irrigation, which can also affect yields of potato through reducing soil aeration, water and nutrient uptake and increasing essential nutrients leaching is effective water management (Shirie JM, *et al* 2006).

Potato (Solanum tuberosum L.) is one of the most well-known vegetable crops which is grown under temperate conditions and highly produced in Ethiopia. There is a blind faith to which potato production held mostly on high land areas rather than low lands. But potato is also produced in low land areas up to 1500 m.a.s as suggested by many researchers. The main requirment that potato production depends on is soil moisture conditions. On the low lands, to gain satisfactorily tuber yield the application of optimum amount of irrigation water to the right time is just a mandatory.

Sustainable use of resources that make up the agricultural production system is the means to support environmental conservation and assure food security. One of the main problems that has been facing nowadays is the low implementation of advanced technologies for irrigation forecasts in a real time. So, there are still using traditional methods of irrigation practices by which water consumption is higher and the scarce resource is lost. Most vegetables grow in the dry season and are sensitive to water deficit in the soil, thus requiring frequent irrigation and light to ensure soil moisture above 75% of the available taking into account those edaphoclimatic conditions in the period that rainfall is insufficient to satisfy the water demand (Cristina etal., 2011).

Irrigation management is performed according to crop water needs that will allow crops to reach their productive potential. For a rational forecast of water management, knowing the crop evapotranspiration during the development phases is very important. Setting the right amount of water and scheduling in each development phase is the most important factor to improve the quality and quantity of potato yield. This is the most important point to efficient utilization of resources and to improve the food security of a growing population in developing countries.

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably leads to an increase in food demand. To maintain self-sufficiency in food supply, one viable option is to raise the unit yield. Irrigation is the most common means of ensuring sustainable agriculture and copying with periods of inadequate rainfall (Dessalegn, 1999)

Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. The interval between two irrigations should be possible to save irrigation water without affecting adversely the growth and yield (Dilip, 2000). Irrigation is also an essential daily management practice for a farm manager growing irrigated crops. Apply the right amount of irrigation water at the right time is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss due to water stress, maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources and minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater (Jerry, 2002).

Effective irrigation is possible with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Therefore, this research activity was conducted to determine the appropriate frequency and amount of irrigation water for improving the productivity and water use efficiency of potato .

Materials and method

Description of the study area

The experiment was conducted in the Amhara region North Shewa Efratanagidiem woreda at Yimlloirrigation site. The site is located 290 km north of Addis Ababa, and 154 km from Debrebirhan 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; rainy and dry season. The rainy season lasts from the beginning of June to the end of September with 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. The average relative humidity during the dried months is 64%.

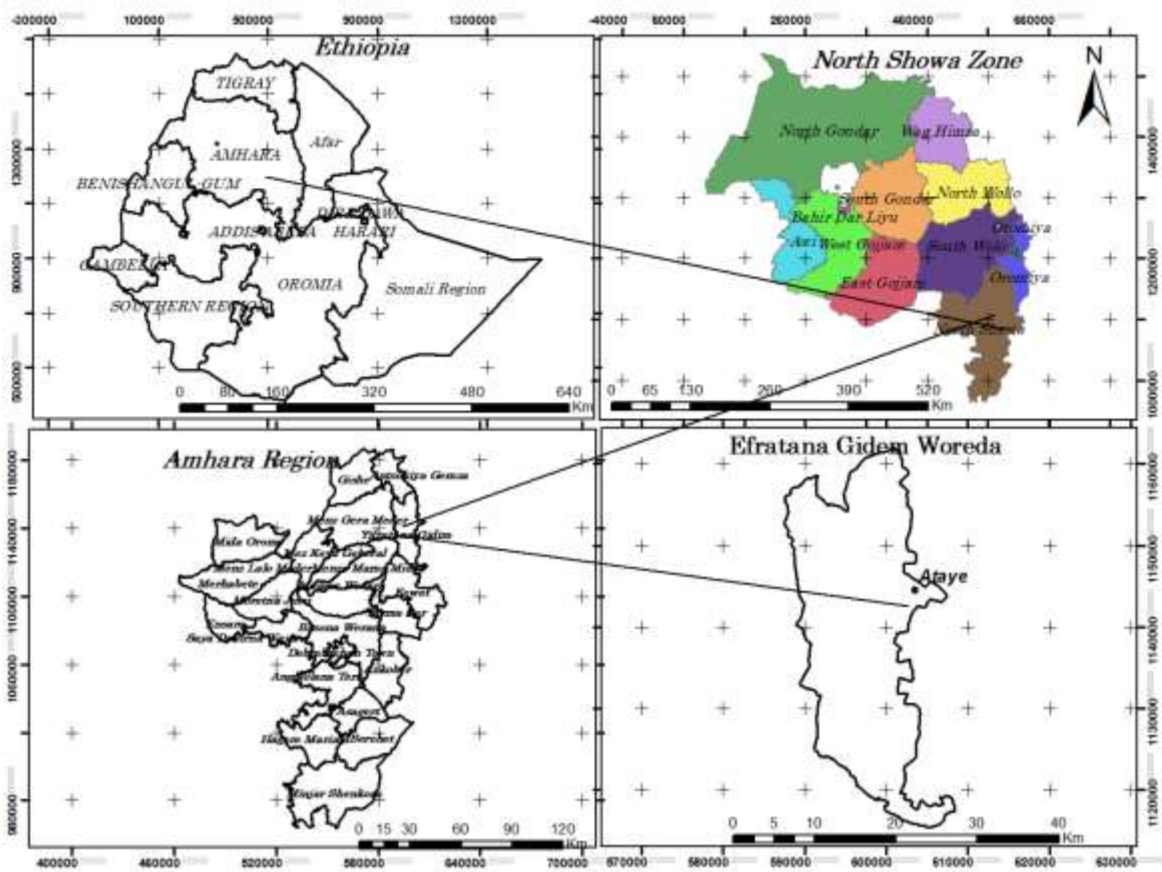

Figure 6. location map of the study area

Soil sampling and analysis

The composite soil samples were taken at depth of 20 cm using a soil sampling auger from the experimental site randomly and ensuring that each treatment was represented within each unit. The samples were taken just before planting to determine the physic-chemical properties. The soil properties of the site (Texture, Bulk density, pH, EC, permanent filleting point, field capacity of the soils) have been determined using the standard soil lab procedures.

Table 1. Physicochemical property of soil at the study area

Site	pH	EC (ds/mm)	Soil texture Clay (%)	Silt (%)	Sand (%)	Textural class	Bulk density g/cm3	PW %	FC %	OC %	OM %	Saturation %
Yimllo	7.8	0.23	38	34	28	Clay loam	1.37	23.4	37.2	1.76	3.04	48.3

The Kc values of potato were fixed at 0.5, 0.77, 1.10, 1.15 and 0.75, for initial, development-1, development-2, middle, and late-stage respectively according to FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The allowable water depletion of potato was assumed to be 0.35 of total available water (P = 0.35) during the whole growing cycle as suggested in FAO 56 (Allen et al., 1998).

ETo was multiplied by an empirical potato Kc (Allen et al., 1998) to calculate ETc values for the experiment. ETc was calculated for each crop development stage and then set to treatment data arrangements.

The experimental area was well prepared in November, just plowed two times with local Marsha. Naturally loose soil, which offers tuber expansion, reach in organic matter, having good drainage aeration are suitable. All experimental plots were irrigated with a uniform amount of water a few days before planting to make the soil soft, well-aerated, well-drained, and workable. The experiment was conducted in a randomized complete block design with 15 treatments and 3 replications, block as a replication. The total plot size was 8.4m^2 for data collection and yield assessment. Treatments corresponds to different irrigation depths applied based on the full CROPWAT generated depth (100% of ETC) with generated fixed interval (12 day). Therefore, the treatment arranges by cascade the generated depth and interval up and down with 25% and 3 days respectively. So the treatment, 50%, 75%, 100%, 125%, 150% of ETC with 12-day interval; before 3 day of CROPWAT generated depth 50%,75%,100%, 125%, 150% of ETC with 9-day interval and after 3 day of CROPWAT generated depth 50%, 75%,100%, 125%, 150% of ETC with 15-day interval. The required fertilizer rates were applied as per the agronomic recommendation 168 Kg/ha urea and 182 Kg/ha NPS.

Data collection

The data collected were the number of stand count, plant height, and tuber yield and number of tubers, then computed water use efficiency from the collected data. After physiological maturity, the sample was taken from the plot area 5.4m^2. Great care was taken to avoid injury and bruising during harvesting, leaving tubers in soil to make the skin too thick for having good data and convert to hectare base.

The basic expression of agricultural water productivity is a measure of output of a given system to the water it consumes, for the whole system or parts of it, defined in time and space. So, the weighed samples of tubers from each plot were converted into kilogram per hectare and divide by their respective total amount of irrigation water supplied throughout the cropping season to determine the water use efficiency (Cook et al., 2006).

$$WUE = \frac{Y}{NIR}$$

Where, WUE is water use efficiency in kg /m^3, Y is crop tuber yield in kg/ ha and NIR is total net irrigation requirement m^3.

Statistical analysis

All yield, yield components and water use efficiency data were subjected to analysis of variance using PROC GLM ANOVA of SAS (statistical analysis software) version 9.0 (SAS Institute, 2004). The significant differences among treatment means for each treatment were compared using Dunken's multiple range test at $p<0.05$ significant difference and at $p<0.01$ highly significant difference.

Results and discussion

The crop consumptive use of potato was determined by using CROPWAT version 8 model with an input of climatic parameters like; minimum and maximum temperature, Relative humidity, wind speed, sunshine hours, solar radiation, crop coefficient, length of growing period and soil parameters.

Climatic parameters

Climate is one of the most important factors determining the crop water requirements needed for unrestricted optimum growth and increased crop yields. The principal climatic parameters such as precipitation, solar radiation, temperature, wind and humidity influence the crop water requirement (CWR). Evaporation and transpiration occur at a potential rate when the supply of water is unlimited and the evapotranspiration of the crop (ETc) becomes higher. Solar radiation supplies the energy for the ETc processes. With increasing day length or solar radiation, evapotranspiration also increased. The rate of ETc in any locality is probably influenced more by temperature (T^0) than any other factor.

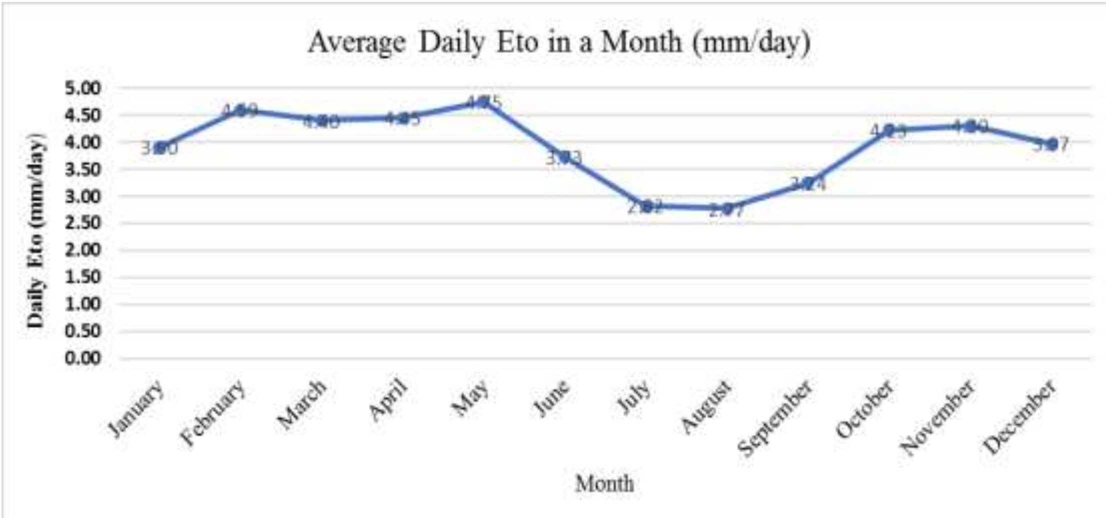

Figure 2. Trend of ETo in the growing season at Efratanagidiem woreda.

The maximum evaporative demand of the atmosphere was found in May (4.75mm/day) and the minimum ET_o was found in August (2.77 mm/day) according to the crop WAT model version 8.0 , based on Penman-Monteith formula.

The net irrigation requirement and scheduling were determined with using the soil data, crop period, crop coefficients and climatic parameters as input data. The full generated depth and irrigation interval were 29.34 mm and 12 days respectively. Then the rest treatment was arranged based on adding and deducting 25% from the full generated depth 29.34 mm with 12 days intervals. Potato was irrigated with 14.67 mm, 22.00 mm, 29.33 mm, 36.67 mm and 44.00 mm with 9, 12 and 15 days. These combinations were usedas treatment and were able to maintain root zone soil water content above allowable depletion threshold and returning soil water content to field capacity. As can be seen in Table 3, Analysis of Variance (ANOVA) was conducted by combining two years of irrigation seasons data using SAS statistical software. Analysis of variance shows a significant difference between treatments for most analyzed parameters except plant height and tuber diameter. Plant height and tuber diameter were statistically non-significant. The maximum plant height (78 cm) was obtained by applying 36.67 mm depth of water for every 12 days. The highest tuber diameter (57 mm) was recorded at 44.00 mm irrigation depth with a 9-days interval. Whereas the minimum tuber diameter (51 mm) occurred by applying 14.67 mm with a 15 days interval. Marketable and total yield of potato tuber as well as water use efficiency (WUE) showed highly significant difference at (P>0.05).

Table 2. Effect of irrigation regime on potato yield and yield parameters and water use efficiency at Efratanagidiem

Treatment	PH (cm)	TD (mm)	TY (ton/ha)	MY (ton/ha)	WUE (kg/mm/ha)
14.67 mm with 12 day	71	55	22.259^{c}	19.351c	97^{b}
22.00 mm with 12 day	71	53	26.725^{bc}	24.067^{bc}	77^{bc}
29.34 mm with 12 day	71	53	27.698^{abc}	24.988^{abc}	59^{cde}
36.67 mm with 12 day	78	55	29.155^{ab}	26.377^{ab}	49de
44.00 mm with 12 day	77	55	31.146^{ab}	28.372^{ab}	44de
14.67 mm with 9 day	76	53	27.859^{abc}	25.538^{ab}	126^{a}
22.00 mm with 9 day	75	55	29.180^{ab}	26.175^{ab}	89^{b}
29.34 mm with 9 day	76	54	27.910^{abc}	25.977^{ab}	66^{cd}
36.67 mm with 9 day	70	54	30.291^{ab}	27.808^{ab}	57^{cde}
44.00 mm with 9 day	77	57	33.653^{a}	30.993^{a}	52de
14.67 mm with 15 day	75	51	21.529^{c}	19.069^{c}	93^{b}
22.00 mm with 15 day	76	52	27.570^{abc}	24.790^{bc}	78^{bc}
29.34 mm with 15 day	69	53	26.771^{bc}	24.586^{bc}	58^{cde}
36.67 mm with 15 day	76	54	29.806^{ab}	27.559^{ab}	51de
44.00 mm with 15 day	72	53	26.429^{bc}	23.868^{bc}	37^{e}
CV (%)	14.9	9.4	17.7	17.9	24.2
LSD (0.05)	Ns	Ns	5435.4	5201.7	2.7

*NB. Ns = mean non-significant, and * means statically significant P≤ 0.05 and ** means statically highly significant, P ≤ 0.001, respectively. PH = plant height, TD = tuber diameter, TY = total yield, MY = marketable yield, WUE = water use efficiency.*

In this experiment, potato tuber yield ranged from 21.5 t/ha to 33.65 t/ha and the water use efficiency ranged from 37 kg/mm / ha to 126 kg/ mm / ha . As reported by (Kassu *et al*, 2017), potato tuber yield in the experiment varied from 16.78 to 33.6 t ha^{-1}, while water use efficiency (WUE) varied from 68.46 to 198.73 kg/ mm/ha . The tuber yield obtained in this experiment agrees with the tuber yield obtained in other studies. For instance, the application of 20 mm irrigation depth with every 6 days brought 33.6 t/ha potato tuber yield (Kassu *et al*, 2017).

The application of 53 mm of irrigation depth with an irrigation interval of 9 days (150% of model depth) resulted in the highest potato tuber yield of 33.65 t/ha. This treatment has had 6 t/ha more tuber yield advantages above the tuber yield obtained with the application of 100% ETC of 27.7t/ha. The best yield obtained 33.65 t/ha and 52 kg/mm/ha water use efficiency with the application 572 mm irrigation depth throughout the growing season. This finding is similar to Tolga *et al*, (2006) who foundin Turkey that a maximum of 45 t/ha with the application of 597mm irrigation depth throughout the growing season. Potato production in developed countries is estimated as 40 t/ha; whereas in developing countries ranged from 5-25 t/ha (FAO, 2002).

The best combination for the Yimllow site for better production with limited water resources is the application of 22.00 mm (75% of model generated depth) with 9 day gives 29.18 t/ha total yield and 89 kg/mm/ha. However, the lowest potato tuber yield was obtained with the application of 32 mm irrigation depth (75% of model generated depth) with every 15 days irrigation interval, which had a 12 ton/ha tuber yield penalty compared with the CROPWAT treatment yield. The application of 25mm depth (50% of model generated depth) with 12 days intervals also resulted in the lowest tuber yield (22.26t/ha).

Water use efficiency

The WUE obtained in this experiment corresponds to the WUE obtained with other studies. For instance, the WUE gained with the application of 15 mm with every 7 days was 12 kg/m^3/ha as reported by Kassu et al, 2017. Potato productivity increases, as the applied water amount increases in the low lands and increases with reduction in water application in high lands area.

The application of 18 mm depth (50% of model) of irrigation water with every 9 days gave the highest WUE (126 kg / mm/ ha), which had an advantage of about 77 kg/mm/ ha) water use efficiency above the CROPWAT treatments. But it resulted in a 1.3 ton/ha yield penalty when compared with the CROPWAT treatment yield. The lowest water use efficiency (37 kg/ mm/ha) is obtained with the application of 97mm irrigation water depth with 15 days irrigation interval. Therefore, the lower the amount of water applied to the field, the higher the water use efficiency (yuan,2003). As the water amount applied increases, water productivity and tuber yield increases and then decreases at excess water application.

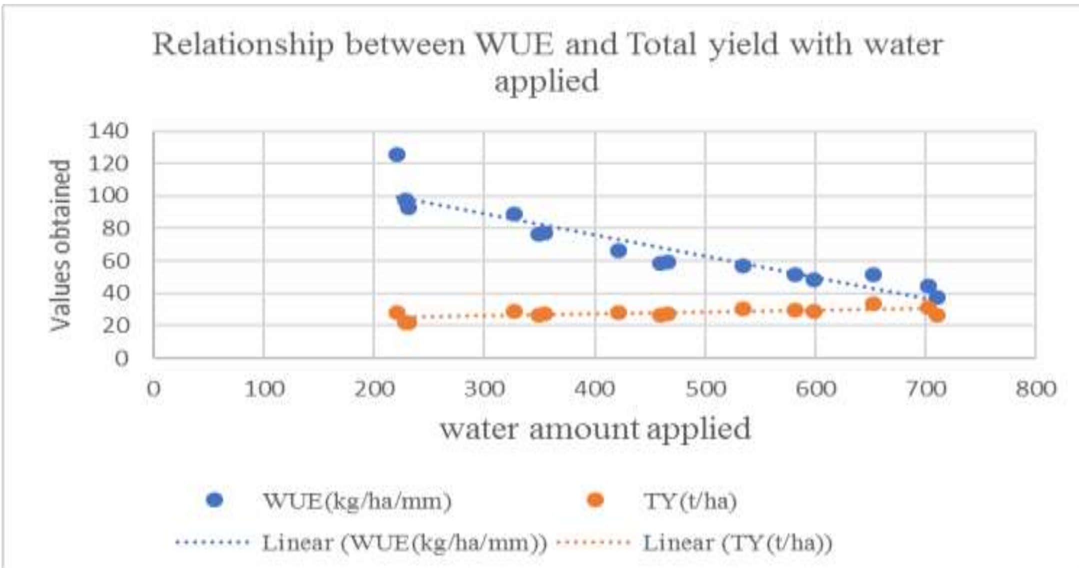

Figure 3. Relationship of water use efficiency and yield to the amount of water applied.

So where does the optimal yield attained if the yield increases with increased water application? to obtain optimum yield of potato tuber at Ataye Yimllow and other similar agro-ecological zone and soil type, it is better to apply 75% of the CROPWAT depth of water with 9 days irrigation interval. That is as irrigation water amounts increase, potato tuber yields also increase to some extent and tend to decrease when the irrigation water amounts increase. As Reported by Yuan (2003) the total tuber yields of potatoes increased with an increasing amount of irrigation water.

The correlation between yield and yield components is presented in Table3; plant height was non-significantly correlated to all parameters. Tuber diameter was positively and strongly correlated with total and marketable yield but negatively and non-significantly correlated with WUE. The result also indicated that WUE was negatively correlated with all other parameters.

Table 3. The correlation between yield and yield components

	PH	TD	TY	MY	WUE
PH	1.00				
TD	0.35^{ns}	1.00			
TY	0.41^{ns}	0.65^{*}	1.00		
MY	0.41^{ns}	0.62^{*}	1.00**	1.00	
WUE	-0.02^{ns}	-0.24^{ns}	-0.49^{ns}	-0.49^{ns}	1.00

*NB Ns=non-significant, *-significant at p≤0.05, **-highly significant at p≤0.01 PH=plant height, TD=tuber diameter, TY= tuber yield, WUE=water use efficiency.*

Conclusion and Recommendations

In the present study, the CROPWAT model was used to determined water requirement and scheduling using the soil data, crop growth? period, crop coefficients and climatic parameters as input data for potatoes at Yimllow irrigation site. CROPWAT model gave different potato tuber yields and water use efficiencies among the treatments. Application of 75% of CROPWAT depth (22.00 mm) with an interval of 9 days was the best combination for the Yimllow site with limited water resource that provided better tuber yield production (29.18 t/ha total yield)and WUE (89 kg/mm/ha). Therefore, The application of 22 mm depth of water with 9 days irrigation interval results in 29.18 t/ha for Yimllow irrigation site and other similar agro-ecological condition and soil types. This is because it improves good irrigation water management with optimum potato tuber yields. Furthermore, it is easy to demonstrate and adopt the improved agricultural water management practices, which save water and increase crop productivity. This result is particularly important as it allows farmers to increase their income through better tuber yield, lower production costs and the water saved used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources.

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Determination of Irrigation water Requirements and frequency for Carrot (*Daucus carota* L.) at Chacha Irrigation Scheme, North shoa zone, Amhara Region, Ethiopia.

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Abstract

The development of efficient irrigation management practice is a key to sustain the optimum crop production system in Ethiopia. The field experiment was conducted to determine the best irrigation regimes and validate CROPWAT 8.0 under field trial at Chacha small scale irrigation scheme. To obtain high quality and quantity of carrot root yield, the right amount of water application at the right time is a mandatory. The experiment was designed with four irrigation depths (50%, 75%, 100%, and 125% of the CROPWAT 8.0 generated depth) and three irrigation frequency (irrigation interval as the model, three days before, and three days after) with Randomized complete block design. Carrot root yields and water use efficiency had a high significance difference among the treatments. The maximum marketable carrot root yield of 36503 kg ha^{-1} was found with the application of 100% ETc with every 15 days and the highest water use efficiency of 9.3kg/m^{3} was found in the application of 50% irrigation depth with 9 days interval. However, the statistical result and the partial budget analysis showed that *the best water use efficiency of 8.1kg/m3 and optimum marketable carrot root yield of 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage with the water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment. Therefore, the application of 75% of the CROPWAT 8.0 generated depth with an irrigation interval of 15 days interval is recommended on the highland agro-ecology area and clay soil type with surface irrigation methods for satisfactorily carrot production.*

Keywords: Carrot, CROPWAT, $Et_{c.}$, root yield, water use efficiency,.

Introduction

Carrot (Daucus carota L.) is grown all over the world. It is an important short duration root vegetable grown for both fresh market and processed foods (Abdel-Mawly, 2004). However, soil water and nutrient absorption seems to increase with increasing root to soil contact. They can be sown in different seasons and climates. Since carrot crop has high economic value, the irrigation management strategy seeks maximum yield by supplying all requirements of the crop. Carrots grown for roots are managed for rapid root growth during a relatively short growing season (Hutmacher et al., 1990).

Irrigation is a national issue that is supposed to transform the agricultural sector to the industrial sector. It ensures optimal soil moisture during the growing period of crops. An irrigation strategy that assures optimum yields and WUE by synchronizing crop water use with the crop growth stages is a key for the development of the communities. The necessity for water supply depends on the crop development stage. Irrigation in critical periods is one of the main conditions ensuring ahigh-quality yield of carrots. The existence of healthy soil and water leads to healthy crop growth and development and, hence crop production and food security of the society. Water and land management needs an integrated approach to soil-water-plant-nutrient management.

One of the main problems that it has been facing nowadays is the low implementation of advanced technologies for irrigation forecasts in real-time so there are still using traditional methods by which water consumption is higher (Yoima et., 2015). Irrigation is typically applied on a routine basis without scheduling and supply often exceeds crop requirements under local practices. Irrigation methods besides irrigation scheduling play an important role in carrot yield. In Chacha small-scale irrigation, carrots have a very important place of vegetables consumed daily and practiced by the local farmers, investors etc. However, the production of carrots is still not stable from year to year in Chacha small-scale irrigation scheme.

Crop water requirements are defined here as "the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment". To calculate ETc a three-stage procedure is recommended: - (1) the effect of climate. (2) the effect of the crop characteristics (3) The effect of local conditions and agricultural practices(FAO & PAPER, n.d.)

A carrot root yield is affected by different factors. Polak et al. (1999) concluded that very important factors, which influence carrot root quality, are soil structure, its cultivation, nutrient coverage and proportional irrigation regime. The highest carrot yield was obtained by using sprinkler irrigation rather than drip and surface irrigation (Zeipi et., 2014).

In water-scarce areas, WUE is the main criterion for evaluating the performance of production systems, the management of water to the most critical growth stage is important. Reid and Gillespie, (2017) report about water stress and high moisture influence on quality and yield of carrots. The solution is to limit water to specific stages, minimizing loss of yield from water stress and waterlogging.

There are no researches done before in this area regarding irrigation water amount and frequency for better yield of carrots using CROPWAT 8.0 model. Therefore, this study was conducted for two years to determine the optimum irrigation amount and frequency of carrots to improve carrot yield and water productivity.

Materials and methods

Description of the study sites

The field experiment was conducted on Chacha irrigation Scheme to determine the crop water requirements of carrots from 206/17-2017/18. The wereda is located 110km from Addis Ababa, in North Shewa near Debre Birhan town. Its geographic coordinates are located at 10^{0}01’00” northing and 39^{0}45’00” Easting and altitude of 2764 meter above sea level. The land topography is near to flat (2%) and the annual rainfall is about 985mm. The whole area is not cultivated at rain-fed system, rather they cultivate in irrigation season. The soil textural class of the study site is clay type. The water source is either from the dam with gravity flow or the perennial river by pumping system.

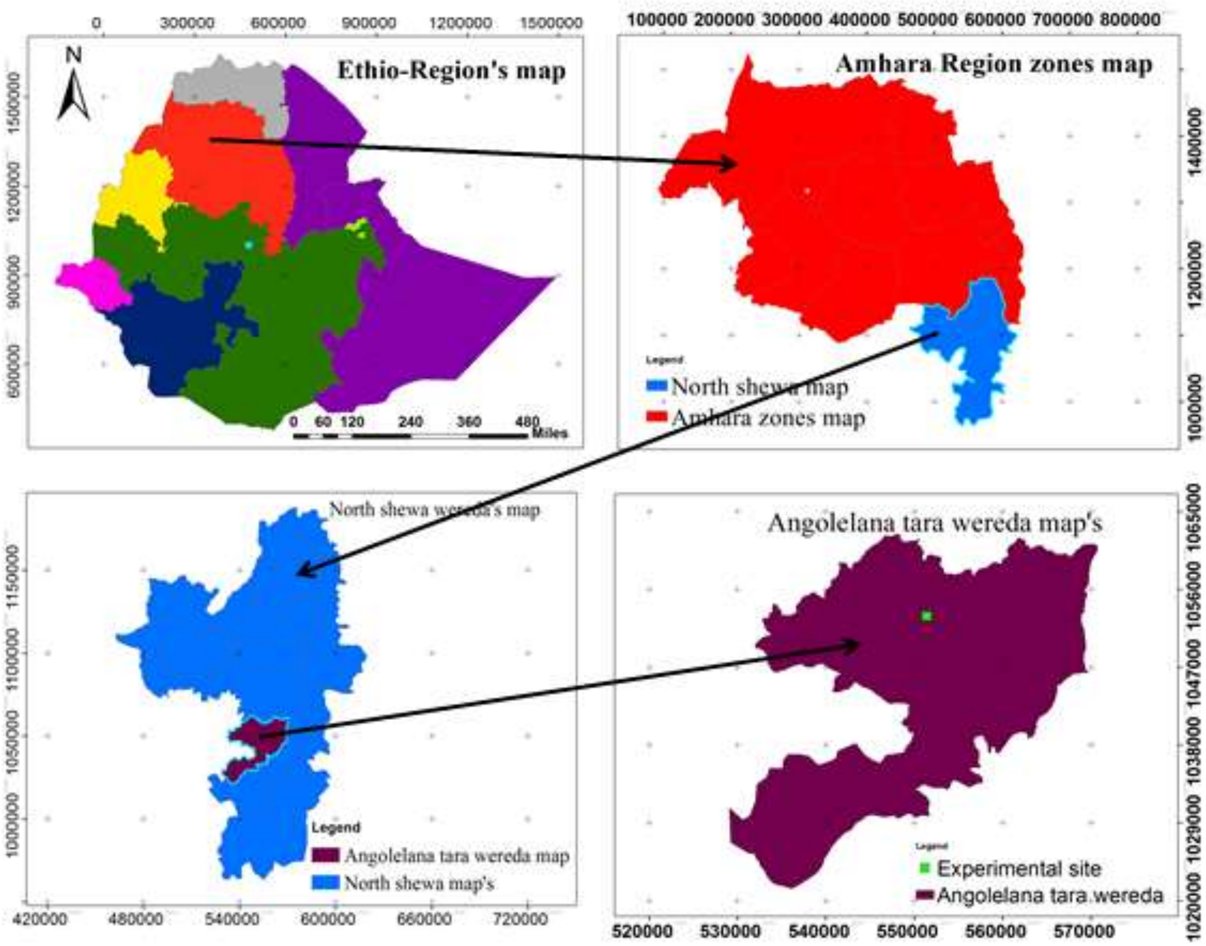

Figure 7. Study location map

Input requirements for CROPWAT 8.0 model

The CROPWAT under windows version 8.0 interfaces was used for determining the irrigation scheduling. The CROPWAT 8.0 version with an input of climatic parameters, soil type, root depth, depletion fraction, crop data (crop type, planting date, crop coefficient /k_c values, stage days) was used to determine the irrigation regimes.

Soil sampling and Analysis

The soil type is one of the inputs for determination of crop water requirement. Composite soil sampling was collected and Analyzed at Debere Birhan Agricultural Research Center during planting to determine the physic-chemical properties. Accordingly, the pH, EC, and OM of the soil was 6.40, 0.089 dSm^{-1}, and 4.27% respectively. The soil water contents at field capacity and permanent wilting point were 31 and 16% respectively.

Crop type and growth stage

Due to the lack of actual Kc of carrot, it was accessed from FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The allowable water depletion of carrot was assumed to be 0.35 of total available water (P = 0.65) during the whole growing cycle as suggested in FAO 56 (Allen et al., 1998). The total period of root carrot from instant of sowing was fixed as 120 days (25 initial stages, 40 development stages, 33 mid stage, 22 late stages).

Climatic parameter

Climatic parameters are a major factor that determines the total water requirements of a crop from sowing to harvesting. The climatic data was taken from nearby metrological station, Debre Birhan Agricultural Research Center.

The maximum evaporative demand of the atmosphere was found on May (4.07mm/day) and the minimum ET_o was found on July and December (3.06mm/day).

Table 11. The monthly average climatic data

Month	Min Temp	Max Temp	Relative humidity	Wind speed	Sun shine hours	Solar radiation	ET_o
	°C	°C	%	km/day	Hours	MJ/m²/day	mm/day
January	5.5	19.7	76	55	8	19.3	3.05
February	7.2	21	68	58	8.4	21.1	3.51
March	8.3	21.8	72	86	7.2	20.3	3.67
April	8.9	21.6	74	78	6.7	19.8	3.62
May	9.1	21.6	74	104	7.6	20.8	3.77
June	8.8	21.8	72	130	6.6	18.9	3.62
July	8.8	19.9	72	104	4.3	15.6	3.04
August	9.1	19.8	74	86	5.5	17.7	3.24
September	8.8	19.7	79	69	6.2	18.8	3.31
October	7.2	19.3	79	69	8	20.7	3.41
November	7.5	19	71	69	9.3	21.3	3.38
December	6.6	18.8	83	86	8.3	19.2	2.98
Average	8	20.3	75	83	7.2	19.5	3.38

Experimental procedures and design

The experiment was designed with four irrigation depths (50%, 75%, 100%, and 125% of the CROPWAT 8.0 generated depth) and three irrigation frequency (irrigation interval as the model, three days before, and three days after) with Randomized complete block design. The carrot seed, Nantus Varity, was sown at beginning of January with seed rate of 1.7 kg/ha (1 seed at every 5 cm and 20 cm row spacing). Prior to sowing the land was well prepared and irrigated to be easily workable. The recommended fertilizer rate of 152.2 kg urea/ha and 157.9 kg/ha NPS was applied, Nitrogen half split application at sowing and vegetation.

The water used in this experiment was sourced from the nearby dam and the river with pumping devices. The mode of applying water used in this experiment was canning system. The ETC of carrots were determined from CROPWAT 8.0 and the treatments were set by using the model as a reference. Common irrigation was applied up to the carrot vegetative and then irrigation was applied as per the treatments code arrangement. Then, the set treatments were applied accordingly to each plot. Unexpected rainfall was recorded with a rain-gauge and it was converted to the effective rainfall by USAD methods in the CROPWAT 8.0 model. Carrot was irrigated 9, 12 and 15 days as per treatment to maintain root zone soil water content above allowable depletion threshold and returning soil water content back to field capacity.

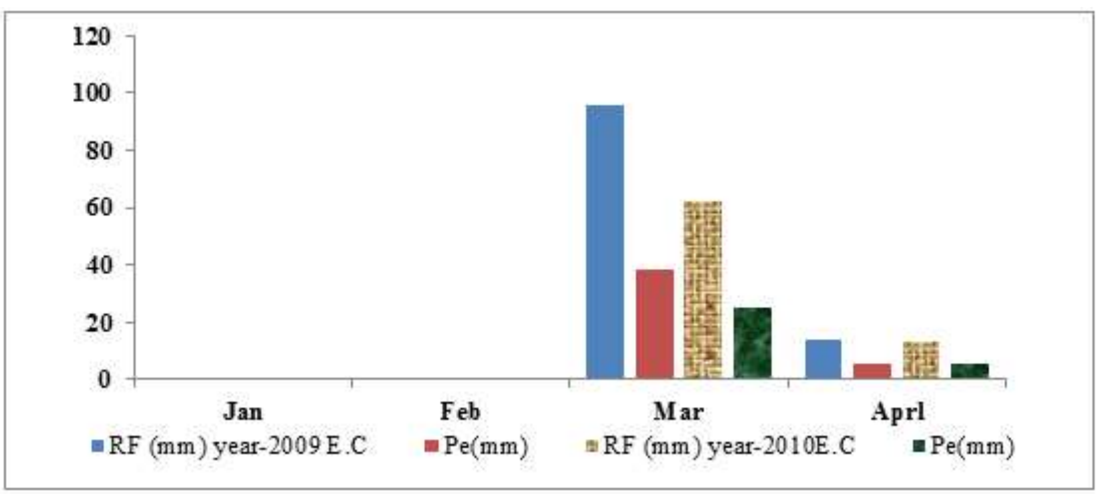

Figure 8. The monthly rainfall pattern in growing season

ET_C=from the CROPWAT model----------------------1

NIR=ETC-P_e---------------------2

GIR=NIR+ losses, or GIR=NIR/E_a. -------------3

Where, ETC is Evapotranspiration of the crop (mm/Season), P_e is Effective Rain fall in mm/Season, NIR is Net Irrigation Requirement in mm/Season, GIR is Gross Irrigation Requirement in mm/Season and E_a is Application Efficiency (taken as 80%)

Table 12. Treatments code and their arrangements in the experimentation

Trt codes	irrigation levels	Initial (mm)	Dev't-1 (mm)	Dev't-2 (mm)	Mid (mm)	Late (mm)
1	50% ETC *12days	16	18	21	25	23
2	75%ETC*12 days	25	28	31	37	34
3	100%ETC*12days	33	37	42	50	46
4	125%ETC*12days	41	46	52	62	57
5	50% ETC *9 days	12	14	16	19	17
6	75%ETC*9 days	18	21	23	28	26
7	100%ETC*9days	25	28	31	37	34
8	125%ETC*9days	31	35	39	46	43
9	50% ETC *15days	20	23	26	31	29
10	75%ETC*15 days	31	35	39	46	43
11	100%ETC*15days	41	46	52	62	57
12	125%ETC*15days	51	58	65	77	71

Trt is Treatment, Dev't is development and ETc is Evapotranspiration of crop by the CROPWAT 8.0.

Data collection

The data collected were number of stand count, plant height, root length, root diameter and core diameter, root yield, number of carrot root and water use efficiency. The weighed samples of carrot roots from each plot were converted into kilogram per hectare and divide by their respective total amount of irrigation water supplied throughout the cropping season to determine the water use efficiency. A sample size of 10 plants per treatment was randomly selected and tagged for easy identification.

Water use efficiency was calculated as ratio of total yield (kg) to total water consumed by the crop (m3). The reciprocal of this gave the amount of irrigation water used to get a kilogram of carrot. As quoted by (Tefera, 2017), the following relationship was employed to calculate water use efficiency (Zhang andOweis , 1999).

$$WUE = \frac{Y}{NIR}$$

Where, WUE is water use efficiency in kg / m ^{3}, Y is carrot root yield in kg ha^{-1} and NIR is total net irrigation requirement m^3 ha^{-1}

Statistical analysis

All yield, yield components and water use efficiency data were subjected to analysis of variance using SAS version 9.0 (SAS Institute, 2004) statistical software. The significance of differences among treatment means was compared using Dunken's multiple range test at $p<0.05$ significant difference and at $p<0.01$ highly significant difference.

Results and discussion

Response of marketable Carrot root yield on the application of water depth and interval

As the combined or two years (2009 & 2010) ANOVA results shows (table 3), that the treatments of 100%ETC*15days, 125%ETC*9days, 125%ETC*12days and 75%ETC*15 days had significantly high on the marketable carrots root yield 36503 kg ha^{-1}, 34674 kg ha^{-1}, kg ha^{-1}, 33750 kg ha^{-1}, and 32551 kg ha^{-1} respectively than other treatments. Rang of the marketable carrot root yield observed in the experiment from 26101 kg ha^{-1} to 36503 kg ha^{-1} in the treatments 50% ETC *12days and 100%ETC*15days respectively. For instance, at optimum moisture, carrot root yield was obtained up to 28,100 - 45,850 kg ha^{-1} (Wassu et al., 2014). Similarly, as reported by Zeipi et al. (2014) the average carrot root yields of Nantus variety was 42,520 kg ha^{-1} when it was released. Quezada et al. (2011) found that the highest yield of carrot crop in a clay soil was obtained with the 100% E_{pan} treatment. The highest root yields were obtained with at 100% evaporation replenishment and 120 kg N/fed. On the other hand, maximum water use value were recorded with 120 kg N/fed and at 75% level of evaporation replenishment (Abdel-Mawly, 2004).

Imtiyaz et al. (2000) reported a higher mean marketable yield of carrot (56.76 and 38.39 t ha^{-1}) and a higher irrigation production efficiency of carrot (9.83 and 6.66 kg m^{-3}). To obtain higher and quality carrot root yields, conditions of good soil fertility and soil structure, optimum soil moisture and efficient technological knowhow are important. As the application of irrigation water depth increases, the yield per unit of water increases and then the trends decrease.

Table 13. Effect of irrigation regimes on carrot yield and yield parameters and water use efficiency

Trt code	Treatment	PH (cm)	RL (cm)	RD (ratio)	TY (kg/ha)	MY (kg/ha)	WUE (kg/m3)
1	50% ETC *12days	24[ab]	12.3[ab]	2.8[ab]	29982[d]	26101[d]	8.7[ab]
2	75%ETC*12 days	24[ab]	12.5[ab]	2.7[ab]	34568[abcd]	29836[bcd]	8.2[abc]
3	100%ETC*12days	26[a]	12.3[ab]	2.8[ab]	34554[abcd]	30211[bdc]	7.1[cde]
4	125%ETC*12days	25[a]	12.4[ab]	3.1[a]	38571[ab]	33750[abc]	6.9[de]
5	50% ETC *9 days	21[b]	12.6[ab]	2.6[ab]	32304[cd]	28452[cd]	9.3[a]
6	75%ETC*9 days	23[ab]	12.7[ab]	2.6[ab]	33247[bcd]	30440[bcd]	7.9[bcde]
7	100%ETC*9days	22[ab]	12.4[ab]	2.7[ab]	36143[abc]	30979[bcd]	7.6[bcde]
8	125%ETC*9days	24[ab]	12.8[ab]	2.6[ab]	37972[ab]	34674[ab]	6.6[e]
9	50% ETC *15days	22[b]	11.9[b]	2.9[ab]	31937[cd]	28795[cd]	8.9[ab]
10	75%ETC*15 days	23[ab]	13.2[a]	2.5[b]	35640[abc]	32551[abc]	8.1[abcd]
11	100%ETC*15days	25[a]	13[ab]	2.4[b]	39542[a]	36503[a]	7.7[bcde]
12	125%ETC*15days	23[b]	12.9[ab]	2.7[ab]	31363[c]	29768[bdc]	5.3[e]
CV (%)		11.8	7.1	12.5	11.5	12.9	12.8
P (0.05)		*	*	*	**	**	**

*Trt is treatment, PH is plant height, RL is root length, RD is ratio of rootdiameter to core diameter, * is significant at 0.05, **is highly significant at 0.001, ns is non - significant, TY is total yield, WUE is water use efficiency, CV is coefficient of variation.*

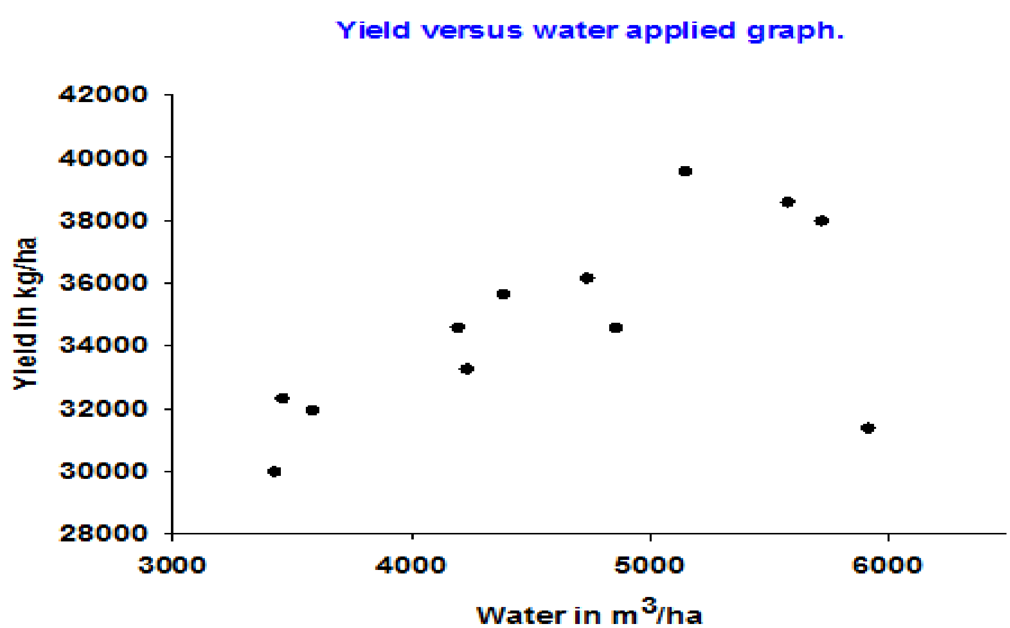

Figure 9. The response of carrot root yield to different water amount

Influence of irrigation regime on water use efficiency of carrot

As the Analysis of variance result indicated, water use efficiencies of carrot root were significantly influenced by irrigation. The combined or two years (2009 & 2010) ANOVA results showed (table 3)that the treatments of 50% ETC *9 days, 50% ETC *15days, 50% ETC *12days, 75% ETC *12days and 75%ETC*15 days had significantly higher water use efficiency of carrots root of yield 9.3 kg m^{-3}, 8.9 kg m^{-3}, 8.7 kgm^{-3}, 8.2 kgm^{-3}, and 8.1 kgm^{-3} respectively than other treatments. The highest and the lowest WUE recorded 9.3 kg m^{-3} and 5.3 kg m^{-3} in 50% of CROPWAT depth with 9 days interval, and 125% of CROPWAT depth with 15 days interval treatments respectively.

As reported by Dysko and Kaniszewski (2007), minimal water supply necessary for carrot development is 350-400 mm, but some authors advise 650 mm for satisfactory development of carrot roots (Fritz et al., 2008). However, the total irrigation water required for its base period in this experiment was between 342mm-591mm. The magnitude and rate of development of soil water deficits markedly influenced carrot responses to developing water deficits (Hutmacher et al., 1990). As a principle, the higher the amount of applied irrigation depth (delta) implies the smaller the duty and hence, the smaller water use efficiency. A total crop water use of approximately 550 to 620 mm was needed to achieve the best yield which is roughly equal to potential evapotranspiration in the San Joaquin Valley, during the time that the crop water use was calculated (Ayars et al. 1991). .

Influence of irrigation regime on marketable carrot root yield and Water use efficiency

The results of this study showed that all irrigation treatments determined based on CROPWAT model gave statistical difference in carrot root yields and water use efficiencies among the treatments. the treatments of 100%ETC*15days, 125%ETC*9days, 125%ETC*12days and 75%ETC*15 days had significantly higher marketable carrots root yield of 36503 kg ha^{-1}, 34674 kg ha^{-1}, kg ha^{-1}, 33750 kg ha^{-1}, and 32551 kg ha^{-1} respectively than other treatments. And the treatments of 50% ETC *9 days, 50% ETC *15days, 50% ETC *12days, 75% ETC *12days and 75%ETC*15 days had significantly higher water use efficiency of carrots root yield 9.3 kg m^{-3}, 8.9 kg m^{-3}, 8.7 kgm^{-3}, 8.2 kgm^{-3}, and 8.1 kgm^{-3} respectively than other treatments. However, the best water use efficiency 8.1kg kgm^{-3} and optimum marketable carrot root yield 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage. The water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment.

The investigation recorded a highest WUE in the 75% ET_c treatment equivalent to 3864 m^3 ha^{-1}, which they recommended as the required water application level in irrigation scheduling (Quezada et. al. 2011). The highest yield of carrot crop obtained with the 100 % E_{pan} treatment (94891kg ha^{-1}) and the maximum WUE corresponded to 75 % E_{pan} treatment (24.6 kg m^{3-1}), with an applied water volume of 3864 m^3 ha^{-1}, with drip irrigation scheduling in carrot (Quezada et al., 2011). Statistically, water use efficiency of the treatments had highly significance difference among the treatments. With reference to the Fig below, as the irrigation water depth increases, the water use efficiency of carrot decreases.

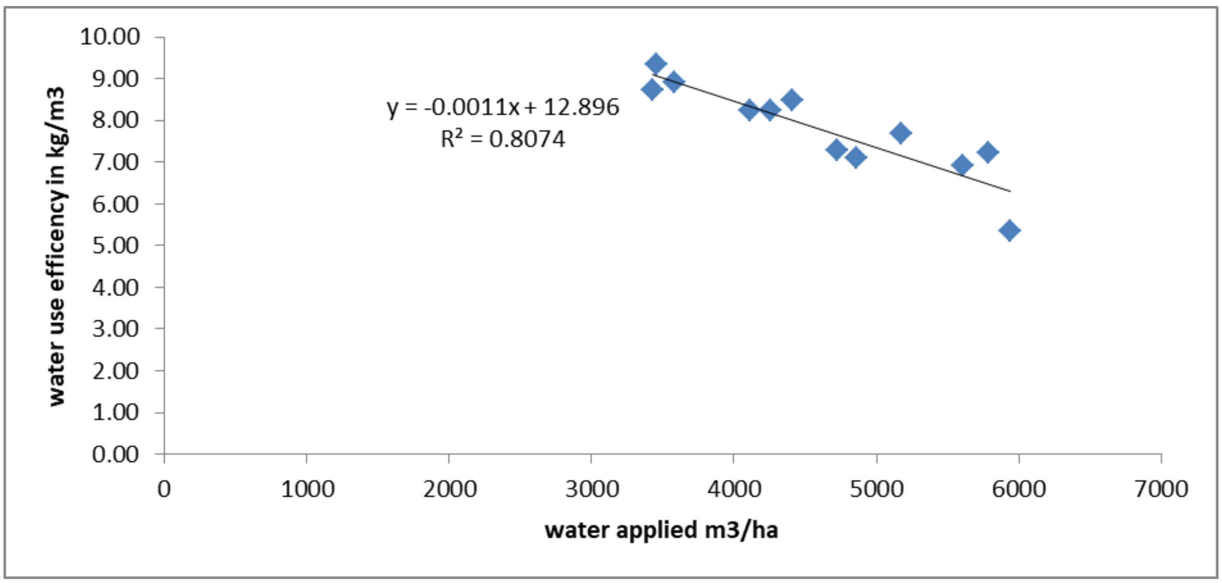

Figure 10. Effect of irrigation regimes on total yield and water use efficiency.

The water saved produce 3829kg from an extra land of 0.1 ha. The 100% CROPWAT model depth; 41mm at initial, 46mmat development-1, 52 mm at development-2, 62 mm at mid, 57mm at late with every 15days registered the highest root yield. However, it is resulted in a yield penalty of 4625kg ha^{-1} due to the 6 percent over application of water above CROPWAT generated. depth.

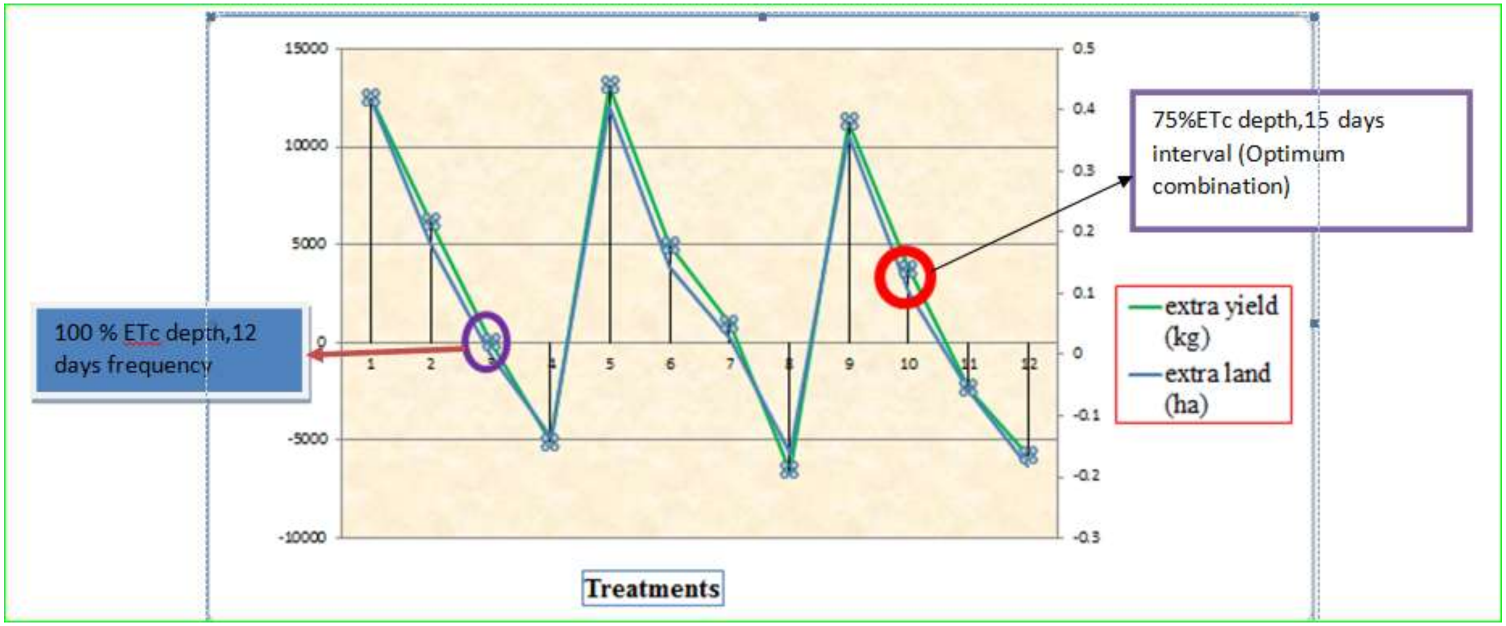

Figure 11. Incremental benefits of different irrigation regimes over the 100% CROPWAT 8.0 generated depth.

Partial budget analysis

The variable cost, which differs due to treatments, is used to determine the marginal rate of return. As the water amount to be applied increases, the marginal rate of return decreases due to the needs of higher labor resources. The marginal rate of return shows that the highest net return resulted with the application of 75% ETc with every 15 days.

Table 14. The partial economic analysis of the experiment

Trt codes	Trt	TVC	GR	NR	MC	MR	MRR (%)
1	50% ETC *12days	51194	181737	130543	-	-	-
9	50% ETC *15days	53570	185495	131926	2376	1383	58
5	50% ETC *9 days	54794	180452	125658	1224	-6268	-512
2	75%ETC*12 days	76791	197327	120536	21997	-5122	-23
10	75%ETC*15 days	80355	217480	137125	3564	16589	466
6	75%ETC*9 days	82191	197483	115292	1836	-21833	-1189
3	100%ETC*12days	102388	223717	121328	20197	6036	30
11	100%ETC*15days	107140	226768	119628	4751	-1700	-36
7	100%ETC*9days	109588	199238	89650	2449	-29978	D
4	125%ETC*12days	127985	213748	85763	18397	-3887	D
12	125%ETC*15days	133925	186365	52440	5939	-33323	D
8	125%ETC*9days	136985	209925	72940	3061	20500	D

TVC is total variable cost, GR is Gross revenue, NR is net return, MC is marginal cost, MR is marginal return, MRR is marginal rate of return

Conclusion and Recommendation

The results of this study showed that all irrigation treatments determined based on CROPWAT model gave statistical difference in carrot root yields and water use efficiencies among the treatments. The treatments of 100%ETC*15days, 125%ETC*9days, 125%ETC*12days and 75%ETC*15 days had significantly higher marketable carrots root yield of 36503 kg ha^{-1}, 34674 kg ha^{-1}, kg ha^{-1}, 33750 kg ha^{-1}, and 32551 kg ha^{-1} respectively than other treatments. The marketable carrot root yield observed in the experiment ranges of from 26101 kg ha^{-1} to 36503 kg ha^{-1} in the treatments of 50% ETC *12days and 100%ETC*15days respectively. And the treatments of 50% ETC *9 days, 50% ETC *15days, 50% ETC *12days, 75% ETC *12days and 75%ETC*15 days had significantly higher water use efficiency of carrots root yield 9.3 kg m^{-3}, 8.9 kg m^{-3}, 8.7 kgm^{-3}, 8.2 kgm^{-3}, and 8.1 kgm^{-3} respectively than other treatments. However, the statistical result and the partial budget analysis showed that the best water use efficiency of 8.1kg/m^3 with optimum marketable carrot root yield of 32551 kg ha^{-1} was observed in the application 75% of the CROPWAT 8.0 generated depth with every 15 days of 31mm at initial, 35mm at development-1, 39mm at development-2, 46mm at mid, 43mm irrigation depth at late stage. The water saved produce 3829 kg extra yield from an extra land of 0.1 ha over the model treatment. Therefore, the application of 75% of the CROPWAT 8.0 generated depth with an irrigation interval of 15 days interval is recommended on the highland agro-ecology area and clay soil type with surface irrigation methods for satisfactorily carrot production.

Therefore, the local farmers in Chacha irrigation schemes and similar agro-ecologies should applies 31 mm at initial, 35 mm at development-1, 39 mm at development-2, 46mm at mid, 43mm at late stage and with 15 days irrigation interval to obtain satisfactorily yield and water use efficiency. Because, it improves good irrigation water management with optimum carrot root yields. It is easy to demonstrate and adopt the improved agricultural water management practices, which save water and increase crop productivity. This result is particularly important as it allows farmers to increase their income through better root yield and the water saved used to irrigate additional irrigable areas.

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Appendix

Appendix Table 1 Range of Kc values for different crops and at different growth stages

Crop	Crop development stages			
	Initial	Development	Mid-season	Late season
Banana	0.4 – 0.5	0.70 – 0.85	1.0 – 1.10	0.90 – 1.0
Barley/Oats/Wheat	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.75
Beans-Dry	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.75
Cabbage	0.4 – 0.5	0.70 – 0.80	0.95 – 1.10	0.90 – 1.0
Cotton	0.4 – 0.5	0.70 – 0.80	1.05 – 1.25	0.80 – 0.90
Groundnut	0.4 – 0.5	0.70 – 0.80	0.95 – 1.10	0.75 – 0.85
Maize	0.3 – 0.5	0.70 – 0.85	1.05 – 1.20	0.80 – 0.95
Onion	0.4 – 0.6	0.70 – 0.80	0.95 – 1.10	0.85 – 0.90
Pepper	0.3 – 0.4	0.60 – 0.75	0.95 – 1.10	0.85 – 1.0
Potato	0.4 – 0.5	0.70 – 0.80	1.05 – 1.20	0.85 – 0.95
Rice	1.1 – 1.15	1.1 – 1.5	1.1 – 1.3	0.95 – 1.05
Safflower	0.3 – 0.4	0.70 – 0.80	1.05 – 1.20	0.65 – 0.70
Sesame	0.3 – 0.4	0.70 – 0.80	1.10 – 1.20	0.70 – 0.85
Sorghum	0.3 – 0.4	0.7 – 0.75	1.0 – 1.15	0.75 – 0.80
Sugar cane	0.4 – 0.5	0.70 – 1.0	1.0 – 1.30	0.75 – 0.80
Teff	0.3 – 0.4	0.70 – 0.80	0.9 – 1.10	0.65 – 0.75
Tomato	0.4 – 0.5	0.70 – 0.80	1.05 – 1.25	0.8 – 0.95

Assessment of Brewery Industry Wastewater Quality for Irrigation and Its Impacts on Selected Soil Properties

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Abstract

Waste water contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements. Traditionally, the amount of water needed to brew beer is several times the volume actually brewed. The current study was designed to determine and characterize the physicochemical quality parameters of waste water from brewery industry for irrigation purpose. The BOD and COD values in the present study were 50.00 mg/L and 148.44 to 197.92 mg/L (mean value = 173.18 mg/L) respectively. Total Hardness as $CaCO_3$ *value ranges from 81.38 to 86.63mg/L, total suspended solid value ranges from 260 to 185mg/L and dissolved solid sample valve ranges from 940 to 1005mg/L. These results highlighted that the final effluent produced from Dashen brewery factory waste water treatment plant (WWTP) did not meet the Standards set by WHO. Therefore, it is recommended that brewery WWTP has to be improved by correcting their treatment process. Hence, the sustainable use of treated waste water in agriculture can be beneficial to the environment in such a way that minimizes the side effects on the quality of downstream water resources. Furthermore, these results indicated that proper management of waste water irrigation and periodic monitoring of quality parameters are required to ensure successful, safe and long-term reuse of waste water for irrigation. It is recommended that waste water treatment has to be a high priority that is considered in the future and made a reliable alternative source in water resources management. Agricultural waste water reuse can effectively contribute to fill the increasing gap between water demand and water availability particularly in water stressed areas.*

Keywords*:* BOD, Brewery industry, effluent, heavy metals, TSS,

Introduction

Advanced industrialization processes have provided comforts to human beings on one hand, and on the other, it has resulted in indiscriminate release of gasses and liquids, which polluted the environment of biological system (Lone, *et al.*, 2003). Industrial waste effluents are discharged into the surrounding environment with multiple effects and changes the physicochemical parameters of environment (Nebel and Wright, 1998). Pollution has adverse effects on land, water or air and its biotic and abiotic components. Water pollution may result from municipal, agricultural or industrial wastes containing organic and inorganic chemical substances, dissolved or suspended solids (Terry, 1996; Nebel and Wright, 1998; Moeller, 2004).

The world's supply of fresh water is limited and threatened by pollution from various human activities. Rising demands of water to supply agriculture, industry and cities are leading to competition over the allocation of the limited fresh water resources (Bartram and Balance, 1996).

In both developed and developing countries, the most prevalent practice is the application of municipal waste water (both treated and untreated) to land. In developed countries where environmental standards are applied, much of the waste water is treated before use for irrigation of fodder, fiber, and seed crops and, to a limited extent, for the irrigation of orchards, vineyards, and other crops.

Other important uses of waste water include recharge of groundwater, landscaping (golf courses, freeways, playgrounds, schoolyards, and parks), industry, construction, dust control, wildlife habitat improvement and aquaculture. Thus, waste water can be considered as both a resource and a source of different problems. Its reuse can deliver positive benefits to the farming community and municipalities.

However, waste water reuse also exerts negative effects on humans and ecological systems, which need to be identified, and assessed (Michalski and Kurzyca, 2006). Of the various sources of pollutants, industrial effluents containing heavy metals pose a threat to the ecosystem. The presence of pollutants in effluent is a common environmental hazard since the toxic metal ions dissolved can ultimately reach the top of the food chain and becomes a risk factor for human beings (Baby, 2010). Toxic metals added to soils through irrigation water or directly and entered to an edible part of a plant leaf, grain, fruit, root or tuber. Large amounts of metals will be a special hazard to animals grazing sludge or effluent treated sites. Therefore humans directly or indirectly consume the plant and animal significantly affected by the toxic metal.

Waste water contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements such as Boron (B), Zinc (Zn), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), mercury (Hg), Nickel (Ni), Lead (Pb), Manganese (Mn), Zink (Zn), Arsenic (As).

High levels of pollutants in waste water systems causes to disturb the biological, chemical and physical characterize of irrigation water. For instance, from biological characters an increase in biological oxygen demand (BOD), from the chemical characters increasing chemical oxygen demand (COD), toxic metals such as Pb, Zn, Cd, Mn, Fe, Cu, Ni, Co, As, Hg and from the physical characters total dissolved solids (TDS), total suspended solids (TSS), properties such as colour, order, test, hardness, etc. make such water unsuitable for drinking, irrigation and aquatic life (Kanu and Achi, 2011). Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use of waste water (Wilcox, 1948).

Beer is the fifth most consumed beverage in the world behind tea, carbonates, milk and coffee and it continues to be a popular drink with an average consumption of 23 liters/person per year (Levinson, 2002 and Ciancia S, 2000). Production of beer includes blending and fermentation of maize, malt and sorghum grits using yeast, which requires large volumes of water as the primary raw material. Traditionally, the amount of water needed to brew beer is several times the volume actually brewed. For instance, an average water consumption of 6.0 hectoliters is required to produce one hectoliter of clear beer (South African Breweries plc., 2001). Large volumes of water are being used by the industry for production of beer for two distinct purposes; as the main ingredient of the beer itself and as part of the brewing process for steam raising, cooling, and washing of floors, packaging, cleaning of the brew house during and after the end of each batch operation. The amount of wastewater that is being discharged from the industry after the production of beer, also contributes to this large volume of water (Simate G., *et al.*, 2011). With the competing demand on water resources and water reuse, discharge of industrial effluents into the aquatic environment has become an important issue (Kovoor, *et al.*, 2012)

The ever-increasing demand on irrigation water supply to farmlands are frequently faced with utilization of poor-quality irrigation water. In many parts of Ethiopia, waste water, which are disposed to wells, ponds, streams and treatment plants, are used as a source of irrigation water as well as for drinking (Alemtsehaye, 2002). In some locality's sludge water and human faces and other are also dumped to these rivers. One surprising aspect is communities use the polluted/waste water from these rivers for irrigation (Waltainformation 2004). Some studies indicated that 40% of the vegetable supplied to Addis Ababa city and animal feed comes from the suburb directly irrigated by these water or fields flushed from waste water during the heavy rainy season or during the dry season. But, the continued application of poor-quality irrigation water can reduce the yield of farmlands. This is due to the fact that the accumulation of heavy metals in the soil has an adverse effect on the growth and development of the wide variety of plant species (Nwajei, *et al.,* 2012).

This study was therefore conduct to characterize physical and chemical quality parameters of waste water from brewery industry for irrigation purpose and assess the effects of wastewater on Selected soil properties.

Material and method

Description of the study area

Debre Birhan town is located in North Shewa Zone of the Amhara Region, about 130 kilometres north east of Addis Ababa on the paved highway to Dessie, The town is at a latitude and longitude of 9°41′N, 39°32′E and at an elevation of 2,840 meters above sea level. The brewery industry is located at about 5 km south east from the Debre Birhan town on the road to Addis Ababa.

Bebre Birhan is one of the few towns in Ethiopia with a newly developing and having relative greater number of large-scale manufacturing plants including Dashen-Brewery Factory, Habesha-Brewery Factory, Mineral Water Bottling Factory's, Blanket factory and Flour Factory. On top of this, the town is selected to be an industrial town by Amhara National Regional State of Ethiopia, which indicates the industrial development and its associated pollution risk will increase in the future. The existing industries have been discharging their wastes into the surrounding environment.

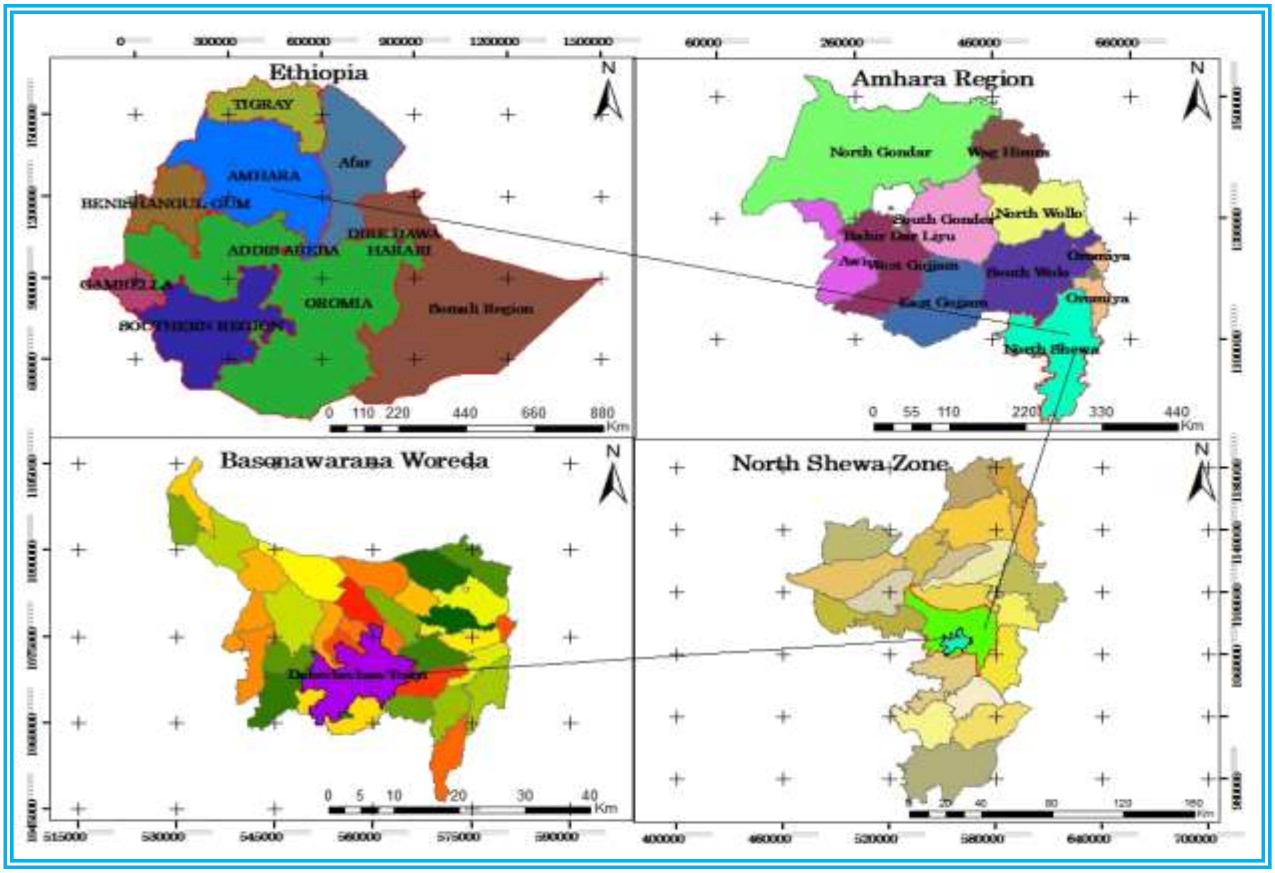

Figure 12. Map of the study area

Sampling Methods

Purposive sampling was used to collect waste water and soil samples. Treated and untreated waste water samples were collected in stopper fitted polyethylene bottles which were prewashed with dilute hydrochloric acid and then rinsed several times with the effluent sample before filling to the required capacity. Four sampling sites/stations were selected for water sample collection: Station-1from the Borehole site just before intering to the factory, Station-2 from the factory after treating the water for beer production, Station-3 just at the upper part of the command area, Station-4 just at the lower command area.

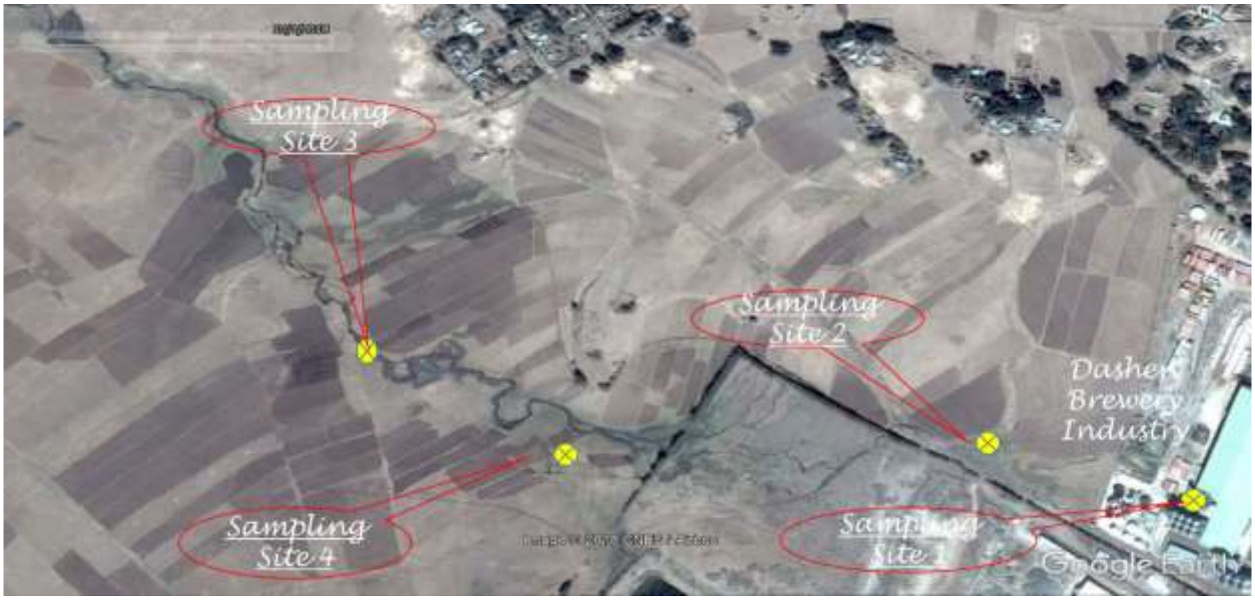

Figure 0. Location of the study site

The method of sample collection at each sampling point/station was done according to the WHO Guidelines (WHO, 1989) for waste water quality assessment and standard methods for the examination of waste water and the water laboratory manual (APHA, 1998). The Collected samples were stored at dry, cool and dark box and deliver the sample within 6 hr. to the laboratory for analysis.

Waste water Sample was filtered with laboratory Whatman Grade 52 filter paper in to wash and rinsed Erlenmeyer flasks. The clear filtered sample was transferred to ICP test tube. The solutions were analyzed for Na, Mg, Ca, K, S, Fe, Mn, Zi, Cu, Co, Cd, Pb, As, Cr and Ni with ICP-OES which was calibrated previously with standard series of all element stock solutions. The standard series uses to draw calibration curve of intensity verses concentration which is used to calculate the unknown sample. The correlation coefficient (R2) for the determination of the sample concentration of respective elements is always between 0.996-1.00. The other parameters also were analyzed with Colorimetric for Nitrate, with Titration for Bicarbonate and with Mohar Method for Chloride.

The sample is injecting with the auto sampler to the plasma by the help of peristaltic pump and the intensity of the light counts on the optic and calculate the Concentration on the Leaner calibration curve by the help of smart analyzer software. Biological Oxygen Demand (BOD) was determined by the 5 Day BOD test while Chemical Oxygen Demand (COD) was determined in the laboratory by the standard Open Reflux Method.

Similarly, the soil sample were collected from the field based on the standard. The Collected samples were stored at dry, cool and dark box and deliver the sample within 6 hr. to the laboratory for analysis. Soil samples were air dried and sieved under 2 mm diameter sieve for analysis. All elements were determined by ICP-OES using IRIS INTREPID (Thermo Elemental, Madison, USA). The calibration curves were linear in the whole concentration range.

Mehlich-3 estimates plant availability of most macronutrients and micronutrients in soils from acid to neutral pH using a dilute Acid-Fluoride-EDTA solution of pH 2.5. Due to the corrosive nature of Chloride in the Mehlich-2 extractant (Mehlich, 1978) and its inability to extract micronutrients on a wide range of soils, particularly copper on organic soils, Mehlich-3 was adopted.

In the process of extraction, phosphorus is solubilized under different mechanisms. Acidity of the two acids, Nitric and Acetic, increases the solubility of Iron and aluminum phosphates and extracts a portion of calcium phosphates if present. Fluoride serves to complex aluminum cations that potentially bind with phosphates thereby increasing the quantity of Orthophosphate in the solution. A benefit of Acetic Acid is to keep the solution buffered below pH 2.9 to prevent calcium fluoride from precipitating. Ammonium exchanges with potassium, calcium and magnesium and EDTA chelates iron, manganese, zinc, and copper. Phosphorus and cations were determined by ICP-AES instrumentation simultaneously. Phosphorus content in solution was determined spectrophotometrically at an acidity of 0.20 M H2SO4 by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of Antimony (Murphy and Riley, 1962). Carbonate (CO32-) and Bicarbonate (HCO3-) were determined by titration with HCl.

SAR is an important parameter for the determination of the suitability of irrigation

$$\mathrm{SAR} = \frac{\mathbf{Na^{+}}}{\sqrt{\dfrac{\mathbf{Ca^{+2}} + \mathbf{Mg^{+2}}}{\mathbf{2}}}}$$

The Soluble Sodium Percentage (SSP) was calculated by the following equation:

$$\mathbf{SSP} = \frac{(\mathbf{Na^+}) * \mathbf{100}}{\mathbf{Ca^{+2} + Mg^{+2} + Na^+ + K^+}}$$

The ratio of the exchangeable Na+ to total exchangeable cations (ESP) is a good indicator for soil structure deterioration.

$$\mathbf{Esp} = \frac{\mathbf{100\,(-0.0120 + 0.01475\,SAR)}}{\mathbf{1 + (-0.0120 + 0.01475\,SAR)}}$$

Another indicator that was used to specify the Magnesium Hazard (MH) for irrigation water as in the following formula:

$$\mathbf{MH} = \frac{\mathbf{Mg^{2+}}}{\mathbf{Mg^{2+} + Ca^{2+}}} * \mathbf{100}$$

If the value of MH is less than 50, then the water is safe and suitable for irrigation.

The excess sum of CO32- and HCO3- in wastewater over the sum of Ca2+ and Mg2+ influences the unsuitability of waste water for irrigation.

To qualify this effect, an experimental parameter termed as residual sodium carbonate (RSC) will be used. It will be calculated as follows:

RSC = (CO32- + HCO3-) – (Ca2+ + Mg2+)

According to the Uinited States Salinity Laboratory (USSL), RSC value less than 1.25 meq/L is safe for irrigation, a value between 1.25 and 2.5 meq/L is of permissible quality and a value more than 2.5 meq/L is unsuitable for irrigation.

The calculated RSC value show that all samples have RSC less than zero and are good suitable for irrigation purposes.

Results and discussion

To evaluate the pollution load in the brewery industrial effluents, the samples were analyzed for various physico-chemical parameters and the results were compared with values of National Environmental Quality Standards (NEQS, 2000) for industrial effluents. Similarly, values of ground water were compared with the standards of World Health Organization (WHO, 1981).

Table15. Wastewater and raw water chemical characteristics with respect to standard

					Effluent mean at site			
Parameter	Unit	Symbol	Raw water	Treated water	1	2	3	standard
Cadmium	mg/L	Cd	0.01	<0.069	<0.069	0.02	0.089	0.005
Arsenic	mg/L	As	0.15	0.41	0.32	0.31	0.63	0.05
Chromium	mg/L	Cr	0.13	<0.088	<0.088	0.04	0.128	0.05
Cobalt	mg/L	Co	0.068	0.06	0.00	0.02	0.02	0.05
Copper	mg/L	Cu	0.04	0.04	<0.033	<0.001	0.034	1
Iron	mg/L	Fe	0.11	0.15	1.76	1.92	3.68	0.3
Lead	mg/L	Pb	0.63	0.4	0.30	0.21	0.51	0.05
Manganese	mg/L	Mn	0.02	0.03	0.34	0.36	0.7	0.1
Mercury	mg/L	Hg	0.79	0.9	0.40	0.34	0.74	1
Nickel	mg/L	Ni	0.02	0.02	<0.01	<0.02	0.0	0.5
Zinc	mg/L	Zn	<0.026	<0.027	<0.028	<0.029	0.057	2
Calcium	mg/L	Ca^{2+}	21.52	21.31	22.81	18.52	41.33	200
Magnesium	mg/L	Mg^{2+}	4.43	4.4	6.93	5.36	12.29	150
Potassium	mg/L	K^+	3.6	3.45	19.18	46.41	65.59	-
Sodium	mg/L	Na^+	11.8	11.54	450.46	404.02	854.48	200
Phosphorus	mg/L	P	20.78	21.03	31.01	23.50	54.51	-
Ammonium	mg/L	NH_4^+	0.23	0.53	61.88	67.83	129.71	20
Bicarbonate	mg/L	HCO_3^-	8.45	6.56	19.31	16.26	35.57	-
Carbonate	mg/L	CO_3^{2-}	ND	ND	11.26	10.96	22.22	-
Nitrate	mg/L	NO_3^-	2.9	2.01	9.45	9.07	18.52	10
Chloride	mg/L	Cl^-	<0.1	<0.1	49.55	38.53	88.08	250

Note: - ND is not detected by the reading laboratory instrument

< the concentration is lower than the lower limit of the instrument.

The results obtained on heavy metal contents (Cd, As, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni and Zn) in brewery industrial effluents are presented in Table 1. Results showed that the levels of Cd, As, Cr Fe, Mn and Pb were above the permissible limits compared with standards. These results confirmed the early work of Banaras (1994). While the level of Co, Cu, Hg, Ni and Zn with in the limit. The main source of Mn in the effluents appeared to be aluminum industries which reduced the pH and thus Mn was released in the waste water.

Heavy metals concentration in raw and pure water was relatively similar to the standard but the west water is highly contaminated and also having complex chemical reaction in the downstream. When goes dawn to the stream the concentration of Cu, Cd, Co, and Cr decline through the irrigation scheme.

The level of Ca^{2+}, Mg^{2+}, K^{+}, P, HCO_{3-}, CO_3^{2-}, NO_{3-} and Cl^{-} ionic concentration is within the permissible limit of the standard. However, the concentration of Na^{+} and NH_4^{+} were higher than the standard. Water containing more than 200 mg/l sodium should not be used for Agricultural purpose. A maximum drinking water standard of 100 mg/l has been proposed for general public (Mahananda *et, al.* 2010). The major source of potassium in natural fresh water is weathering of rocks, but the quantities increase in the polluted water due to the disposal of waste water. It has a similar chemistry like sodium and remains mostly in solution without undergoing any precipitation. Similarly, it is not very much significant from the health point of view but in large quantities may be laxative. The concentration of potassium in natural water is very low but high value being an indication of pollution by domestic waste (Trivedi and Goel, 1986).

Nitrate content is an important parameter to estimate organic pollution in a particular environment, and it represents the highest oxidized form of nitrogen. Nitrate is one of the very common contaminants in waste water. Agricultural sources of nitrates include livestock waste matter and chemical fertilizers. The presence of nitrates in the water samples is suggestive of some bacterial action and bacterial growth (Majumder S. *et, al*., 2006). Sulfates are not considered toxic to plants or animals at normal concentrations. Sulfates are formed due to the decomposition of various sulfur-containing substances present in water bodies. The sulfate ions (SO_4^{-2}) occur naturally in most water supplies and hence are also present in waste water (Tüfekci N. *et*, *al.*, 2007)).

Table 2. Electrical conductivity and acidity of effluent

Parameter	Unit	Symbol	Raw water	Treated water	Effluent @ site 1	Effluent @ site 2	standard
Acidity	Pt. Co scale	pH-H_20	6.08	7.63	8.15	7.87	6.5-8.5
Conductivity	dS/m	EC	0.15	0.16	1.68	1.46	0.80 - 2.50
Temperature	^{0}C	T^0	20	21.5	27.33	22.17	25

The pH of the waste water collected from different stations was ranging from 6.3 to 8.15, and the result was shown in Table 2. The pH of raw, treated and waste water slightly increase and goes from slightly acidic to slightly alkaline, but not out of the range of the standard. The pH of the water is known to influence the availability of micronutrients as well as trace metals (Kirkham M. B., 2006). The principal component regulating ion pH in natural waters is the carbonate, which comprises CO_2, H_2CO_3, and HCO_3 (APHA, 1995). Electrical conductivity also shows slightly increment, but not out of the standard. Electrical conductivity is mainly attributed to the dissolved ions liberated from the decomposed plant matter (Sarwar and Majid, 1997) and input of inorganic and organic wastes (Wright, 1982). High EC values indicate the presence of high amount of dissolved inorganic substances in ionized form and the fluctuations in EC depends on the fluctuation in TDSs and salinity (Pandey *et*, *al*., 2003).

Temperature is an important indicator of water quality with regards to survival of aquatic organisms. The effluents temperature depends on the process of production in the industry. The temperature values of various industrial effluents ranged from 22.17–27.33 ^{0}C. However, the temperature of the effluent is warmer at the initial point from the factory and declined when going down.

Table 3. Wastewater physicochemical characteristics

	Analytical Result			
Parameter	symbol	*@site 1*	*@site 2*	*Unit*
Total Hardness as CaCO3	TH	86.63	81.38	mg/L
Total Suspended Solid	TSS	185	260	mg/L
Total Dissolved Solid	TDS	1005	940	mg/L
Carbonate	CO	ND	10.71	mg/L
Chemical Oxygen Demand	COD	148.44	197.92	mg/L
Biological Oxygen Demand	BOD	50	50	mg/L

Note: - ND is not detected by the reading laboratory instrument

As shows in Table 3 the concentration of TTS, TDS, CO and COD were higher and decrease from upstream to downstream, however total hardness increase in to downstream slightly and BOD remains constant in the irrigation scheme. In waste water, TDSs are composed mainly of bicarbonates, chlorides, carbonates, phosphates, and nitrates of calcium, magnesium, sodium, and potassium, manganese, salt and other particles (Mahananda., *et, al.*, 2010). The higher values of TDS may be due to the discharge of waste from effluents from various small-scale industries (Kataria., *et, al.*, 1996). BOD increases due to biodegradation of organic materials that exerts oxygen tension in a water body (Abida and Harikrishna, 2008). Increases in BOD can be due to heavy discharge of industrial waste water effluent, animal and crop wastes, and domestic sewage. BOD value has been widely adopted as a measure of pollution in the particular environment. It indicates the amount of organic matter present in water (Lokhande., *et, al.*, 2011). All organic compounds with few exceptions can be oxidized by the action of strong oxidizing agents under acidic condition. The COD determination is a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. While determining COD, oxygen demand value is useful in specifying toxic condition and presence of biologically resistant substances. The COD and BOD values are a measure of the relative oxygen-depletion effect of a waste contaminant. Both have been widely adopted as a measure of pollution effect. COD is also one of the most common measures of pollutant organic material in water. COD is similar in function to BOD, in which both measure the amount of organic compounds in water (Lokhande., *et, al.*, 2011).

Table 4. Contaminated and pure soil physicochemical characteristics

Parameter		*Pure soil @ site1*	*Pure soil @ site2*	*Contaminated soil @ site1*	*Contaminated soil @ site2*
Silicon	Si	433.57	410.32	622.68	456.38
Iron	Fe	288.86	291.16	308.28	338.44
Manganese	Mn	137.83	106.78	214.18	117.98
Zinc	Zn	3.41	3.67	2.99	3.97
Boron	B	0.22	0.23	0.90	0.51
Copper	Cu	1.68	2.49	1.71	1.35
Molybdenum	Mo	0.49	0.45	0.41	0.42
Cobalt	Co	1.23	0.83	2.43	0.93
Phosphorus	P	6.47	6.22	40.03	35.15
Potassium	K^+	36.26	32.46	172.98	156.64
Calcium	Ca^{2+}	3307.16	2326.81	3972.82	3636.10
Sodium	Na^+	48.66	21.78	1130.00	1294.28
Magnesium	Mg^{2+}	613.03	292.61	772.33	633.56
Sulphate	S	26.95	20.58	36.40	40.08
Acidity	PH	5.3	5.5	7.73	7.63
Conductivity	EC (μ	12.9	18.8	31.03	30.70
Organic Carbon	OC (%)	1.6	2	2.30	2.37
Organic Matter	OM (%)	2.8	3.5	4.13	3.93
T. Nitrogen	TN (%)	0.2	0.2	0.20	0.20

The result of pure soil and irrigated soil with waste water is shown in the Table 4. The concentration of heavy metal Si, Mn, Fe, P, S, Co and B and ions Na^+, Ca^{2+}, Mg^{2+} and K^+ increase as compared to the pure soil from adjacent land not irrigated with industrial waste water especially Na^+ increase seriously. However, Mo, Zn and Cu concentration decline in the pure soil than the contaminated soil. The concentration of PH, OM (%), OC (%), EC (μ s/cm) also increase in contaminated soil, except total nitrogen as it remains constant in both pure and contaminated soil.

Table 5. Soil texture and Bulk density of the study site

Parameter		Pure soil @site 1	Pure soil @site 2	Contaminated soil @site 1	Contaminated soil @site 2
Bulk density(g/cm^3)	Bd	1.37	1.42	1.37	1.24
Texture	%sand	44	52	44	22
	%clay	28	22	28	46
	%silt	28	26	28	26
	Tex. class	Clay loam	Sandy Clay loam	Clay loam	Clay

As show in Table 5 texture of the site ranges from clay to clay loam and is highly reactive and suitable for chemical reaction. Even if the concentration of sodium and other cations are slightly higher than the standared, the bulk density is similar in pure and contaminated soil. Na^+ broke down the edge of the clay particle and fill the pore space and block the infiltration of water and increase bulk density of soil.

Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reducing soil permeability. The water can be used for irrigation when the concentration of sodium is about 184.00 mg/L. Sodium hazard is usually expressed in terms of Sodium Adsorption Ratio (SAR) and it can be calculated from the ratio of sodium to calcium and magnesium. SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the sodium hazard, since it is more closely related to exchangeable sodium percentages in the soil than the simpler sodium percentage. Sodium that replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure.

Water with SSP greater than 60 % may result in sodium accumulations that will cause breakdown of the soil's physical properties. The ratio of the exchangeable Na^+ to total exchangeable cations (Exchangeable Sodium Percentage, ESP) is a good indicator for soil structure deterioration. Although, the ESP of 10 to 15 % is generally accepted as a critical level, an ESP of 25 % may have little effect on soil structure in a sandy soil, whereas an ESP of 5 % is considered high particularly in soils containing 2:1 clay mineral like montmorillonite.

The excess sum of CO_3^{2-} and HCO_3^- in waste water over the sum of Ca^{2+} and Mg^{2+} influences the unsuitability of waste water for irrigation. In water having high concentration of CO_3^{2-} and HCO_3, there is tendency for Ca^{2+} and Mg^{2+} to precipitate as carbonates. To qualify this effect, an experimental parameter termed as RSC will be used.

According to the USSL, RSC value less than 1.25 meq/L is safe for irrigation, a value between 1.25 and 2.5 meq/L is of permissible quality and a value more than 2.5 meq/L is unsuitable for irrigation. The calculated RSC value show that all samples have RSC less than zero and are suitable for irrigation purposes.

The most common toxicity is from chloride (Cl^-) in the irrigation water. Cl^- is not adsorbed or held back by soils, therefore it moves readily with the soil-water, taken up by the crop, moves in the transpiration stream, and accumulates in the leaves. If the Cl^- concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue.

High concentration of Ca^{2+} and Mg^{2+} ions in irrigation water will increase soil pH, resulting in reducing of the availability of phosphorous. Water containing Ca^{2+} and Mg^{2+} higher than 10 meq/L (200 mg/L) cannot be used in agriculture. Another indicator that will be used to specify the Magnesium Hazard (MH) for irrigation water is less than 50, then the water is safe and suitable for irrigation.

Conclusion and recommendation

Interpretation of physical and chemical analysis revealed that the treated waste water of Dashen Brewery Factory is slightly alkaline. Among heavy metals Co, Cu, Hg, Ni and Zn, were within the permissible limits in all sites but Cd, As, Cr, Fe, Mn and Pb beyond the permissible limits in the effluents. The level of Ca^{2+}, Mg^{2+}, K^+, P, HCO_3^-, CO_3^{2-}, NO_3^- and Cl^- ionic concentration is within the permissible limit of the standard. However, the concentration of Na^+ and $NH4^+$ were higher than the standard. Therefore, it is recommended that Brewery WWTP has to be improved by correcting their treatment process. Otherwise use this water for agricultural purpose is dangerous. Therefore, the sustainable use of treated waste water in agriculture can be beneficial to the environment in such a way that minimizes the side effects on the quality of downstream water resources. Similarly, BOD and COD was above the permissible limit in almost all of the effluents. Chloride values are increasing intensively which is not recommended by the WHO standards and other standard agencies; hence which are not recommended for irrigation purpose. Based on these results, it is recommended that proper management of waste water irrigation and periodic monitoring of quality parameters are required to ensure successful, safe and long-term reuse of waste water for irrigation. Therefore, in the future high priority should been given for waste water treatment . This is because treated waste water is considered and made a reliable alternative source in water resources management. Agricultural waste water reuse can effectively contribute to fill the increasing gap between water demand and water availability particularly in water stressed areas.

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Determination of Irrigation Regime for Hot Pepper in Dry-Land Areas of Wag-Himra, North Eastern Amhara.

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Abstract

A field experiment was conducted in 2014 and 2015 in Ziqualla and Abergelle woreda. This field experiment was therefore conducted to determine net irrigation requirements and irrigation schedules of hot pepper using CROPWAT computer model and to validate using field trial. A split plot design with the main plot of water depth and subplot of irrigation frequency has been used. Three levels of water amount with (I_1), (I_2), and (I_3) CROPWAT generated depth and three levels of irrigation frequency at (5), (7) and (9) days were used as a treatment. Additionally, one treatment farmer practice of irrigation depth and interval has been used as a control. The experimental result showed that irrigation application of I_1 CROPWAT generated depth at 5 days irrigation interval obtained a relatively higher and statistically significant marketable yield, water productivity on both Ziqualla and Abergelle. , Congruently, in terms of economic profitability, it was found that irrigation application I_1 CROPWAT generated depth at 5 days irrigation interval had 7.7 ton/ha and 6 ton/ha economical yield advantageous as compared to the irrigation application of I_2 CROPWAT generated depth with 7 days irrigation interval on Ziqualla and Abergelle. Considering the above results, irrigation application of I_1 CROPWAT generated depth at 5 days interval was found economically feasible and recommended to improve crop and water productivity of the irrigation schemes by saving a significant amount of water for irrigating additional lands for hot pepper crop production both in Ziqualla and Abergelle small-scale irrigation schemes.

Keywords: Hot pepper, Irrigation regime, Marketable yield, Wag-himra, Water productivity,

Introduction

Hot pepper *(Capsicum annum L.)* is an important commercial crop, cultivated for vegetable, spice, and value-added processed products (Nalla *et al.*, 2017). It originated from the American with their cultivars are now grown around the world because they are widely used as food and medicine (Mazourek *et al.*, 2009). Peppers are one of the most susceptible horticultural crops to drought stress due to its broad range of transpiring leaf surface, high stomatal conductance(Alvino *et al.*, 1994) and shallow root system (Kulkarni and Phalke, 2009, Liu *et al.*, 2012). Pepper production accounts for 34% of the total spice production in the three regions of Ethiopia namely Amhara, Oromia and Southern Nations Nationalities and Peoples Regional States (Roukens *et al.*, 2005). FAO, (2009) report indicated that the estimated production of peppers in Ethiopia was 220,791ton from 97,712 ha in green form and 118,514 ton of dry pepper from an area of 300,000 ha.

Increase in population has led to an upsurge in the demand of food (pepper) and fiber which has also resulted in the adoption of irrigation to sustain plant growth(Delfine *et al.*, 2001). As population rises and development calls for the distributions of ground and surface water for domestic, agriculture and industrial sectors augmented; as a result, the pressure on water resources strengthens. The increasing stress on freshwater resources transported about by an ever-rising demand for water is of thoughtful concern (FAO, 2008).

Notwithstanding the increase in water use by subdivisions other than agriculture, irrigation carries on to be the main water user on a worldwide. Irrigated agriculture consumes more than 70% of the water demanding from the rivers of the world and for the developing world; the proportion can reach 80% (FAO, 2002). The condition is no more different in Ethiopia. It has been obviously and noisily stated that if Ethiopia is to feed its ever-increasing population, lessen the risk of disasters caused by drought, and increase population density in the dry and thinly populated areas, incessant and extensive effort need to be made towards developing irrigated agriculture and intensifying agricultural production. Irrigation will, therefore, play a progressively important role now and in the upcoming both to increase the yield from already refined land and to permit the cultivation of what is today called marginal or unusable land due to moisture deficiency.

Water availability is the most limiting factor for crop production in the dry-land areas of Ziqualla and Abergelle. Moreover, lack of crop water requirement studies for major crops had been a challenge for appropriate utilization of scarce water resource in irrigated agriculture and it leads to low water use efficiency through improper irrigation scheduling.

Determination of water requirement of the crop, appropriate irrigation scheduling can be designed, which can lead to improvements in the yield, income, and water saving(Bossie *et al.*, 2009). To ensure the highest crop production with the least water use, it is important to know the water requirement of the crops(Tyagi *et al.*, 2000). This improves the efficient and economic use of irrigation water. However, effective irrigation water management is possible only with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Applying too much water to the plot of land will cause to extra pumping costs, wasted water due to evaporation and runoff, and increased risk for leaching valuable agrichemicals below the rooting zone.

Proper timing of irrigation water applications is therefore an important decision tool for a farm manager to meet the water needs of the crop, to prevent yield loss due to water stress, and for maximizing the irrigation water use efficiency which resulted in beneficial use and conservation of the scarce water resources, and minimize the leaching potential of nitrates (Valipour, 2015). Ziqualla and Abergelle woreda, small-scale irrigation scheme is typically applied on a monotonous basis without scheduling and inadequate management of irrigation water has been an important limiting factor to pepper production. Growers generally lack knowledge on features of soil-water-plant relationship and they apply water to the crop irrespective of the plant needs. They seem to relate irrigation occurrence to days after planting with fixed intervals and water amounts rather than to crop stage progress. The knowledge of proper irrigation scheduling, when to irrigate and how much water to apply, is essential to optimize crop production per unit water and for sustaining irrigated agriculture on permanent footing(Kirda, 2002). Therefore, this study was conducted with the objective of determining the net irrigation requirements and irrigation schedules of hot pepper using CROPWAT computer model and to validate using a field trial.

Material and methods

A field experiment was conducted during 2014 and 2015 in Ziqualla and Abergelle district, Wag Himra Administrative Zone of Amhara Region (Figure 1). The study sites are located at 1414332N and 475070E at Ziqualla; 1425280N and 495749E at Abergelle. The altitude of the study areas are 1465m and 1260m Ziqualla and Abergelle m.a.s.l respectively. The soil samples from the study area were collected and analyzed, characterized the soil at Sekota dry land agricultural research center (SDARC)and Mekelle university soil laboratory. The sites are characterized by clay texture soils. The soil particle size distribution of clay, silt, and sand is 41.29%, 29.92%, 28.79% at Ziqualla and 41.3%, 26.7%, 32% at Abergelle, respectively (SDARC Soil Laboratory). The soil moisture content field capacity and permanent wilting point of the sites are 32.92% and 19.03% for Ziqualla and 32.51% and 16.28% for Abergelle (Mekelle University soil Laboratory).

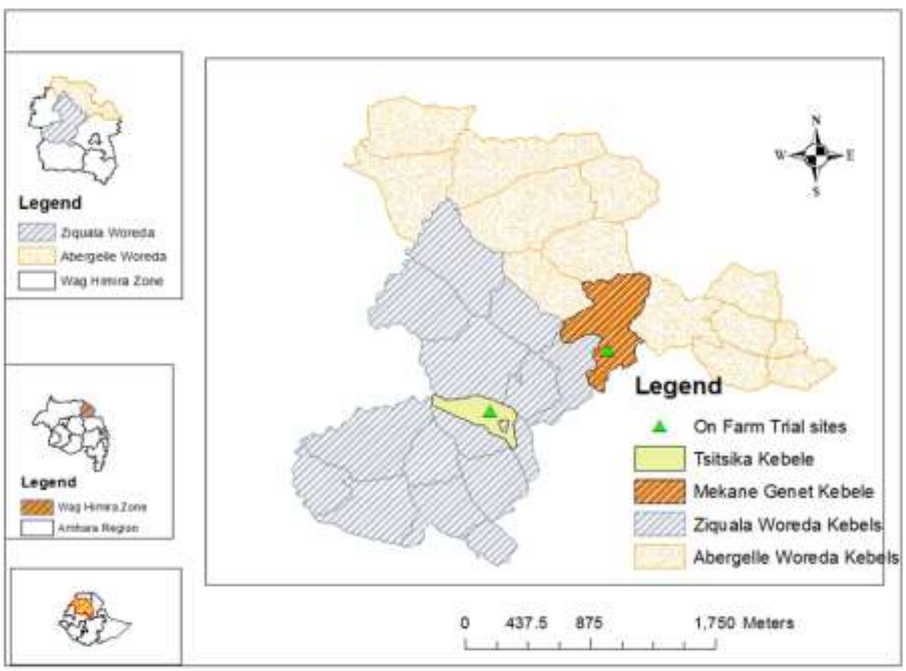

Figure1. Location map of study areas

Experimental setup

The experimental design was split plot with replicated three times. The experimental plot of 2.8m by 3m was used to test irrigation regimes. Hot pepper (Marko fana) was selected as the test crop. The selected marko fana has a production cycle of 125 days including transplanting up to second harvesting with the initial crop growth stage of about 20 days, crop development stage of 35 days, mid-season stage of 50 days and late season stage of 20 days, which was derived from CROPWAT software. Plant spacing was set at 70cm and 30cm between rows and plants, respectively. Blanket recommended fertilizer rate of Dia Ammonium Phosphate (DAP) 100kg/ha at transplanting and urea fertilizer of 100kg/ha at half transplanting and half 45 days was applied in both experimental sites. Both diseases and weed infestations were regularly monitored, and proper management action has been undertaken timely. Cutworms were observed during the early seedling establishments on the actual field, whereas Fusarium wilt was a problem at a vegetative and plant development stages. Karate and Mancozeb (3kg/ha) were used to control the disease infestation which was practiced according to the label in the bag.

CROPWAT optimum depth and interval was considered as a benchmark to set ten irrigation regime treatments including farmers practice. A split-plot design with three replications was used at which water depth assigned as main plot and interval as subplot treatments. The depth of irrigation was fixed at (I3), (I2), and (I1) of optimum CROPWAT generated depth and irrigation interval of (5), (7), and (9) days. The hand held watering cane was used to measure the amount of water entering in to each furrow with the experimental plot(Yihun, 2015).

Table 16. CROPWAT fixed application depth and optimal time of application on amount of applied water (mm) treatments in the experimental area.

Treatments	Amount of applied water(mm)	
	Ziqualla	Abergelle
125% (I3)CROPWAT fixed depth (and optimal time of application at 5-day interval	455.3	445.7
125%(I3) CROPWAT fixed depth and optimal time of application at 7-day interval	406.9	397.2
125% (I3)CROPWAT fixed depth and optimal time of application at 9-day interval	343.2	338.1
100% (I2)CROPWAT fixed depth and optimal time of application at 5-day interval	288.2	295.3
100%(I2) CROPWAT fixed depth and optimal time of application at 7-day interval	284.8	279.4
100%(I2) CROPWAT fixed depth and optimal time of application at 9-day interval	251.1	247.9
75%(I1) CROPWAT fixed depth and optimal time of application at 5-day interval	225.7	229.1
75%(I1) CROPWAT fixed depth and optimal time of application at 7-day interval	233.9	240.7
75%(I1) CROPWAT fixed depth and optimal time of application at 9-day interval	222.9	218.2
Farmer's practice irrigation depth (Fd) and irrigation interval in days (Ff)	728.5	796.5

Determination of reference evapotranspiration

The reference evapotranspiration (ETo) on daily basis was calculated by applying the modified FAO Penman-Monteith equation based on daily record of climatic data (Allen *et al.*, 1998) using FAO CROPWAT software version 8.0. The input data for the CROPWAT software includes location i.e. altitude, latitude, and longitude of the meteorological station, daily values of maximum and minimum air temperatures, air humidity, sunshine duration, and wind speed were used from the nearest meteorological station located on the experimental field.

Determination of Crop Water Requirement using CROPWAT

The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and hot pepper crop coefficient (Kc) given by (Allen *et al.,* 1998) as 0.5 for the initial stage, 0.5<Kc<1.15 for the crop development stage, 1.15 for the mid-season stage and 0.6 for the late season stage. Calculation of crop water requirement (ETc) using CROPWAT software over the growing season was from ETo and crop coefficient (Kc).

ETc=ETo*Kc--Equation (1)

Where, ETc = actual evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day). The net irrigation requirement was calculated using the CROPWAT software based on (Allen *et al.,* 1998) as follows:

IRn=ETc-Pe---Equation (2)

Where, IRn =Net irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (pe) was estimated using the method given by (Allen *et al.*, 1998) as.

Pe = 0.6 * P – 10/3 for P month <= 70 mm or---Equation (3)

Pe = 0.8 * P – 24/3 for P month > 70 mm--Equation (4)

Where, Pe (mm) = effective rainfall and P (mm) = total rain fall.

Composite soil samples were collected from field plots and the soil textural analysis was done by hydrometer and soil textural class was determined from soil textural triangle. Field capacity, permanent wilting point, and moisture at saturation were determined using Pressure plate apparatus from laboratory analysis of soil samples. Total Available Moisture (TAM) in the soil for the crop during the growing season was calculated as field capacity minus wilting point times the rooting depth of the crop.

Readily Available Moisture (RAM) was calculated as TAM*P, Where P is the depletion fraction as defined by the crop coefficient (Kc) files. Water productivity, also known as water use efficiency, was determined as the ratio of crop yield per unit area, in terms of grain, to crop evapotranspiration (mm), and was expressed as kg of grain or biomass per m^3 of consumed water.

$$\text{water productivity}\left(\frac{\text{kg}}{\text{m3}}\right) = \frac{\text{Total yield of green pepper}}{\text{water delivered up to harvesting}}$$

Data analysis

All the agronomic data like plant height, pod length, pod diameter, canopy diamter, yield and water productivity were recorded and being subjected to analysis. Analysis of variance and correlation was performed using SAS Statistical Software Version 9.1. Effects were considered significant in all statistical calculations if the P-values were ≤ 0.05. Means were separated using Fisher’s Least Significant Difference (LSD) test.

Results and Discussion

The result revealed that I1 and I2 CROPWAT generated depth using 5 and 7days irrigation interval improved marketable yield, total yield and water productivity of hot pepper production respectivly. But farmers’ irrigation scheduling and depth application practices provided low yield gain because of more apply water and some of gap irrigation intervals cause water logging, plants are not freely aired. In general, I1 CROPWAT generated depth at 5 days irrigation interval provided a better yield and yield related components (Table 2). The result in agreement with the finding of (Yang *et al.*, 2017) who stated that water deficit from reducing irrigation amounts to 1/3 to 2/3 of full irrigation during the development and mid season stages did not affect pepper yield; compared with full irrigation, the water deficit even increased fruit yields. These results occurred mainly because the water content under deficit irrigation in the study by (Yang *et al.*, 2017) still reached higher than 70% of FC, which is sufficient for pepper growth (Liu *et al.*, 2012). At the same time, full irrigation with a water content of 100% of FC in their study is very high and can reduce pepper yields (Liu *et al.*, 2012). This study could be used for irrigating an additional land of 0.28 ha. The finding was in line with (Serna and Zegbe, 2012) who described in the hot pepper study, a water deficit of 15–45% application can conserve 8–30% of irrigation water, compared with full irrigation. Moreover, those study I1 CROPWAT generated depth application at 5 days irrigation interval as compared to farmer's practice, irrigation scheduling and application depth saved 5028m^3/ha amount of irrigation water (Table 1). This amount of irrigation water could be used to irrigate an additional irrigation land of 2.2ha with a yield benefit of 25.2ton/ha of hot pepper crop production.

Table 17. Interaction effects of depth and frequency on marketable yield, total yield, and water productivity on Ziqualla.

	Total yield(ton/ha)				Marketable yield(ton/ha)				Water productivity(kg/m^3)			
	Depth				Depth				Depth			
Frequency	I1	I2	I3	Fd	I1	I2	I3	Fd	I1	I2	I3	Fd
5 days	11.5	9.3	9.2		11.2	9.0	8.9		5.06	3.85	2.63	
7 days	9.1	11.6	9.1		8.8	11.3	8.8		2.86	4.55	2.87	
9 days	3.1	3.1	3.4		2.8	2.7	3.1		1.82	1.56	1.33	
Ff				5.7				5.4				1.64
LSD	0.9				1.0				0.57			
Cv (%)	10.09				10.13				15.21			

Where, I1=75% crop water requirement, I2=100% crop water requirement, I3=125% crop water requirement, Fd=farmer practice irrigation depth, Ff=farmer practice irrigation interval.

There were non-interaction effects in both depth and frequency on pod length, pod diameter, number of pod per plant, plant height, canopy diameter and the unmarketable yield on Ziqualla experimental site. The optimum application of I1, I2, CROPWAT generated depth had better pod length, pod diameter and a number of pod per plant compared with irrigation application of farmers' practice. Considering the interval of the irrigation application, statistically, there was non-significance difference in terms of pod length, pod diameter, number of pod per plant, canopy diameter and unmarketable yield for 5 and 7 days interval.

For instance, the farmer's irrigation practices contributed to the lowest pod length of 6.42 cm whereas irrigation application with 5, 7, days irrigation interval had 9.4, 8.96 cm, respectively. This result was in line with (Delelegn, 2011) who informed that hot pepper which obtained a better pod diameter and pod length using Mareko Fana at Jimma areas. The result of I1 CROPWAT generated depth and irrigation application of 5 days irrigation interval offered the highest value for the yield and yield related parameters of Ziqualla experimental site (Table 3). The result indicated that the variability of the amount of water application and irrigation interval has a significant effect on yield and yield correlated component for hot pepper.

Table 3. Effects of depth and frequency on pod length, pod diameter, No pod per plant, plant height, canopy diameter and unmarketable yield at Ziqua1la experimental site.

Treatment	Pod length (cm)	Pod diameter (cm)	No of pod per plant	Plant height (cm)	Canopy diameter (cm)	Unmarketable yield (ton/ha)
Depth						
I1	9.06a	1.47a	18.78a	71.33a	39.34a	0.24a
I2	8.80a	1.45a	20.15a	70.62a	38.97a	0.27a
I3	8.92a	1.41a	19.65a	69.07a	38.01ab	0.26a
Fp	6.42b	1.18b	13.96b	64.30a	34.56b	0.27a
LSD	1.97	0.19	3.15	9.95	3.67	0.09
Cv (%)	17.09	10.57	12.47	10.71	7.18	27.14
Frequency						
5 days	9.40a	1.51a	23.85a	76.32a	42.28a	0.25a
7 days	8.96a	1.45a	22.36a	71.82ab	42.44a	0.24a
9 days	8.42a	1.37ab	12.37b	62.90b	31.60b	0.27a
Fp	6.42b	1.18b	13.96b	64.30b	34.56b	0.29a
LSD	1.97	0.19	3.15	9.95	3.67	0.09
Cv (%)	17.09	10.57	12.47	10.71	7.18	27.14

Correlation analysis between yield parameters was tested using t-test as shown in table 4. The result revealed that a highly correlation coefficient ($r \geq 0.9$) of marketable yield with a number of pod per plant, total yield, and water productivity. Similarly, water productivity had also a highly significant correlation (r≥0.8) with the number of pod per plant. However, unmarketable yield was negatively correlated with other parameters at p<0.05 probability (Table 4).

Table 18. Correlation coefficient of the different parameter (number of pod per plant, marketable yield, unmarketable yield, total yield, and water productivity) from the study data.

Parameters	Number of pod per plant	Marketable yield	Unmarketable yield	Total yield	Water productivity
Number of pod per plant	1				
Marketable yield	0.93***	1			
Unmarketable yield	-0.11ns	-0.15 ns	1		
Total yield	0.93***	0.99***	-0.12ns	1	
Water productivity	0.84**	0.90***	-0.13ns	0.90***	1

*(P≤0.05) *** Very highly significant, ** Very significant, * significant, ns none significant*

There was an interaction effect both in depth and irrigation frequency on a number of pod per plant, marketable yield, total yield, and water productivity in Abergelle sites(Table 5). The effect indicated that irrigation application of I1 and I2 CROPWAT generated depth with 5 and 7 days irrigation intervals were recorded the highest pods per plant, marketable yield, total yield, and water productivity respectively. These results provided statistically significant pods per plant, marketable yield, total yield, water productivity compared with other treatments. They had a yield enhancement of 3.1ton/ha and 2.8 ton/ha in that order related to the farmer's irrigation application practices. In relationships of water productivity, irrigation application of CROPWAT generated depth I1 and I2 with 5 days irrigation interval, about 662m3/ha amount of irrigation water was saved which would like to irrigate an additional lands of 0.29 ha that produce 2.6 ton/ha. The yield variance between the two application depth was 3.7 ton/ha of hot pepper crop yield advantages by using I1 CROPWAT generated depth. In the same way, as compared to farmer irrigation practices, 5675m3/ha amount of irrigation water, which could confine to irrigate another land of 2.4ha that produces 22.1ton/ha yield gain of hot pepper production in Abergelle areas. (Zegbe-Dominguez et al., 2003, Kang et al., 2001) reported that for optimum irrigation scheduling, sound knowledge of the soil-water status, crop water requirements, crop stress status, potential yield reduction if the crops remain in stressed condition is required to maximize yield and optimizes water productivity.

Table 19. The interaction effects of depth and frequency on N<u>o</u> of pod per plant, total yield, marketable yield and water productivity in Abergelle experimental site.

	No of pod per plant				Total yield (ton/ha)				Marketable yield(ton/ha)				Water productivity(kg/m^3)			
	Depth				Depth				Depth				Depth			
Frequency	I1	I2	I3	Fd	I1	I2	I3	Fd	I1	I2	I3	Fd	I1	I2	I3	Fd
5 days	19.6	17.6	17.3		9.2	8.0	7.6		8.8	7.8	7.2		4.10	3.14	2.00	
7 days	13.9	20.0	18.7		7.8	8.9	7.9		7.5	8.6	7.5		2.92	4.09	2.73	
9 days	10.4	12.9	14.4		3.0	2.8	3.0		2.6	2.5	2.7		1.91	1.29	1.19	
Ff				13.0				6.0				5.7				0.88
LSD	2.30				0.7				0.7				0.35			
Cv (%)	10.96				8.35				8.89				10.97			

Where, I1=75% crop water requirement, I2=100% crop water requirement, I3=125% crop water requirement, Fd=farmer practice irrigation depth, Ff=farmer practice irrigation interval.

Not at all interaction effects in both depth and frequency on pod length, pod diameter, plant height, canopy diameter and unmarketable yield of a hot pepper crops trendy instance of Abergelle. Since, irrigation interval point of view, the table exhibited that there were the non-significance difference between irrigation application of 5 and 7 days in terms of pod length, pod diameter, plant height, and canopy diameter.

Table 20. Effects of depth and frequency on pod length, pod diameter, plant height, canopy diameter and the unmarketable yield on Abergelle.

Treatment	Pod length (cm)	Pod diameter (cm)	Plant height (cm)	Canopy diameter (cm)	Unmarketable yield (ton/ha)
Depth					
I1	8.41a	0.80ab	69.90a	39.48a	0.31ab
I2	8.21a	0.85a	69.02a	37.91ab	0.25b
I3	8.24a	0.86a	68.95a	38.05ab	0.34a
Fd	7.41a	0.65b	68.00a	32.26b	0.33ab
LSD (0.05)	1.67	0.15	9.66	6.90	0.08
Cv (%)	15.28	13.94	10.49	13.68	19.72
Frequency					
5 days	9.46a	0.93a	72.22a	41.82a	0.35a
7 days	8.83ab	0.90a	70.87a	41.65a	0.27b
9 days	6.58c	0.67b	64.77a	31.97b	0.28ab
Ff	7.41bc	0.65b	68.00a	32.26b	0.33ab
LSD (0.05)	1.67	0.15	9.66	6.90	0.08
Cv (%)	15.28	13.94	10.49	13.68	19.72

The correlation coefficient analysis such as indicated that marketable yield was significantly correlated ($r \geq 0.9$) with total yield, and also water productivity was significantly correlated through marketable yield and total yield ($r \geq 0.8$), but negatively correlated with unmarketable yield (Table 7). The t-test analysis for correlation coefficient with 95% confidence interval showed that there was a significant difference in all the parameters except unmarketable yield.

Table 21. Correlation coefficient of different parameters (number of pod per plant, marketable yield, unmarketable yield, total yield, and water productivity) from the study data.

Parameters	Number of pod per plant	Marketable yield	Unmarketable yield	Total yield	Water productivity
Number of pod per plant	1				
Marketable yield	0.78*	1			
Unmarketable yield	0.04ns	0.09 ns	1		
Total yield	0.78*	0.99***	0.12 ns	1	
Water productivity	0.73*	0.81**	-0.08ns	0.80 **	1

*($P \leq 0.05$) *** Very highly significant, ** Very significant, * significant, ^{ns} none significant*

Conclusion and recommendation

The results of the experiment was conducted at Ziqualla, Tsitsika small-scale irrigation scheme, and Abergelle, Bahir small-scale irrigation scheme. Application of irrigation depth at specific irrigation interval has shown a significant effect on yield and water productivity when compared with farmers' irrigating practices. Irrigation application of I1 and I2 CROPWAT generated depth at 5 and 7 days irrigation interval provided a relatively significant and higher value in terms of yield and yield related parameters including marketable yield and water productivity both on Ziqualla and Abergelle. Comparing with farmers' practice, I1 CROPWAT generated depth at 5 days irrigation intervals saved irrigation water that would irrigate an additional land of about 2.2ha on Ziqualla and 2.4ha on Abergelle. Hence, research intervention was very important for improving crop production by saving a significant amount of water for irrigating the additional land in the study areas.

However, considering the economic advantage of water productivity between I1 CROPWAT generated depth at 5 days irrigation interval and I1 CROPWAT generated depth at 7 days irrigation interval, I1 depth at 5 days interval had a relatively higher yield advantage of 7.8 ton/ha and 6.1ton/ha on Ziqualla and Abergelle, respectively. Considering this, the irrigation application of I1 CROPWAT generated depth at 5 days irrigation interval was found economically feasible. Accordingly, it is recommended to be used by the farmers and other water users in Ziqualla and Abergelle woreda and other similar agro-ecological zones. Furthermore, further research on fertilizer rate for hot pepper under irrigation is suggested.

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Evaluation of supplementary irrigation for sorghum yield improvement in Wag-Himra, North Eastern, Amhara, Ethiopia

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Abstract

Water is the most limiting factor for agricultural production in dry land areas of Wag-Himra. Supplying of adequate water is very crucial in stabilizing crop yields and increasing their production and productivity of sorghum. Therefore, the experiment was conducted for two cropping seasons (2014 to 2015) at Aybra on a farmer's plot in Sekota, Wag-Himra, North Eastern Amhara. The study aims to evaluate different supplementary irrigation potentials on Sorghum yield and water productivity. The design of the experiment was Randomized Complete Block Design (RCBD) and seven treatments (C1, C2, FMSO, S1, S2, S3, and S4) with three replications were tested. The statistical analysis indicated that there was a significant difference in head weight, grain yield, stem diameter, and water productivity of sorghum among treatments. The analysis of variance for both years showed that there was a significant interaction effect between treatments across years on head weight, grain yield, and water productivity. Supplementing the sorghum crop with S3 and S1 treatments with an application of 219.4mm and 328.4mm of irrigation water respectively at eight days interval during moisture stress time better head weight, grain yield, water productivity, and stem diameter was obtained. Therefore, this study recommended that supplementing rain-fed for sorghum production starting from the development stage (20 days after sowing down to harvesting) with an application of 328.4mm irrigation water at eight days interval. However, water is a limiting factor for crop production supplementing during development and mid-season stage only 219.4mm application of irrigation water at eight days interval at moisture stress or rainfall is ceased.

Keywords: Irrigation requirement, Sorghum, Supplementary, Wag-himra, water use efficiency

Introduction

Rainfall is the major source of water for agricultural production. However, farmers' grain yield in rain-fed regions in developing countries is low largely due to low rainwater use efficiency because of non-optimal soil, water, nutrient and pest management options, as well as a shortage of seeds from improved cultivars (Rockström and Barron, 2007, Wani *et al.*, 2008). There are three primary ways to develop rain-fed agricultural production, namely: (i) enhance the effective rainfall use through improved water management; (ii) increase crop yields in rain-fed areas through agricultural research; and (iii) transform policies and improved investment in rain-fed areas. As the Amhara Regional State Government is emphasizing on irrigation-based agriculture to attain food security at the household level, appropriate technologies must be available for adoption by farmers. This focuses on the first way, in which supplemental irrigation plays a major role in increasing water use efficiency and yields of rain-fed crops. For instance, a supplemental irrigation study (Rockström *et al.*, 2002) carried out in Burkina Faso (seasonal rainfall of 418-667mm) and Kenya (seasonal rainfall of 196-557mm) reported 37-38% increase in sorghum grain yield by supplemental irrigation alone.

Estimating seasonal rainfall characteristics based on records is of importance to assess drought risk and to improve drought mitigation strategies such as supplementary irrigation. There have been reported of rainfall variability and drought associated food shortage (Tilahun, 1999, Bewket and Conway, 2007). So, farmers and private sales are now opting for the production of sorghum under supplemental and/or full irrigation (Shenkut *et al.*, 2013). Water scarcity is a common feature of Northern Ethiopia; particularly in Wag-Himra (Bekele, 2006, Araya *et al.*, 2011, Feyisa, 2016). Due to this, moisture stress is the major limiting factor for crop production which highly reduces the crop yield in these areas.

One of the approaches taken as a countermeasure to the unpredictable rain to overcome such problems is using supplementary irrigation during the growing season. Supplemental irrigation (SI) is a highly efficient option to achieve this strategic goal by providing the crop with the required amount of water at the required time (Oweis, 1997). Applying 50% of full supplemental irrigation requirements would reduce yield by 10-15% while applying the saved water to lands otherwise rain-fed increased the total farm production by 38% (Oweis, 1997, Oweis and Hachum, 2006). Alleviating soil moisture stress during the critical crop growth stages is the key to improved production. In this study area, supplementary irrigation is necessary for the increment of sorghum grain yield and yield components and enhancement of food security. However, the additional amount of water alone may be inadequate for crop production, as irrigation timing relative to critical crop growth stages is critical. Therefore, this study was conducted to evaluate different supplementary irrigation potentials on Sorghum yield and water productivity.

Materials and methods

Description of the study area

The experiment was conducted for two cropping seasons (2014 to 2015) at Fikire Selam Kebele on a farmer’s plot in Sekota woreda, Wag-himra, North Eastern Amhara, 12.680N Latitude, 39.010 E Longitude and at an altitude of 1976 m.a.s.l. The mean maximum and minimum temperatures are 26.5 and 12.1oc respectively and the mean annual rainfall in the area was 275.7mm with a considerable year-to-year variation. But this amount of rainfall didn't fulfill the crop water requirement in the growing season. Such rainfall variation results in a range of conditions under which the use of supplemental irrigation is a useful option to improve and stabilize yields.

Analysis of soil samples for the major soil physical and chemical properties was done at Sekota Dry-Land Agricultural research center soil laboratory and soil moisture content at Mekelle Soil Research Center. The result of the soil analysis from the study area showed that the average composition of sand, silt, and clay percentages were determined. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil.

The organic matter content of the soil is taken as a basic measure of fertility status. Organic Matter (OM) is considered to improve water-holding capacity, nutrient release, and soil structure. The composite soil sample contributed soil OM which is rated as low shown in table 1. This was in agreement with findings of (Okalebo et al., 2002) who reported that soils having OM value in the range of 0.86-2.59% are considered low. Thus it needs additional materials or nutrients that increase the amount of organic matter in the soils.

As described in the table below, the salinity of soil (ECe) of the experimental site was determined. According to (Hazelton and Murphy, 2007) soils having the ECe less than 4dS m-1 are considered as non-saline and suitable for crop production. Moreover, the pH value of the experimental site was secure. According to (Chimdi et al., 2012), soils having pH value in the ranges are considered neutral soils. The topsoil surface had a slightly lower bulk density (1.2g/cm3) than the subsurface (1.26g/cm3) which might be due to high organic matter contents in the topsoil surface and the compaction level increased in the lower part. But in general, the average soil bulk density (1.24 g/cm3) and which was suitable for crop root growth.

The average soil moisture content values at the field capacity of the experimental site were 39.26, 33, and 18% at 0-30, 30-85, and 85-105cm soil depths, respectively. The moisture content at the permanent wilting point also showed variation with depth and increasing from the surface to the lower depth. The total available water (TAW) that is the amount of water that a crop can extract from its root zone is directly related to variation in FC and PWP and its root depth.

Table 1. Soil physical and chemical characteristics of the experimental site

Depth (cm)	Textural classification				Bulk density (g/cm3)	Organic matter (%)	PH	EC (ds/m)	FC (%)	PWP (%)
	Sand (%)	Clay (%)	Silt (%)							
0-30	37.7	31.3	31	clay loam	1.2	1.55	6.9	0.15	39.3	13.12
30-85	51.2	25	23.8	sandy clay loam	1.25	1.18	6.7	0.27	33	13
85-105	35	36.3	28.7	clay loam	1.26	1.38	7.1	0.2	18	7

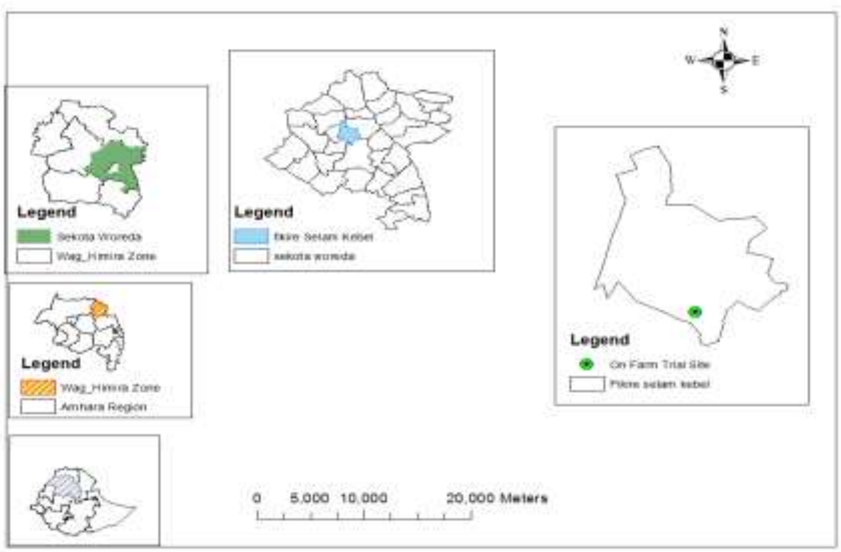

Figure 13. Map of the study area

Experimental design and Crop

The experimental design was a Randomized Complete Block Design (RCBD) replicated three times. The experimental Plots were 3m x 5m. The experimental treatments were seven with two control treatments (C1 and C2) (no supplementary irrigation). The experimental treatments were C1=rain-fed without a furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1=Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2=Supplementing the CROPWAT generated depth (100%) starting from the mid-season stage at eight days interval at moisture stress, S3=Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4=Supplementing the CROPWAT generated depth (100%) during the mid-season stage at eight days interval at moisture stress.

Irrigation water was applied using hand-held watering can having a fixed volume of water Conveyed to the furrow. Sorghum (Miskre variety), which has a relative maturity of 125 days was used as a test crop. Fertilizer was applied at the rate of 100kg/ha for Di Ammonium phosphate (DAP) at planting and 50kg/ha of urea (applied in two splits, half at planting and a half at 45 days after sowing). The crop data, crop type, planting date, growth stage in the day, maximum rooting depth, Kc values, depletion fraction, and yield reduction coefficient were used as inputs to the CROPWAT computer model.

Table 2. Length of the growing season and other factors of sorghum

Parameters	Crop growth stage				Total growing period
	Initial	Development	Mid-season	Late season	
Length of growing (days)	20	35	40	30	125
Crop coefficient (kc)	0.50	0.83	1.15	0.6	
Rooting depth (cm)	30	50	100	100	
Depletion level (p)	0.5	0.50	0.5	0.8	
Yield response factor (ky)	0.6	0.6	1.2	0.8	

Source: FAO CROPWAT model (Smith *et al.*, 2002)

Determination of reference evapotranspiration

Reference evapotranspiration (ETo) daily was calculated by applying the modified FAO Penman-Monteith equation and based on a daily time step (Allen et al., 1998) using FAO CROPWAT software version 8.0. The input data for the CROPWAT software includes location i.e. altitude, latitude, and longitude of the meteorological station, daily values of maximum and minimum air temperatures, air humidity, sunshine duration, and wind speed were used from a 10km meteorological station located on the experimental field.

Supplementary irrigation water requirement

The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and sorghum crop coefficient (Kc) given by (Allen et al., 1998) as 0.5 for the initial stage, 0.5<Kc<1.15 for the crop development stage, 1.15 for the mid-season stage and 0.6 for the late-season stage. Calculation of crop water requirement (ETc) using CROPWAT software over the growing season was from ETo and crop coefficient (Kc).

$$ETc = ETo*Kc \quad \text{------equation (1.1)}$$

Where, ETc = actual evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day). The net irrigation requirement was calculated using the CROPWAT software based on (Allen et al., 1998) as follows:

$$IRn = ETc - Pe \quad \text{------equation (1.2)}$$

Where, IRn = Net irrigation requirement (mm), ETc in mm, and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (pe) was estimated using the method given by (Allen et al., 1998).

$$Pe = 0.6 * P – 10/3 \text{ for P month} <= 70 \text{ mm or} \quad \text{------equation (1.3)}$$

$$Pe = 0.8 * P – 24/3 \text{ for P month} > 70 \text{ mm} \quad \text{------equation (1.4)}$$

Where, Pe (mm) = effective rainfall and P (mm) = total rain fall.

Water productivity, also known as water use efficiency, was determined as the ratio of grain yield per unit area divided by the total seasonal water use of the crop (rainfall + supplemental irrigation) (Irmak et al., 2011). Statistical analysis, (ANOVA) was used with SAS, to test the effects of seasonal supplemental irrigation water on grain yield, head weight, stem diameter, and water productivity during the two cropping seasons (2014 and 2015).

Soil and Water Sample Collection and Analysis

The soil samples were collected from the field experiment three sample based on the soil depth. The composite soil samples were collected and air-dried, thoroughly mixed. The samples were properly labeled, packed, and transported to the laboratory. The samples were dispersed after testing for pH, and soil organic matter (SOM). Soil textures were analyzed at Sekota dry land Agricultural research center Soil Laboratory. The soil pH was measured in the supernatant suspension of a 1: 2.5 using a Standard glass electrode pH meter (Carter and Gregorich, 2008). The soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962).

The water sample was taken from the site harvested rainwater which was used for the irrigation application. The plastic bottle was used to collect the water samples from the harvested rainwater. The water sample was labeled carefully and transported to the laboratory and analyzed for their selected chemical composition of pH and ECw. Laboratory analyses were done at Sekota dry-land Agricultural research center soil laboratory for selected chemical composition only for their pH and ECw. ECw of the water samples was measured using a conductivity meter. Field capacity and permanent wilting point of the experimental site was done.

Table 3. the treatment setup of supplementary irrigation on the experiment in the Wag-himra area.

	The 2014 Year			The 2015 Year			Mean of the two Years		
Treatment	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)
C1	351.7	351.7	0	199.7	199.7	0	275.7	275.7	0
C2	351.7	351.7	0	199.7	199.7	0	275.7	275.7	0
FMSO	481.7	351.7	130.0	656.3	199.7	456.6	569.0	275.7	293.3
S1	687.7	351.7	336.0	520.6	199.7	320.9	604.1	275.7	328.4
S2	650.3	351.7	298.6	453.7	199.7	254.0	552.0	275.7	276.3
S3	567.0	351.7	215.3	423.2	199.7	223.5	495.1	275.7	219.4
S4	529.6	351.7	177.9	356.3	199.7	156.6	443.0	275.7	167.3

Where, Treatments C1=rain-fed without a furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from the mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during the mid-season stage at eight days interval at moisture stress.

Result and discussion

Clear year-to-year variations were seen due to treatment effects. Although the actual rainfall amount which occurred in the second year was less than the long-term mean value, more rainfall was measured at the initial stage of sorghum affecting its growth and resulted in stunted growth. Moreover, the grain yield in the second year was highly affected by the damage of birds during the mid-season stage (at about maturity time)

The combined analysis showed that there was a highly significant difference among treatments in head weight, grain yield, and stem diameter and water productivity. Moreover, the treatments over year interaction result indicated that there was a highly significant difference in head weight, grain yield, and water productivity (Table 4). Table 5 indicated that in both 2014 and 2015 there was a statistically significant difference among experimental treatments in head weight, grain yield, stem diameter, and water productivity. However, there was no significant difference among treatments in plant height.

According to the result supplementing the crop with treatment S3 and S1 application of 219.4mm and 328.4mm of irrigation water respectively at eight days interval at moisture stress obtained better head weight, grain yield, water productivity, and stem diameter as compared to other treatments. But there was a statistically significant difference in grain yield and water productivity of sorghum. The result was in agreement with the finding of (Feyisa, 2016) who reported that supplementing the crop with S3 and S1 at eight days interval obtained good sorghum yield and yield-related parameters. The result was in line with (Ziadat, 2015) which reported that full supplementary irrigation of green pepper yield improvement of 32.6kg/ha compared with the unsupplementary irrigation of green pepper in Gumara maksegnit watershed. Similar to our result, the research conducted in India indicated that supplementary irrigation early during the vegetative growth stage and early reproductive stage on clay soils contributed to increased yield (Singh and Das, 1987). Sorghum grain yield under rain-fed condition control treatment constantly had a low yield in both experimental seasons 2014 and 2015. The production potential of the crop was particularly affected by rainfall amount and distribution season to season.

The seasonal water use (rainfall and supplemental irrigation) was used to calculate the water productivity of crops. The experimental results in water productivity of sorghum grain yield to improve from 0.30kg/m3 of water for rain-fed and 0.78kg/m3 of water at supplementary irrigation. The result was in line with the finding of (Zhang and Oweis, 1999) water productivity was about 0.96kg of wheat grain m−3 of water under rain-fed conditions and 1.36kg of wheat grain m−3 under supplemental irrigation. The result also was similarly that the finding of (Oweis and Hachum, 2009) reported supplemental irrigation caused rainwater productivity in northwest Syria to increase from 0.84kg/m3 of water for rain-fed and 1.06 kg/m3 of water at full supplemental irrigation. From our finding supplementing the crop with S3 at 2194m3/ha irrigation water application at eight days interval at moisture stress period evaluated to supplementing the 3284m3/ha of water irrigated S1 at eight days interval at moisture stress was achieved 1090m3/ha of water saved. This amount of applying the saved water also 0.49 hectares of additional lands was irrigated.

Table 22. Analysis of variance

Source of variation	Degree of freedom	Mean square			
		Head weight (kg/ha)	Grain yield (kg/ha)	Stem diameter (cm)	Water productivity (kg/m^3)
Treatment	6	14205114.55**	10533905.99**	0.05089**	0.33844**
Replication	2	28359.76	27152.19	0.00032	0.00195
Year	1	1560638.93 **	800253.77**	0.3564**	0.1060**
Treatment* year	6	99171.05**	58965.94**	0.0157	0.0113**
Error	26	21166.52	8676.45	0.0066	0.0005

***=Significant at (0.01) level of significance, *=Significant at (0.05) level of significance*

Table 23. Mean separation result of the effects of supplementary irrigation on head weight, grain yield, plant height, stem diameter, and water productivity

Treatment	The 2014 Year					The 2015 Year					Combined over Year			
	Head weight (kg/ha)	Grain yield (kg/ha)	plant height (cm)	Stem diameter(cm)	Water productivity(kg/m^3)	Head weight (kg/ha)	Grain yield (kg/ha)	plant height (cm)	Stem diameter(cm)	Water productivity(kg/m^3)	Head weight (kg/ha)	Grain yield (kg/ha)	Stem diameter (cm)	Water productivity(kg/m^3)
C1	1484.4e	804.4cd	152.4a	1.21c	0.23[e]	1311.1c	805.1d	139.6a	1.01b	0.40e	1397.8cd	804.8c	1.11c	0.32d
C2	2123.7d	949.8c	155.3a	1.2c	0.27d	1188.9c	639.1e	142.6a	1.16ab	0.32f	1656.3c	794.5c	1.20bc	0.30d
FMSO	1437.8e	646.6d	156.9a	1.37b	0.13f	1022.2c	602.1e	148.7a	1.16ab	0.09g	1230d	624.4c	1.27abc	0.11e
S1	3983.7c	3063.1b	158.8a	1.31b	0.44c	3695.8b	2599.8c	138.8a	1.30a	0.50d	3839.8b	2831.5b	1.31ab	0.47c
S2	4081.0c	3029.8b	156.6a	1.22c	0.47c	3700b	2696c	140.4a	1.18ab	0.60c	3890.5b	2862.9b	1.21bc	0.53c
S3	5110.4a	4089.8a	151.2a	1.47a	0.72a	4904.2a	3558.1a	140.4a	1.16ab	0.84a	5007.3a	3824a	1.32ab	0.78a
S4	4233.3b	3166.0b	164.0a	1.46a	0.60b	3933.4b	2916.8b	145.3a	1.29a	0.79b	4083.4b	3041.4b	1.39a	0.69b
Cv (%)	2.15	4.08	6.94	3.32	4.72	7.1	4.22	6.60	9.13	4.82	9.5	9.68	10.92	16.49
LSD (0.05%)	122.71	163.22	19.34	0.07	0.03	356.59	148.28	16.71	0.18	0.04	336.36	240.17	0.16	0.08

Where, Treatments, C1=rain-fed without a furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from the mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during a mid-season stage at eight days interval at moisture stress.

Conclusion and recommendation

Supplemental irrigation is a viable irrigation management scheme that can be used by farmers in a dry- land area like Wag-himra to enhance and stabilize their rain-fed grain sorghum production. Supplemental irrigation using a limited amount of water, if applied during the critical crop growth stages of vegetative and early reproductive, can result in a substantial improvement in yield and water productivity. The application of supplemental irrigation can also assist the crop to escape critical stages particularly terminal drought or moisture deficit. In rain-fed dry areas, where water is the most limiting factor, the priority should be to maximize yield per unit of water rather than yield per unit of land.

As a result, it can be concluded that dry-land areas like wag-himra which has problems of rainfall distribution and amount and have access to irrigation water can increase their yield advantage 835.2 kg/ha by supplementary irrigation starting from the crop development stage up to harvesting stage at eight days interval following moisture deficiency indicators like crop physiological indicator and soil moisture stress with amount of 328.4mm seasonal irrigation water requirement for improving the variety of sorghum (Miskre) from the analysis of the two-year results.

As an option, if the water is the restraining factor during the sorghum growing season, applying supplementary irrigation only during development and mid-season stages at eight days intervals on moisture stress can give good grain yield, head weight, and water productivity and it had grain yield improvement of 728.5 kg/ha. Therefore, it is possible to recommend supplementary irrigation for sorghum production starting from the development stage (20 days after sowing down to harvesting) (328.4 mm) at eight days interval. However, if still water is highly scarce supplementing during development and mid-season stages only (219.4 mm) every eight days interval at moisture stress is recommended.

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Verification of the efficiency of alternate furrow irrigation on water productivity and onion yield in Sekota Woreda

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Abstract

The experiment was conducted on 2017/2018 irrigation season in woleh irrigation scheme Sekota woreda. Three irrigation methods, alternating furrow irrigation (AFI), conventional furrow irrigation (CFI) and fixed furrow irrigation were verified on three separate plots. Each irrigation method was using 75% amount of irrigation water for each methods at five days irrigation interval, were verified for irrigated onion. The results shows that total irrigation water applied in the AFI and FFI treatment was roughly half (3038m^3) that applied to the CFI treatment (6078m^3). There was significant reduction in irrigation water used with the AFI but a non-significant reduction on the onion yield production. The AFI water productivity was a stastically significantly difference from FFI and CFI. The water productivity obtained 4.05 kg m^{-3} with AFI and 3.16 kg m^{-3} with FFI which was nearly double the 2.15 kg m^{-3} with CFI. Alternate furrow irrigation (AFI) is gaining interest as a means of saving water while minimizing loss in crop production. Given the potential water savings of AFI, a field experiment was conducted in Sekota woreda at woleh irrigation scheme by growing onion with AFI, conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI) in which every furrow irrigated. While this reduction in yield and/or potential income may appear small, it could be critical to the welfare of individual farmers, who may as a result hesitate to make changes from CFI to AFI. Therefore; it is recommended that areas with insufficient water resource for irrigation in Sekota or agro-climatically similar areas can use 75% of irrigation water at five days irrigation interval in alternate furrow irrigation methods throughout the growing season, for optimum production of irrigated onion.

Key words: Alternate furrow, conventional irrigation, fixed furrow, irrigation amount, yield

Introduction

Onion (*Allium cepa* L.) belongs to the genus Allium of the family Alliaceous which was believed to be originated in southwestern Asia, being the center of domestication and variability, from where it was spread first across the world and has been cultivated for over 4700 years as annuals for bulb production purposes(Brewster, 2008). The onion is recognized as one of the most important vegetable crops that cultivated throughout the world since its introduction to the worlds. It has grown mainly as a food source and used as cousins and value addition for different dishes. In Ethiopia, the consumption of the crop is very important in the food seasoning and in daily stews as well as in different vegetable food preparation uses and also the chemical flavonoids, anthocyanins, fructo-oligosaccharides and organosulphur compounds found in the onion is considered as medicinal and health benefits to fight different diseases including cancer, heart and diabetic diseases(Goldman, 2011).

Onion is one of the most popular vegetables in Ethiopia with a volume of2, 648,493.54 Quintal onion bulbs from 29,517.01ha of lands. Onion is among the largest production and highly commercialized vegetable crops in Amhara region grown under irrigation. Currently farmers in most irrigable areas of the Amhara region produce large amount of onion bulbs every year. For instance, in 2015/16 production year the region have 12,262.79 hectare of land covered by onion crop (*CSA*, *2016*).Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem. During the last two decades, water–saving irrigation techniques such as deficit irrigation (DI) and partial root zonedrying (PRD) or alternative furrow irrigation (AFI) have been developed and tested for field crops and fruit trees. Most recently, these irrigation techniques are being tested also in vegetable crops such as tomatoes(Zegbe-Domınguez *et al.*, 2003). Water use efficiency should be improved by reduced leaf Transpiration .Stomata control the door of plant gas exchange and transpiration water loss. Recent Investigations have shown that stomata may directly respond to the availability of water in the soil such that they may reduce their opening according to the amount of water available in the soil. Alternate furrow irrigation was practiced for a number of crops such as potato, tomato, soybean and corn to conserve water (Shayannejad and Moharreri, 2009, Nasri *et al.*, 2010, Rafiee and Shakarami, 2010, Kashiani *et al.*, 2011). In the study on tomato at Orissa (India), alternate furrow irrigation gave the highest wateruse efficiency (5,140kg ha^{-1}

mm^{-1}) among several furrow treatments. Alternate furrow irrigation can prevent severe leaf water deficit, which develops in the shoots when irrigation is drastically reduced. It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgor is reduced as a result.

Globally and more particularly in developing Countries, changing water availability and quality pose complex problem and management options are not easy. The changing situation comes partly from increasing demands such as population, industry and domestic requirements and partly from consequences of climatic change(Awulachew, 2006). Therefore, great emphasis is placed in the area of crop physiology and crop management with the aim to make plants more efficient in water use under dry condition(Stikic *et al.*, 2003).Partial root zone drying is a practice of using irrigation to alternately wet and dry (at least)two Spatially prescribed parts of the plant root system to simultaneously maintain plant water status at maximum water potential and control vegetative growth for prescribed parts of seasonal parts of plant development (Sepaskhah and Ahmadi, 2012).

The concept of alternate furrow irrigation is that:

- In alternate furrow irrigation less surface water is wetted and less evaporation from the surface occurs.
- More lateral roots are stimulated and a chemical signal is produced in drying roots to reduce the shoot water loss.
- The amount of water needed (irrigation water use), time and labor requirement for Irrigation is decreased.
- Water use efficiency was nearly doubled by using this method.

Material and methods

Description of the study areas

The study was conducted for one irrigation seasons 2017/18 in woleh on five farmer trial site about15km from Sekota town. Sekota woreda is one of the woreda in wag-himra zone administrative of Amhara region. The experimental sites are found within 1384757N and 505143 E of longitude and an altitude of 2119m. The Agro-climatically of the woreda is situated in dry areas. The meteorological data was used extrapolated from nearby station abiady; maychew and Lalibela were used for the designing of irrigation infrastructures. The long term average ETO in the study area was 4.47mm/day. The mean annual maximum temperature ranges from 23.1^{oc} to28.6^{oc}. The woreda receives annual average rainfall of the area ranges from 329mm to 833mm. most of the rain is received from the fourth week of June to the end of August. The coincidence of late onset, early cessation and uneven distribution of rainfall with short effective season has resulted terminal dry spells, recurrent drought and unreliable rain-fed cropping in the area.

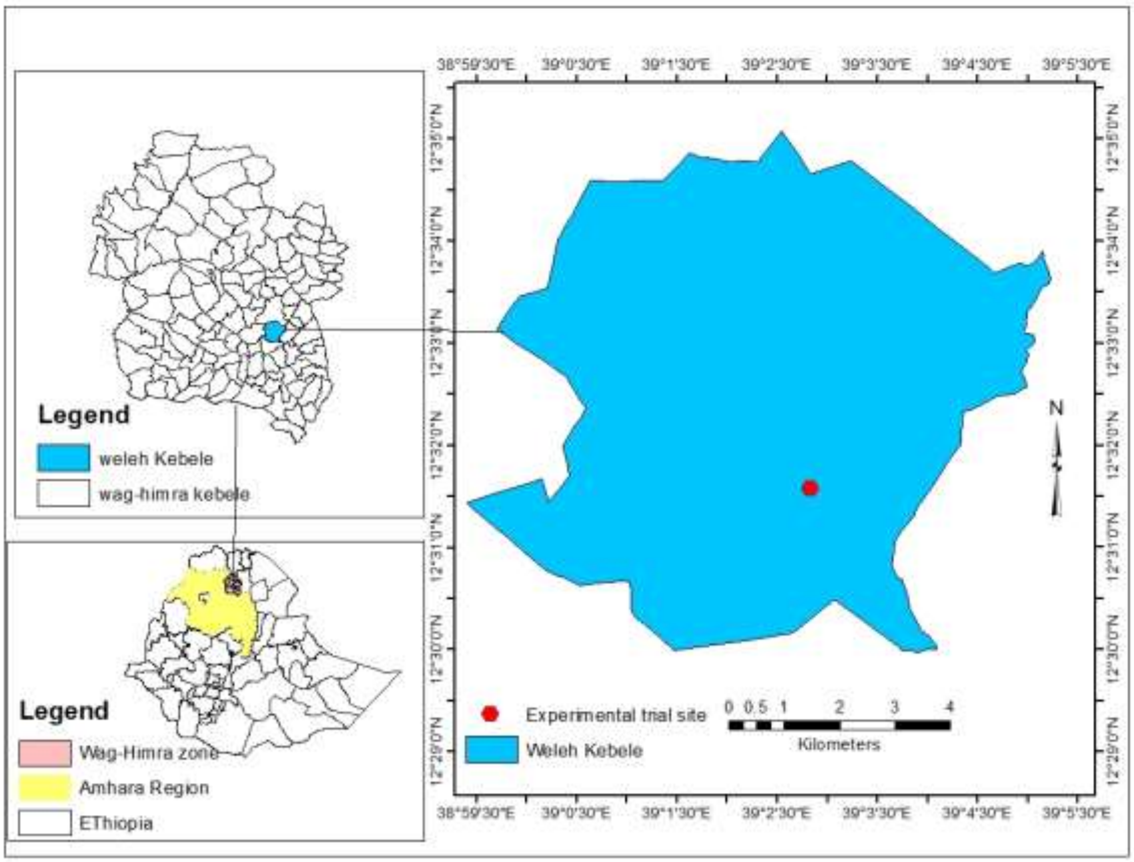

Figure1. Map of the study area

Crop selection and crop agronomy in the study areas

The most important irrigable crops in the irrigation schemes were identified in terms of crop type, market opportunity, crop variety and length of growing season. Considering all these factors, onion with Bombay red variety was selected as experimental crop. The experiment of onion variety has a total growing period of 115 days including transplanting up to harvesting with the initial crop growth stage about 20 days, crop development stage of 30 days, mid-season Stage of 40 days and late season stage of 25 days, which was derived from CROPWAT software. The experimental plot size of 10m×10m double row planting with spacing of 40cm×20cm×10cm (between rows including the furrow × between rows on the bed × between plants in a row) were used respectively. The spacing between the plots was 1m. Blanket recommended fertilizer rate of NPS 100kg at transplanting and urea fertilizer of 200kg at half transplanting and half 45 days was applied in experimental sites. Both diseases and weed infestation was regularly monitored, and proper management action has been undertaken timely. Thribes were observed during the early seedling establishments on the actual field, vegetative and plant development stages. Profit was used to control the disease infestation which was practiced by protection researcher recommendation

Crop Water Requirement of onion

Calculation of crop water requirement, net irrigation requirement, and schedule of the water application were carried out with inputs of soil, climatic and crop data's, and the CROPWAT Computer model was implemented for undertaking the operation. The model requires crop data such as crop type, planting date, growth stage days, maximum rooting depth, Kc values, depletion fraction and yield reduction coefficient and climatic data including maximum and minimum Temperature, rainfall, wind, sun shine hours and relative humidity and soil type. Climatic data of the experimental sites were collected from neighboring stations and extrapolated using LocClim Software. For calculating the crop water requirement, given the input of the required data, the reference evapotranspiration was calculated first using the Penman-Monteith equation in the CROPWAT program (Allen *et al.,* 1998). Composite soil samples were collected from field plots and the soil textural analysis was done soil analysis method and soil textural class was determined from soil textural triangle. Field capacity, permanent wilting point, and moisture at saturation were determined from laboratory analysis of soil samples.

Total Available Moisture (TAM) in the soil for the crop during the growing season was calculated as Field capacity (FC) minus wilting point (PWP) times the current rooting depth (D)of the crop as indicated in the following relation. TAM= (FC-PWP)*D. Readily Available Moisture (RAM) was calculated as TAM*P, Where P is the depletion fractions defined by the crop coefficient (Kc) files. The estimated crop water requirements were converted in to the field irrigation water requirement. The net irrigation requirement (NIR (mm/period)) was determined based on the equation. NIR=CWR - Peff, where, CWR=crop water Requirement (mm/period), Peff=Effective precipitation. The exact volume of water needed to fulfill the irrigation water requirement throughout the growing season was calculated using thee equation below.

$$\text{Gross irrigation requirement (mm)} = \frac{\text{Net irrigation requirement (mm)}}{\text{Application efficiency}}$$

Water productivity, also known as water use efficiency, was determined as the ratio of crop yield per unit area, in terms of grain, to crop evapotranspiration (mm), and was expressed as kg of grain or biomass per m^3 of consumed water.

$$\text{Water use efficiency (kg/m}^3\text{)} = \frac{\text{total yield of onion (bulb)}}{\text{Water delivered up to harvesting}}$$

Furrow irrigation was the method used for applying water for this experiment. Since water is applied directly to the plot; conveyance and distribution losses was ignored and 90% irrigation application efficiency was taken.

Experimental set up

The design of the experiment was RCBD with four as farmer replications. In field experiment three furrow irrigation water application methods were verified. Alternate furrow irrigation (AFI), Conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI) and the recommended irrigation amounts; of 75%. The Alternate furrow irrigation means that one of the two neighboring furrows was alternately irrigated during consecutive watering. Fixed furrow irrigation means that irrigation was fixed to one of the two adjacent furrows while the Conventional furrow irrigation was the conventional way where every furrow irrigated during each watering. The frequency of irrigation water was applied at 5 days irrigation interval, hence all plots was irrigated 20 times throughout the growing season. There was 1.2mm of rainfall throughout the growing season. Prior to planting all plots were irrigated with equal amount of water up to the field capacity. Weeding and other agronomic practices were conducted on time equally for each treatment. Hand held watering Cane was used to control the amount of water entering each furrow. Agronomic parameters like bulb diameter, plant height, marketable yield, unmarketable yield, total yield and water productivity were collected as per the schedule.

Data analysis

All the agronomic, yield and water productivity data were recorded and being subjected to analysis. Analysis of variance was performed using Statistix 10.0 statistical Software. Effects were considered significant in all statistical calculations if the P-values were ≤ 0.05. Means were separated using Fisher's Least Significant Difference (LSD) test.

Treatment set up

1. 75 % CROPWAT fixed depth and Alternate furrow irrigation (AFI) at 5 days interval.
2. 75 % CROPWAT fixed depth and Conventional furrow irrigation (CFI) at 5 days interval.
3. 75 % CROPWAT fixed depth and Fixed furrow irrigation (FFI) at 5 days interval.

Results and discussion

The results of the experiment shows that, there was no statistically significance difference in the plant height, marketable and unmarketable yield of onion on the application of 75% amount of irrigation water at five days irrigation intervals on alternate and conventional furrow irrigation methods(Table1).But there was significant difference in bulb diameter and water productivity (Table 1&2).AFI enables more efficient use of irrigation water associated with some water stress compared to CFI this is why significant difference in bulb diameter as well as water productivity. However, the analysis result on irrigation type showed that application of alternative furrow irrigation type has a statistical significance difference in all parameter as compared to fixed furrow except bulb diameter. It is obvious that conventional furrow irrigation is labour intensive and time consuming, each furrow is irrigated at each frequency of irrigation, and however, alternate irrigation consumes half of the labour, time and amount of required irrigating. In addition to this advantage in the experimental result alternate furrow irrigation with 75% of irrigation water saves the highest total yield of 122.9qt/ha while the conventional and fixed ones with double amount of water application gave 132qt/ha and 96qt/ha total yield respectively. This result in line with the finding of (Birru *et al.,* 2010) alternate furrow irrigation was achieved better total and marketable yield of potato as compared to conventional and fixed ways of furrow irrigation methods. On the other hand the finding of (Gelu, 2018) stated that alternative furrow irrigation system in areas where there is water scarcity as well as labor expensiveness is the best options to increase the production of onion and other vegetables.

Figure 2. Field status of the experimental plot

Table 1. Mean bulb diameter, plant height, marketable, total and unmarketable yield of onion in 2017/2018

Treatment	Ph(cm)	Bd(cm)	My(qt/ha)	Unmy(qt/ha)	Ty(qt/ha)
AFI	50.4[a]	4.31[b]	120.03[a]	2.89	122.92[a]
CFI	50.3[a]	4.68[a]	129.47[a]	3.13	132.6[a]
FFI	47.01[b]	4.32[b]	92.82[b]	3.34	96.16[b]
CV (%)	1.11	1.9	5.08	15.82	5.15
LSD(0.05)	0.95	0.14	10.03	NS	10.45

Means with the same letter are not significant different. Bd= bulb diameter; ph= plant height; my= marketable yield; Ty=total yield; Unmy= unmarketable yield

As shown in Table1 the marketable onion bulb yield was obtained from CFI (129.47qt/ha) and AFI (120.03qt/ha) systems were significantly different from FFI (92.82qt/ha) system. The statistical analysis onion crop yield obtained in our experiment is presented in Table 1. It shows that the difference in onion crop yield obtained with CFI and AFI was non-significant. However, A slightly yield reduction obtained by AFI compare with CFI.A slight reduction in crop yield with AFI compared to CFI was also reported by (Sepaskhah and Ghasemi, 2008, Rafiee and Shakarami, 2010).The results also in agreement with the finding of (Slatni *et al.*, 2011, Crabtree *et al.*, 1985)using alternative furrow irrigation methods insignificant a yield reduction on sorghum and soybeans production as compared to conventional furrow irrigation methods. This is also supported by (Stone and Nofziger, 1993)who found that AFI may result insignificant cotton yield production because too little water is applied, particularly when evaporative rates are very high. Under the AFI method, the onion plant root system was partially wetted which could result in reduced stomata conductance and a reduction in plant transpiration. Photosynthesis and dry matter accumulation can however be less affected by this partial stomata closure (Kang *et al.,* 2000) and also the roots on the irrigated side of the furrow (wet soil) will continue to take up water to try and meet the required water demand of the plant(Ahmadi *et al.,* 2010). Zhang *et al.* (1987)reported that plants with two halves of their root system under alternate drying and wetting cycles resulted in reduced stomatal opening but without significant increase in leaf water deficit. This could be part of the reason why there was a non-significant reduction in crop yield with AFI compared with CFI. Kang *et al.* (2000) also observed a high grain yield for maize when subjected to a half reduction in the amount of irrigation applied. Sepaskhah and Ahmadi (2012)also recommended partial root zone drying (similar to AFI) for better fruit quality and increased crop water productivity in areas with limited water resources. Table 2 shows the crop water productivity of AFI, CFI and fixed methods for growing onion. The highest water productivity of 4.05kgm^{-3} was obtained with AFI followed by FFI with 3.16kgm^{-3} and conventional furrow irrigation, which had the lowest water productivity of 2.15kgm^{-3}.It shows that the variation in WP for all treatments were highly significant, which highlights the effect the method of irrigation has on water productivity. Ibrahim and Emara (2010)reported that the AFI method had higher WP compared with the CFI method. Slatni *et al.* (2011)reported that AFI resulted in a slight decrease in crop yield but increased water productivity.(Rafiee and Shakarami, 2010) also reported that AFI enables more efficient use of irrigation water but with a lower crop yield associated with some water stress compared to CFI. There was a significant reduction of 75%in the volume of water applied to the AFI treatments. This means 6076m^3 volume of water is needed to irrigate 1 hectare area in CFI system which is enough to irrigate 2 hectare area of land in AFI system. So, when the area to be irrigated becomes double in AFI system using the saved volume of water, the yield obtained also becomes double. The reason why the yield result is well performing as compared to CFI system is probably because of a better application efficiency and physiological response associated with AFI (Kang *et al.,* 2000, Zhengbin *et al.*, 2011)and less evapotranspiration associated with AFI (Gelu G, 2018).This result conformity with (Abdel-Maksoud *et al.*, 2002, Tavakkoli and Oweis, 2004)applied the same amount of water alternate furrow irrigation obtained highest maize and wheat grain yield production and water productivity as contrast to conventional and fixed furrow irrigation techniques. In addition to that (Nouri and Nasab, 2011)accomplished that the alternate furrow irrigation system generally increases sugar cane production, water productivity and field water use efficiency.

Table 2. Effect of applied water and furrow irrigation method on water productivity of onion

Treatment	Number of irrigation	Irrigation water(m^3/ha)	Total yield (t/ha)	Water productivity (kg/m^3)
75%AFI	20	3038	12.29[a]	4.05[a]
75%CFI	20	6076	13.26[a]	2.15[c]
75%FFI	20	3038	9.62[b]	3.16[b]
CV (%)	_	_	5.15	10.07
LSD (0.05)	_	_	10.45	0.45

In field experiment observed that conventional furrow irrigation is labor intensive and time consuming each furrow is irrigated at each frequency of irrigation and however, alternate irrigation consumes half of the labor, time and amount of required irrigating. In addition to this advantage in the experimental result alternate furrow irrigation saves the highest total yield of 12.29ton/ha while the conventional (double amount of water) and fixed furrow irrigation system gave13.2ton/ha and 9.39ton/ha total yield respectively.

Therefore, in areas with scarce water resource for irrigation in Sekota woreda or agro climatically similar areas can use 75% (3038m^3/ha) of water at five days interval in alternate furrow irrigation methods irrigation water application throughout the whole growing season was obtained optimum total yield production of irrigated onion.

Table 3. Economic water productivity of onion in alternate furrow irrigation (AFI), conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI**).**

Treatment	Total Gross benefits (TGB) birr/ha	Irrigation water(m^3/ha)	Economic water productivity (WP(e)) birr/m^3
AFI	110610	3038	36.41
FFI	84510	3038	27.81
CFI	119610	6076	19.68

Table 3 shows that economic water productivity (WP (e)) of onion crops in the AFI, FFI and CFI irrigation methods the highest (WP(e)) 36.41birr/m3was obtained in AFI followed by FFI with 27.81birr/m3 and CFI irrigation 19.68birr/m3 which had the lowest Economic water productivity(WP(e)).

Table 4. Partial budget analysis for the experimental irrigation treatments

Treatment	Unadjusted yield(t/ha)	Adjusted bulb yield by 10% (t/ha)	Total gross benefits (birr/ha)	Total cost that vary (birr/ha)	Net benefits (birr/ha)	MRR
AFI	12.29	11.061	110610	12490.63	98119.37	785.543
FFI	9.39	8.451	84510	12490.63	72019.37	D
CFI	13.29	11.961	119610	24981.27	94628.73	-27.946

NB. "D" stands for domination

Table 4 indicated that for every birr 1.00 invested in Conventional furrow Irrigation the farmers including 1.00birr 27.71birr was loosed and obtained an additional 7.85birr after recovering on Alternative furrow Irrigation. Since MRR>100% adopting AFI is economically feasible. The total cost mainly included operating and variable Operating costs (land preparation, seeds, Fertilizer and chemicals) were based on the planted area. Therefore, the operating costs of the AFI treatments were the same as the conventional CFI and FFI treatment. Variable costs depended on the number of irrigation events and water unit price. The water unit price was estimated to be 3.5birr/1000m3 according to irrigation water prices of Awash River basin Authority(Ayana et al., 2015). Total water cost for each season was calculated by multiplying the water unit price by the total amount of irrigation water required for the onion crop.

Therefore10.633birr/3038m3for AFI and FFI where as 21.266birr/6076m3 for CFI and the labor cost due to irrigation events are 12480birr to AFI and FFI but 24960birr for CFI which shown that higher cost in labor as well as water price than the two.

Conclusion and Recommendations

Results obtained from this study show that, in AFI system the total water used was half of CFI system, but the onion yield obtained was slightly reduced due to high evaporation with little amount of water applied despite of AFI provides CFI this Significant amount of water (3038m3/ha) was saved by AFI system while it also maintains onion yield. So, AFI is water saving irrigation method was suited for onion production without a significant bulb yield loss with maximum water productivity.

AFI systems saved labor and time used for irrigation water which is half of CFI system. Because in CFI system four furrows irrigated at same time while in AFI only two furrows out of four furrows. This may improves working conditions as technology allows irrigator moving on the dry furrows.

This reduction in applied water is also important to minimize the risks of soil sod city development in irrigated area, especially when the quality of irrigation water deteriorated. Rather than using 6076m3/ha of water for 1 hectare in CFI system, it is possible to double the irrigated area to 2 hectares in AFI system. Onion needs high amount of irrigation water during the development stage, but in FFI system as half of the root stay dry throughout the growth period, continuous stress significantly reduces fresh bulb yield.

Alternative furrow irrigation system is the best technology among the tested technologies to be recommended for the communities of the study area, because of its high water application efficiency, yield performance, in addition to time, labour and irrigation cost saving. So alternative furrow irrigation system in areas where there is water scarcity as well as labor expensiveness is the best options to increase the production of onion.

Therefore, it is advised that areas with insufficient water resource for irrigation in Sekota or agro

climatically similar areas can use of 75% (3038m3) of irrigation water at five days interval in alternative furrow irrigation methods throughout the growing season, for optimum production of irrigated onion.

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III) Soil and Water Conservation

Long term trends of hydrology, sediment yield and crop productivity in Andit Tid watershed central highlands of Ethiopia

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Abstract

Previously in Ethiopia reliable climatic and hydro-meteorological data are not available and not maintained properly but the long-term database is needed for the assessment and planning of resource dynamics. To minimize the lack of reliable database, the Soil Conservation Research Program (SCRP) established observatory model watersheds since 1981. The study was initiated to compile, analyze and document the spatial and temporal distribution of the rain fall; trends of runoff and sediment loss and their relation and the influence of position of terraces on crop production. From the rainfall trend analysis result, the rainfall of the watershed has insignificant spatial (PCI=1.07) and temporal (CV=16.7%) variation which is also an indicator for less vulnerability of the watershed to drought. The precipitation coefficient (%) value of the watershed indicates that July and August have big rain with high concentration; September has big rain with moderate concentration and these three months contributed higher rainfall amount. The highest runoff and sediment yield were observed in August and July, while sediment concentration was generally high in June for the land was plown and open for crop production and hence small drops of rainfall can carry much soil and can contribute for high sediment concentration. All crops delivered statistically highest yield ($P<0.05$) immediately above bunds because the trapped and accumulated soil and plant nutrient could contribute for better performance and production of the crops. The outcome of this research highlights that, more refined data collection using better recording instruments is needed for explicit and accurately predict climatic, hydrological, soil loss and related processes investigation.

Key words: Hydrologic, PCI, precipitation coefficient, SCRP, sediment loss

Introduction

In most countries reliable climatic and hydro-meteorological data are not available and not maintained properly but the long-term database is needed for the assessment and planning of resource dynamics and its impacts on human life. Data on soil erosion and its controlling factors can be collected in the field or simulated conditions, in the laboratory (Hudson, 1982; Morgan, 1995). For realistic data on soil loss, field measurements are the most reliable because condition varies in both time and space, it is often difficult to determine the causes of erosion or understand the process at work (Hudson, 1982). But in countries like Ethiopia where the agro-climatic and topographic conditions are too diverse, it is difficult and expensive to monitor hydrological and related soil loss data (Tegenu, 2009). It is not possible to measure runoff-soil loss processes at every vulnerable spot in the country and most physical based models usually have extensive data requirements and it is difficult to build input parameters.

Andit Tid watershed was established in June 1982 as one of seven long term Soil Conservation Research Project (SCRP) sites. The SCRP was initiated in 1981 by the Institute of Geography of the University of Bern in Switzerland, implemented jointly by Soil and Water Conservation Department (SWCD) of the Ethiopian Ministry of Agriculture (MOA) and the University of Bern, and financed by both the Switzerland and Ethiopian governments. The goal of establishing these watersheds was stated as ‘to develop and promote ecologically sound, economically viable and socially acceptable conservation measures in Ethiopian highlands’. To achieve this goal long-term monitoring of these model watersheds has been conducted. In Andit Tid climate, runoff, sediment loss, crop production and land cover changes have been monitored since June 1982. It is widely reported that presently land degradation rates and erosion rates have been accelerating due to the increasing rural population (Grunder, 1988; Desta et al., 2000; Hurni et al., 2005). At the same time, a large number of soil and water conservation (SWC) practices have been installed attempting to reduce soil loss (Hurni, 1988; Nyssen et al., 2008; Herweg and Ludi, 1999). It is not clear what the effectiveness of these practices is beyond the immediate locations of where they have been tested (Vanmaercke et al., 2010).

Precipitation directly affects the availability of water resources and is one of the most important climatic factors and hydrological parameters (De Luis et al., 2011). Investigating the temporal–spatial variations of precipitation in previous time periods is critical for making reliable predictions of future climate changes. Furthermore, precipitation data of this type can be used to understand the response of hydrological cycles to climatic change and consequently the impact on the availability of water resources at regional and global scales (Allan and Soden, 2008; Xiao et al., 2017; Zamani et al., 2018). Given the changes in global warming and the resulting alterations in the hydrological cycle, an increasing number of researchers are paying attention to the temporal–spatial changes in precipitation and the subsequent outcome on the management of water resources, agricultural irrigation, and flood or drought forecasting (Gu et al., 2017).

The precipitation concentration can also be used to investigate the risks of extreme precipitation events. Additionally, the temporal precipitation concentration is a key parameter for monitoring the pace of physical processes occurring in the atmosphere (Monjo and Martin-Vide, 2016). Similarly, to evaluate precipitation heterogeneity at a monthly scale within a year, Oliver (1980) suggested a monthly precipitation concentration index (PCI), which was later adopted by De Luis et al. (1997). The PCI is very useful to assess the degree of seasonal precipitation concentration and provides information for the comparison of different climates in terms of precipitation regime for different seasons.

For several reasons, long-term monitoring of seasonal and annual crop yield and biomass production in the same research catchment over a decade is a unique and rare indicator of the performance of Ethiopian agricultural production. It enables a scientific assessment of quantitative on-farm measurements of a high density sampling in a relatively large area. Obviously many factors are involved in crop yield and biomass as an indicator, such as the natural environment (climate, soil, water, crop diseases), the social environment (cultural practices, organization, production needs and preferences), and the economic environment (farm gate prices, agricultural policies, land tenure, etc.).

The generated data have been and will extensively use by local and international researchers and students, for capacity building on sustainable land management and to design policy in the field of agriculture. The 13 years (1982 – 1994) data was analyzed and reported by Hurni

(2000) that provides important information on the impacts of treated watersheds and implications on productivity, sediment and discharge. Though there have been some discontinuity on data collection, the report is the second of its kind in availing systematically collected and organized data to establish trends of rainfall-runoff relationship, hydro-sedimentology, climate and other available data at watershed scale. The objectives of this study were: (1) to analyze the long term data and establish trends of climate (rainfall and temperature), discharge, sediment yield and crop productivity impacts of soil and water conservation practices, and (2) to provide a hydro-sedimentological characterization of the watershed, so that information has been available for longer time series monitoring since 1982..

Materials and methods

Description of the study area

Andit Tid watershed is one of the SCRP sites. It is situated on 39°43’E longitudes and 9°48’N latitudes (Figure 1) 180 km northeast of capital city Addis Ababa. The watershed covers a total area of 475 ha, and the altitude of the catchment ranges between 3040 to 3550 m.a.s.l. The mean annual rainfall is 1581 mm, the minimum and maximum temperatures are 7°C and 17°C, respectively. The minimum and maximum average soil temperatures are 8°C and 20°C, respectively. The agro-climatic zone of the watershed is moist humid. Andit Tid has been administered by the Amhara Regional Agricultural Research Institute (ARARI) under the supervision of the Debre Brehan Agricultural Research Center (DBARC). In the study area, there is a huge amount of collected and available data such as discharge, soil loss, climatic, crop productuction and land use/cover data for the last 35 years.

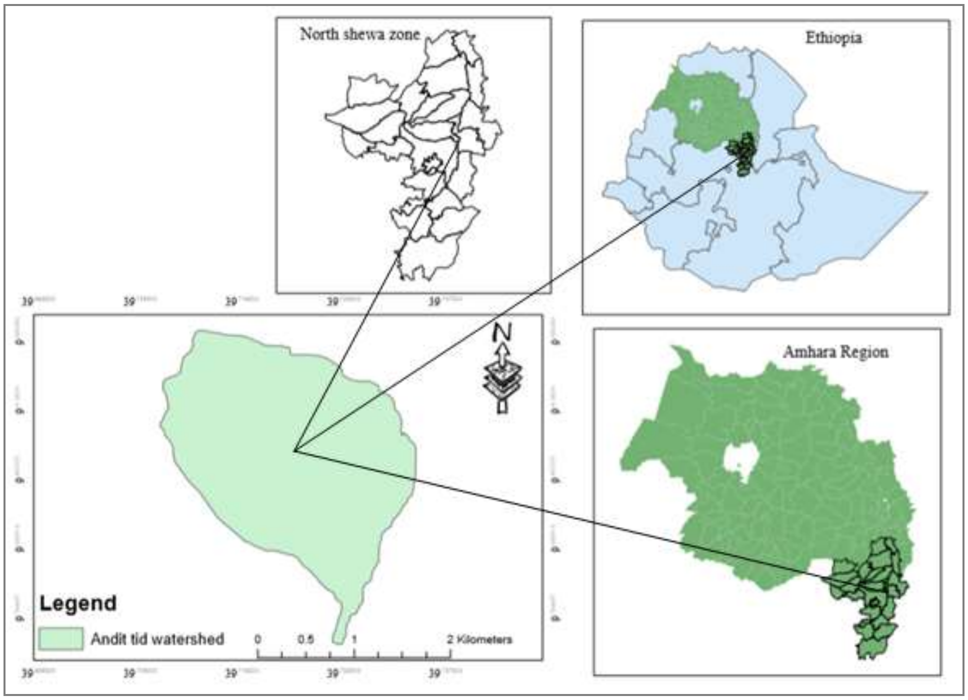

Figure1. The location map of the study area

Data collection and analysis

A-class meteorological instruments were installed near the outlet of the watershed. The rainfall data was recorded using both an automatic pluviometer rain gauge installed at the station (i.e., close to the outlet) and four manual rain gauges, distributed throughout the watershed to collect catchment-scale representative data. From continuous readings of the automatic rain gauge, rainfall characteristics including amount, intensity, and time intervals between storm events were determined.

We have used precipitation concentration index (PCI) which is the ratio of square of the rainfall amount of the specific month to the square of the total rainfall to show the distribution of rainfall in the watershed. According to the Oliver (1980), the PCI value of less than 10% represents a uniform rainfall distribution (i.e. low rainfall concentration); PCI values between 11-15 denote a moderate rainfall concentration; values from 16-20 denote irregular rain fall distribution, and values above 20% represents the irregularity(i.e. high rainfall concentration) of rainfall distribution (De Luis, 2011).

Precipitation coefficient (PC) was calculated as the ratio between the mean monthly rainfall and one twelfth of the mean annual rainfall. When the PC greater than one, the month is wet month that can contribute more than one twelfth of the mean annual rainfall and dry months contribute less than one twelfth of the mean annual rainfall. A month is rainy if the rainfall coefficient is greater than 0.6. The expression “small rains” are used to refer to months with rain fall coefficient of 06-0.9; and the expression “big rains” refer to months with rainfall coefficient of 1 and above. Big rainy months are further classified in to three groups: months with “moderate concentration” (coefficient of 1 to 1.9); months with “high concentration” (coefficient of 2-2.9); and months with “very high concentration” (coefficient of 3 and above) (WLRC, 2015).

The climatic data at the station also include minimum and maximum air temperature, minimum and maximum soil temperature. Air and soil temperature were measured using 1.5 and 0.1 meter above ground thermometers that were installed in the station under shelter respectively.

River discharge and sediment data collection

The river gauge stage was monitored continuously using limuniograph accompanied with manual water level measurements during storm events. Whenever there was runoff events, one-liter grab samples were taken every 10 minutes interval as soon as the water turned brown for sediment measurement. When the water level decreased and the runoff water returned to its original color, sampling rate decreased to 30 minutes intervals and then hour intervals. Together sediment sampling, the river water level was measured manually to determine the total stream flow and to estimate the suspended sediment carried by the flow at that specific time interval. The amount of sediment load within the sample was determined by oven drying the one liter samples then weighing the oven dried soil. Total soil loss for that sampling interval was then calculated by multiplying total water flow per time by the sediment concentration determined from the one liter sample. We used the rating equation developed by Bosshart (1997) to convert stage height to discharge:

$$Q\,(H <= 67) = 0.03 * H^{2.749}$$ ……………………………………………Equation (1)

$$Q\,(67 < H <= 250) = 10.846 * H^{1.35}$$ ……………………………………Equation (2)

Where Q is the runoff discharge in l/s and H is the true water level (height of stage) in cm

Drainage ratio which is the ratio of runoff to rainfall was calculated to identify when the rainfall and runoff reaches maximum and minimum. Time of concentration is useful in predicting flow rates that would result from hypothetical storms, which are based on statistically derived return_periods through IDF_curves (Monjo, R. (2016). The time of concentration (T_C) and time of peak discharge (T_P) were also generated as:

$$Tc = \frac{0.019471*L^{0.77}}{S^{0.385}}$$ ……………………………………………………………………….Equation (3)

$$S = \frac{\text{upper stream elevation} - \text{Lower stream elevation}}{L}$$ …………………………………..Equation (4)

$$TP = 0.6 * T$$ …………………………………………………………………………....Equatio n (5)

Where, T_C is time of concentration; L is the length of the largest stream; S is the slope variation between the upper stream and the lower stream and T_P is the time of peak discharge.

Crop yield data collection

Catchment harvest data is the representative yield and biomass sample including data on management practices, inputs, soil depth, slope, tillage, precursor crop, and crop type data taken from 35 fixed and 50 non-fixed plots from the farmers' land. In the fixed plot the samples were taken from 'a' (above terrace (zone of deposition)), 'b' (between terrace) and 'c' (below terrace (zone of transportation)) to represent the soil erosion gradient effect. This data was used to show the productivity impacts of SWC applied in the watershed.

The reliability of all collected rainfall (both rain gauge and pluvio-graph readings), stream flow and suspended sediment load raw data were checked before the analysis. Rainfall and stream discharge were cross-checked with pluvio-graph and limno-graphic river height charts. Data events at which the river height was beyond the rating equation were also avoided. Wrongly written starting and ending times for stream flow recordings and sediment samplings were also adjusted so that the total data calculations were not affected (Bosshart, 1997).

Results and discussion

Rainfall characteristics

Temporal and spatial rainfall characteristics are very important factor that affect runoff generation. The four rain gauges installed in the watershed provided information on the spatial distribution of rainfall. The PCI value of the watershed is 1.07% which means the rainfall in the watershed have uniform distribution (i.e. low rainfall concentration) as shown in Table 1. In fact the distribution of the rainfall can also be verified by the rainfall recorded from four different rain gauges distributed in different location of the watershed. Based on the recorded rainfall from these four rain gauge sites of the watershed there was insignificant variation among the rainfall amount. The precipitation coefficient (%) value of the watershed indicates that July (PC=2.551) and August (PC=2.395) have high rainfall with high concentration; September (PC=1.068) also has has high rainfall with moderate concentration and these three months contributed higher rainfall amount per year. The months of March, April, May, June and October have small rainfall with PC values of 0.68, 0.82, 0.74, 0.78 and o.653 respectively. The months of January, February, October and November are dry months as verified from the precipitation coefficient values as mentioned in Table 1.

Table1. The monthly average, annual standard deviation, CV (%), PC and PCI value of the watershed

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average RF(mm)	60.1	54.3	93.4	112.4	101.5	107.6	351.5	330.0	147.2	90.0	67.9	65.3	1581.2
St deviation	36.5	32.5	54.6	65.5	52.6	49.3	82.3	78.9	64.3	67.6	45.0	44.6	264.7
CV (%)	60.7	59.8	58.4	58.3	51.8	45.8	23.4	23.9	43.7	75.2	66.3	68.3	16.7
PC	0.4	0.4	0.7	0.8	0.7	0.8	2.6	2.4	1.1	0.7	0.5	0.5	1.0
PCI (%)	0.2	0.1	0.3	0.5	0.4	0.5	4.9	4.4	0.9	0.3	0.2	0.2	1.1

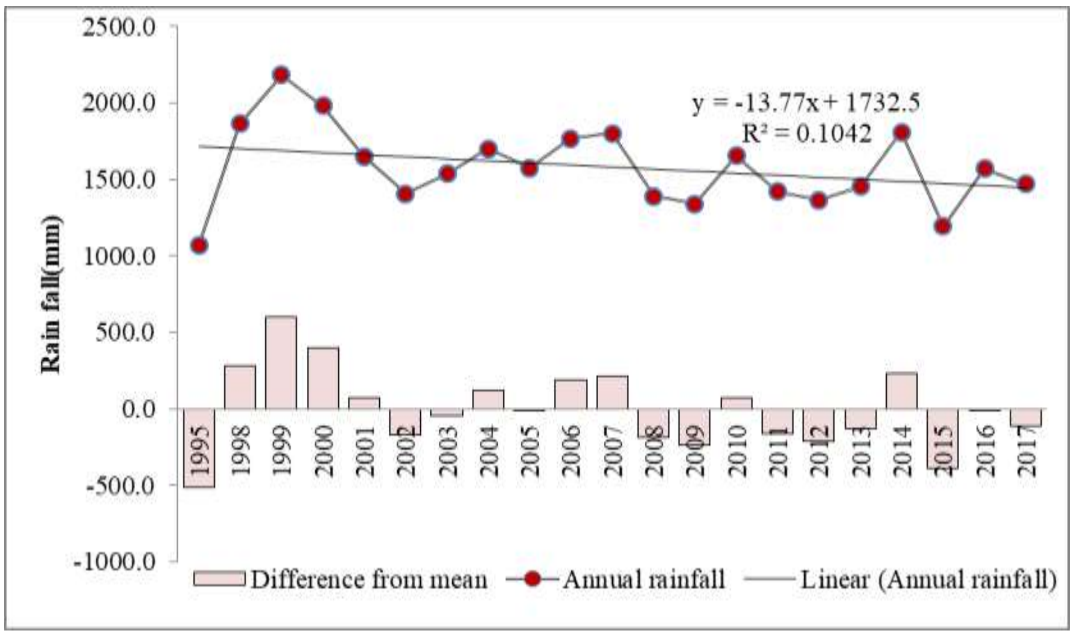

Figure2. The average annual rainfall, difference from the mean and linear rainfall (mm) of the watershed

The long-term average annual rainfall based on 20 years of observation (1995–2017) is 1581mm. The maximum minimum annual rainfall ever received was 2183.6 mm in 1999 and 1069 mm which was received in 1995 as expressed in Table 2. As mentioned in Table 1 and Figure 2 the coefficient of variation for annual rainfall is 16.7%, which means the rainfall amount of each year is fairly scattered around the mean. Derib (2005) states annual rainfall with CV > 30% is an indication of high vulnerability to drought. Regardless of the higher monthly rainfall variability; the low variability of total annual rainfall minimizes the risk of drought in the study area. Hurni and Grunder (1986) verified that drought is not a problem in Andit tid because of low variability of annual rainfall. Similar to the previous study; this study also confirms that the watershed will not be vulnerable to drought and dry spell according to the low annual variability of the rainfall. The seasonal rainfall analysis result implied that; since 2008 the rainfall falling at Bulg (February to May) season is less than the long term average rainfall of the Bulg season in most years as shown in Table 2. Holden and Shiferaw (2000) also mentioned that the short rainy seasons have recently become more unreliable. The standardized climatic diagram of Andit Tid (according to Walter, 1964) is characterized by a bimodal rainfall regime with one dryer month (June) between Belg (first, small rainy season) and Kremt (second, main rainy season). Even though the rainfall amount of the Bulg season is smaller than the long term average of the Bulg rain fall; the rain fall regime of the watershed has still bimodal characteristics as mentioned in Table 2. During six months (April, May, June, July. August and September) mean monthly rainfall exceeds 100 mm; with similar result of Walter (1964); which states the four months (May, July, August and September) mean monthly rainfall exceeds 100mm.

Table2. The annual average and seasonal rainfall distribution of the watershed from 1995 to 2017 with missing value of 1996 and 1997

Year	Annual rainfall	Difference from mean	June-Sept rainfall	Difference from the mean June-Sept rainfall	Feb-May rainfall	Difference from mean Feb-May rainfall
1995	1069	-512.0	770.6	-165.6	93.1	-268.5
1998	1863.5	282.5	1026.2	90.0	433.9	72.3
1999	2183.6	602.6	1231.9	295.7	454.8	93.2
2000	1979.7	398.7	1147.3	211.1	347.1	-14.5
2001	1650.2	69.2	960.2	24.0	403.9	42.3
2002	1407.7	-173.3	794.8	-141.4	401.3	39.7
2003	1538.9	-42.1	906.8	-29.4	416.4	54.8
2004	1699	118.0	1000.9	64.7	380.5	18.9
2005	1574.9	-6.1	911.4	-24.8	401.4	39.8
2006	1768.8	187.8	871.6	-64.6	377.9	16.3
2007	1799.3	218.3	1079.3	143.1	487.9	126.3
2008	1391.5	-189.5	756.8	-179.4	180.6	-181.0
2009	1340.6	-240.4	708.0	-228.2	179.2	-182.4
2010	1655.3	74.3	1001.5	65.3	433.2	71.6
2011	1418.5	-162.5	910.9	-25.3	361.4	-0.2
2012	1364.5	-216.5	900.0	-36.2	310.3	-51.3
2013	1453.1	-127.9	955.4	19.2	317.8	-43.8
2014	1810.2	229.2	918.6	-17.6	585.9	224.3
2015	1193.9	-387.1	681.6	-254.6	216.3	-145.3
2016	1570	-11.0	1149.6	213.4	359.6	-2.0
2017	1469	-112.0	976.9	40.7	451.0	89.4
Average	1581.0	__	936.2	__	361.6	__

Air and soil surface temperature (^{o}C)

Air temperature was measured 1.5 m above ground on a daily basis for the period from 1995 to 2017. The daily minimum air temperature was ranged from -9 °C to 23 °C which was recorded on 22/7/2017 and 01/31/2008 respectively. The daily maximum air temperature was ranged from 2 °C to 26°C which was recorded on 11/22/2010 and 08/06/2006 &01/01/2017 respectively. The daily minimum soil surface temperature was ranged from -6 °C to 22 °C which was recorded on 07 and 09/01/2012 and 03/05/2004 respectively. The daily maximum soil surface temperature was ranged from 1 °C to 34°C which was recorded on 02/01/2014 and 16/06/2010 & 06/01/2015 respectively. The mean daily minimum and maximum air temperature of the watershed were 7.5° and C 17.6° C respectively. The mean daily air temperature of the watershed was 12.6 °C as indicated in Table3. The mean minimum and maximum soil surface temperature of the watershed were 8° and C 20° C respectively. The mean soil surface temperature of the watershed was 14.2 °C as mentioned in Table3.

Table3. The long-term minimum, maximum and mean air and soil surface temperature of the watershed

Month	Airminimum temperature (°C)	Air maximum temperature (°C)	Mean air temperature (°C)	Max soil surface temperature (°C)	Min soil surface temperature (°C)	Mean soil surface temperature (°C)
Jan	6.7	17.2	12.0	20.7	7.0	13.8
Feb	7.6	17.9	12.7	21.1	7.4	14.3
Mar	7.9	18.1	13.0	21.0	8.2	14.6
Apr	8.3	18.2	13.3	20.9	8.6	14.8
May	8.7	18.7	13.7	21.5	8.9	15.2
Jun	8.3	18.9	13.6	21.7	8.9	15.3
Jul	7.5	17.4	12.4	19.4	8.8	14.1
Aug	7.4	17.6	12.5	19.7	8.8	14.3
Sep	8.0	17.4	12.7	19.8	8.6	14.2
Oct	7.1	16.9	12.0	20.1	7.4	13.8
Nov	6.5	16.6	11.5	19.9	6.8	13.3
Dec	6.1	16.6	11.4	20.4	6.4	13.4
Minimum	6.1	16.6	11.4	19.4	6.4	13.3
Maximum	8.7	18.9	13.7	21.7	8.9	15.3
Mean temp	7.5	17.6	12.6	20.5	8.0	14.2

The air and soil surface temperature of the watershed did not have a continuous declining or increasing trend. Based on the long term time series air temperature data November and December were the coldest months with average value of 11.5 °C and 11.4°C respectively; whereas May and June are the hottest months with average value of 13.7°C and 13.6°C respectively as indicated in Table 3. In more than 96% of the records, daily soil surface temperature was higher than daily air temperature. The difference between air temperatures versus soil surface temperature was greater during the dry season than during the rainy season. With a few exceptions the daily range of soil surface temperature (difference between minimum and maximum temperature) was larger than that of air temperature; this is clearly shown in Figure 3. Soil surface temperature is more sensitive to seasonal weather variations than air temperature. During the dry season, especially in the months after the rainy season, when insulation and radiation are most intense, soil surface maximum temperatures are relatively high and soil surface minimum temperatures relatively low.

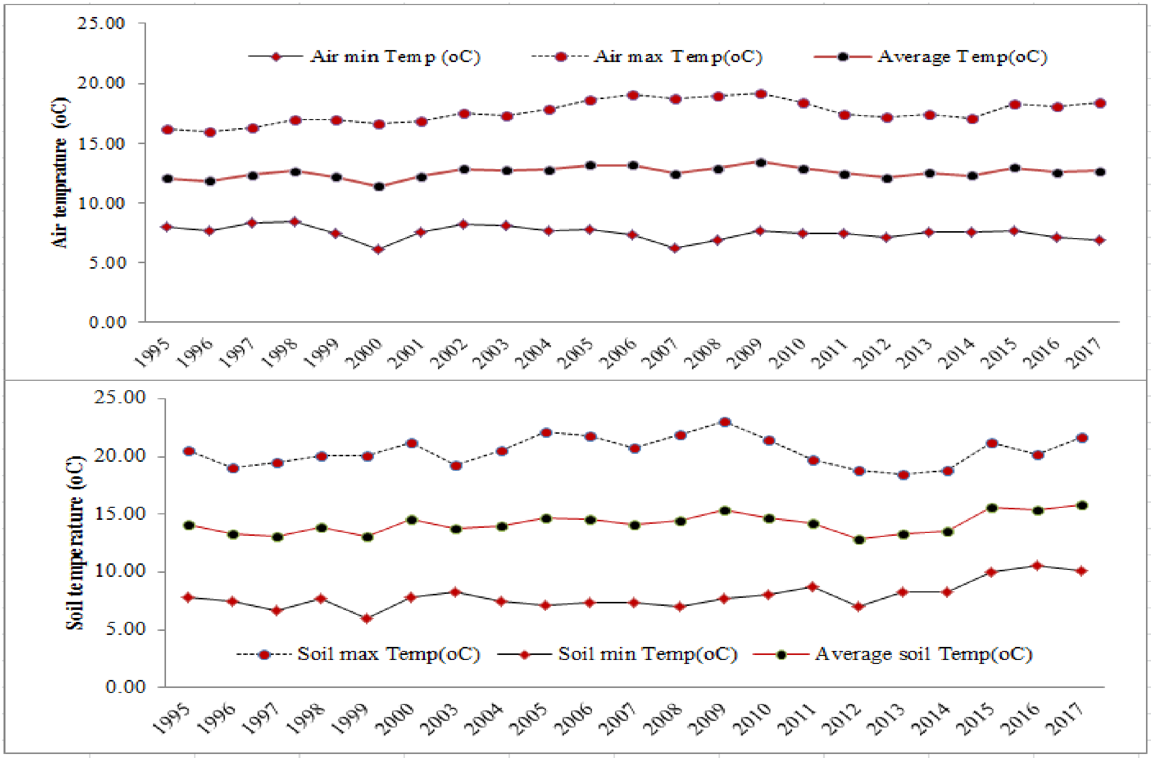

Figure3. Annual average air and soil surface temperature of Andit Tid watershed (°C)

Trends of discharge and sediment yield

Two small rivers, Gudibado and Wadyat, drain the catchment from east to west. Their confluence is approximately 150 m above the gauging station, which is just upstream of the asphalt bridge crossing of the Hulet Wenz. Both rivers originate from the protected perennial grass lands on a wide plateau located in the upper portion of the watershed where water accumulates and saturates then drains to the two streams. Wadyat River is a perennial river, while Gudibado is mostly seasonal. The stream flow data in the period between 1994 and 2017 shows that the discharge varied between 93.6 mm (2014) and 1103.7 mm (1996) with a mean annual discharge of 417.7 mm.

The maximum and minimum annual average sediment loss of Andit tid watershed was 6.45 ton/ha and 0.825 ton/ha which was recorded in 1994 and 2007 respectively. The long term annual average sediment loss of the watershed is 3.4 ton/ha. The rates of river discharge and sediment yield indicate a major impact of mechanical soil conservation measures at catchment level. Since 2008, though the rainfall amount was decreased, the suspended sediment concentration and sediment loss are increased. This is because of the old soil conservation structures and the need of maintenance of the structure. The annual run off and sediment loss of the watershed were illustrated in Figure4.

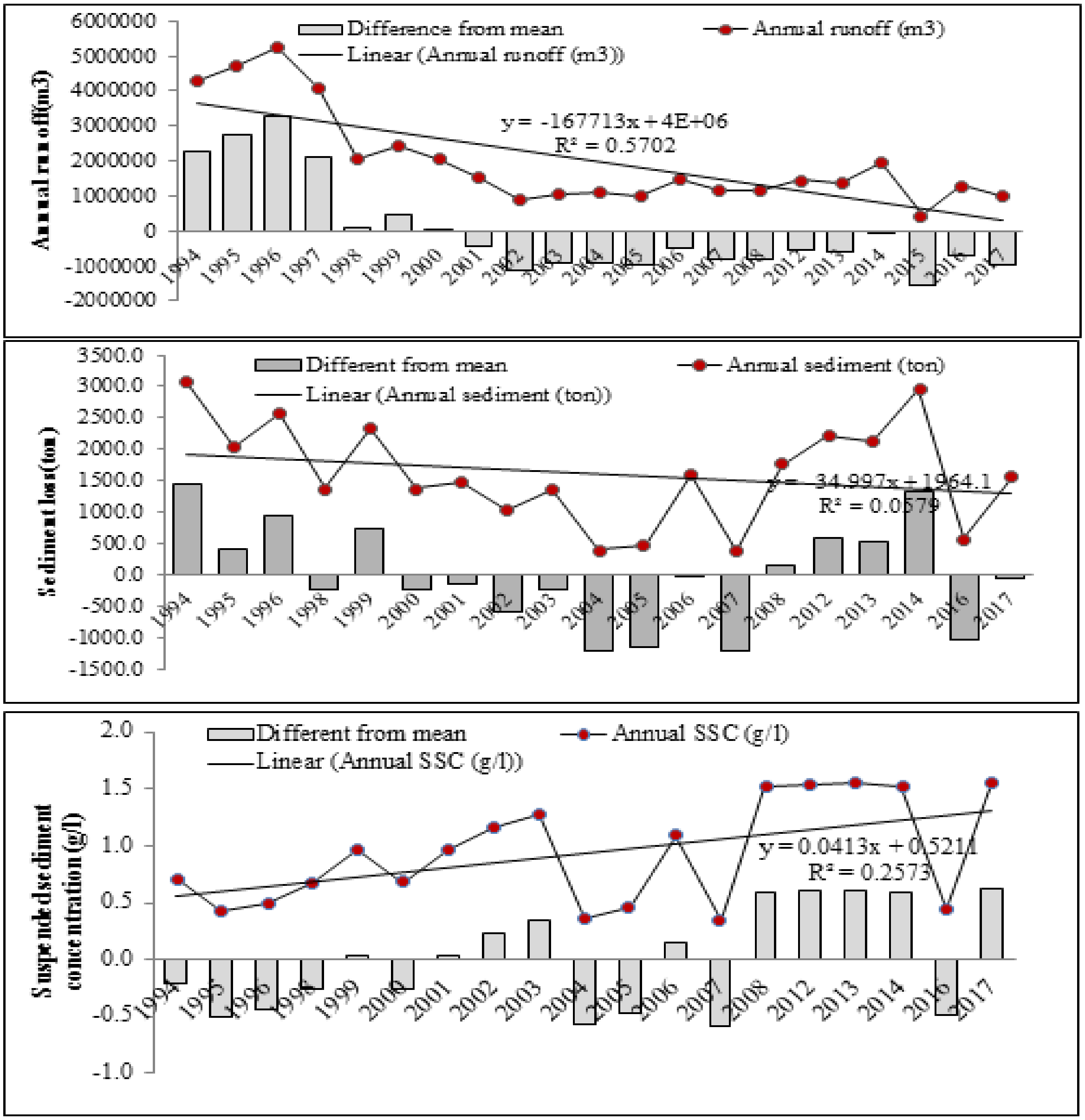

Figure 4. The annual runoff volume; sediment loss and suspended sediment concentration (SSC) of the watershed and the difference from mean of each individual year

From the Figure 4, the runoff volume was high from 1994 to 2000 but since 2001 it implies decrement and the total annual run off volume was below the mean. In similar condition the sediment loss of the watershed also high from 1994 to 1999 and it starts to decrease from 2000 and continued up to 2007. The decreased quantity of run off and sediment loss since

2000 was expected to be the result of soil and water conservation intervention works applied in the watershed. Whereas the increased trend of sediment loss starting from 2008 was the result of the oldness and destruction of applied soil and water conservation structures due to need of maintenance and other biological strengthen methods. The decreased quantity of runoff volume was clearly shown in the figure (Figure4**)** from 2001 to 2017; this may have the relation with other factors (rainfall patterns; soil structure and watershed shape) that did not addressed in this paper.

Table4. The annual runoff volume, sediment loss and suspended sediment concentration (SSC) of the watershed and the difference from mean of each individual year

Year	Annual runoff (m3)	Difference from mean	June-Sept runoff	Diff from mean June-sept runoff	Annual sediment (ton)	Diff from mean	Annual SSC (g/l)	June SSC(g/l)	July SSC(g/l)	Aug SSC(g/l)	Sept SSC (g/l)
1994	4260765	2276675	3555128.0	2054468.0	3064.7	1450.6	0.7	13.7	0.6	0.7	0.0
1995	4721545	2737455	3469422.2	1968762.2	2028.3	414.2	0.4	1.8	1.3	0.2	0.0
1996	5242418	3258328	2805852.8	1305192.8	2559.2	945.1	0.5	0.2	0.6	0.5	0.6
1997	4071007	2086917	2275910.2	775250.2	nd	Nd	nd	nd	Nd	nd	nd
1998	2060137	76046.75	1865094.1	364434.1	1376.3	-237.8	0.7	0.0	1.0	0.5	0.5
1999	2420500	436409.7	1761390.1	260730.1	2342.9	728.8	1.0	22.0	2.1	0.5	0.5
2000	2032989	48899.1	1589601.6	88941.6	1380.8	-233.3	0.7	0.0	1.5	0.6	0.6
2001	1520584	-463506	1411653.0	-89007.0	1466.0	-148.1	1.0	0.0	2.0	0.4	0.3
2002	880767	-1103323	856031.3	-644628.7	1021.3	-592.8	1.2	0.0	4.9	1.0	0.3
2003	1067722	-916368	906243.9	-594416.1	1368.5	-245.6	1.3	7.4	2.3	0.5	0.4
2004	1092495	-891595	924795.1	-575864.9	403.4	-1210.7	0.4	0.0	0.5	0.4	0.1
2005	1005153	-978937	980398.0	-520262.0	463.3	-1150.8	0.5	2.8	0.7	0.2	0.0
2006	1470352	-513738	1322937.4	-177722.6	1599.2	-14.9	1.1	0.0	2.5	0.6	1.0
2007	1147684	-836406	966320.3	-534339.7	392.1	-1221.9	0.3	0.5	0.7	0.2	0.0
2008	1155160	-828930	976442.7	-524217.3	1755.1	141.0	1.5	0.0	1.3	1.8	3.8
2012	1448200	-535890	1413896.5	-86763.5	2219.8	605.7	1.5	13.2	1.4	0.3	0.6
2013	1383312	-600778	1026795.4	-473864.6	2140.1	526.0	1.5	0.2	3.3	1.3	1.2
2014	1941020	-43070.4	1039890.4	-460769.6	2958.0	1343.9	1.5	0.0	1.2	1.1	1.2
2015	444779.5	-1539311	337438.1	-1163221.9	nd	Nd	nd	nd	Nd	nd	nd
2016	1303781	-680309	1209261.4	-291398.6	582.6	-1031.5	0.4	0.0	0.4	0.2	2.2
2017	995513.5	-988576	819362.8	-681297.2	1546.1	-68.0	1.6	0.0	5.2	0.0	0.0
Average	1984090	0	1500660	0	1613.7	0.0	0.9	3.3	1.8	0.6	0.7

From the table (Table4) the long term annual run off of the watershed is 1.984*10^6 m^3. From the total volume of the run off 75.6% was flowed during June to September in the summer season of the watershed and the remaining 24.4% was flowed during the remaining 8 months including the Bulg season. The long term average sediment loss of the watershed was 1613.7 ton (3.4 ton/ha). The long term suspended sediment concentration (SSC) was 0.9 g/l. The annual suspended sediment yield leaving the catchment varied between 392 ton (2007) and 3064.7 ton (1994), and the annual suspended sediment concentration varied between 0.3 g/l (2007) and 1.5 g/l (2008, 2012, 2013 and 2014). The suspended sediment concentration (SSC) of June, July, August and September was 3.3 g/l, 1.8 g/l, 0.6 g/l and 0.7 g/l respectively; this was expected to have a relation with vulnerability of bare surface (soft plowed land which is prepared for crop growth) to high erosion at the start of the summer season and green coverage and development of high cohesion force of the soil after saturation. At mid-June all lands are plowed and prepared for crop growth except some parcels planted at Bulg season; following this small rainfall can carry much soil and can contribute for high suspended sediment concentration at June and relatively in July also. At the mid-summer all the farm land and other land use types are covered with green floras and the soil also develop high cohesive force and this leads to decreased suspended sediment concentration at August and September.

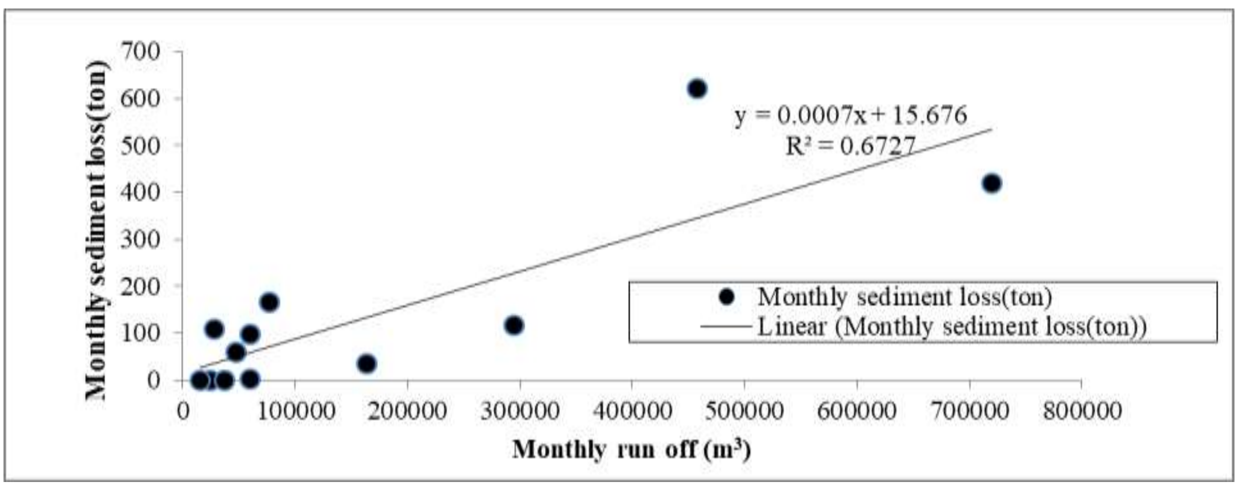

Figure 5. Monthly sediment loss (ton) and runoff volume (m^3) regression chart

The relationship between river discharge and sediment loss in Andit Tid watershed is 67.27% as mentioned in figure (Figure5). The result indicated that as the river discharge increased by

$10m^3$ the sediment loss will increase by 6.7kg of sediment. This result confirms that 67 percent of the agent of sediment loss is runoff and the remaining 33 percent is the result of other factors (edaphic, topographic, and land cover).

Time of concentration (T_C)

The time of concentration of the Andit Tid watershed is the result of the length of longest stream and the slope gradient of this stream. With this the length of the stream is 4174 m and the upper stream elevation and lower stream elevation are 3540m and 3020 m respectively with this the time of concentration of the watershed is 26.61 minute.

Trends of crop yield under conserved lands

Crop yield samples were collected on cultivated land along the existing conservation structures, i.e. within the open area between terraces/bunds. Each cropping season sampling was done permanently on various farmers' cultivated fields in the entire catchment. Three comparable samples within a terrace were taken on different locations: one immediately above (zone of deposition), one in between, and one immediately below (zone of transportation) the conservation structures.

Table 5. Statistical variation of crop yield over different position of terrace ("a": above, "b": in between terrace and "c": below terraces with α=0.05)

	Average crop yield(kg/ha)			
Position	wheat	Barley	Linseed	Horse bean
A	1245.8a	2084.8	691.2a	927.31a
B	1040b	1850.2	608.9ab	839.7ab
C	1020.2b	1651	563b	734.5b
Mean	1102	1862.3	621	833.8
LSD(0.05)	**	ns	*	*
CV (%)	18.54	43.07	20.97	14.34

The result of on-farm yield data in relation to its positions on terraces is shown in Table5. The table shows the impact of conservation structures on the crop productivity. All crops delivered statistically highest yield immediately above bunds and the lowest yield immediately below bunds. This is the result in which the bunds could trap the soil which comes from the upper parts and the accumulated soil expected to have plant nutrients that helps for better performance and production of crops.

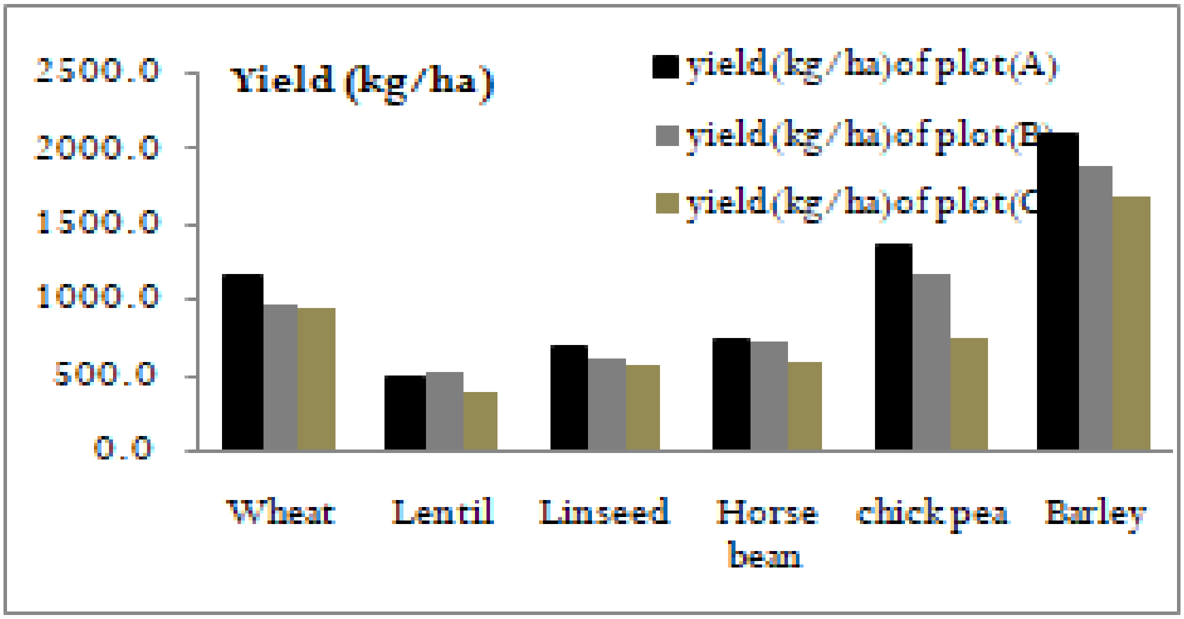

Figure 6. The response of major crops yield for different locations of terraces

The long term average grain yield result of crops in the study watershed was slightly greater than the grain yield reported by Hurni (2000) from the period (1983-1994). In general, the situation in Andit Tid is difficult for peasants. It is characterized by relatively high population and livestock densities, a high degree of land degradation, low crop yield and production as well as drastically reduced fallow periods (Hurni, 2000). Beside shortage of land, the lack of manure for fertilizer is a main problem for the farmers. Yields are further endangered by hailstorms, frost, pests (i.e. wag, fake) and rodents. The result of on-farm yield data of commonly growing crops in relation to its positions on terraces is shown in Figure6, 7and 8. Even though the general trend of grain yield in the watershed is low, the graph shows the impact of conservation structures on the yield of crops. Lower yields in the zone below the bunds are expected to be the result of two processes: (1) decreased nutrient level in the soil caused by a loss of topsoil and (2) moisture stress caused by a diminished effective water storage capacity. Nearly for the last 3-4 years the grain yields of all commodity crops are generally declining this is expected to be the result of the diminishing the efficiency of the long term bunds constructed on those plots.

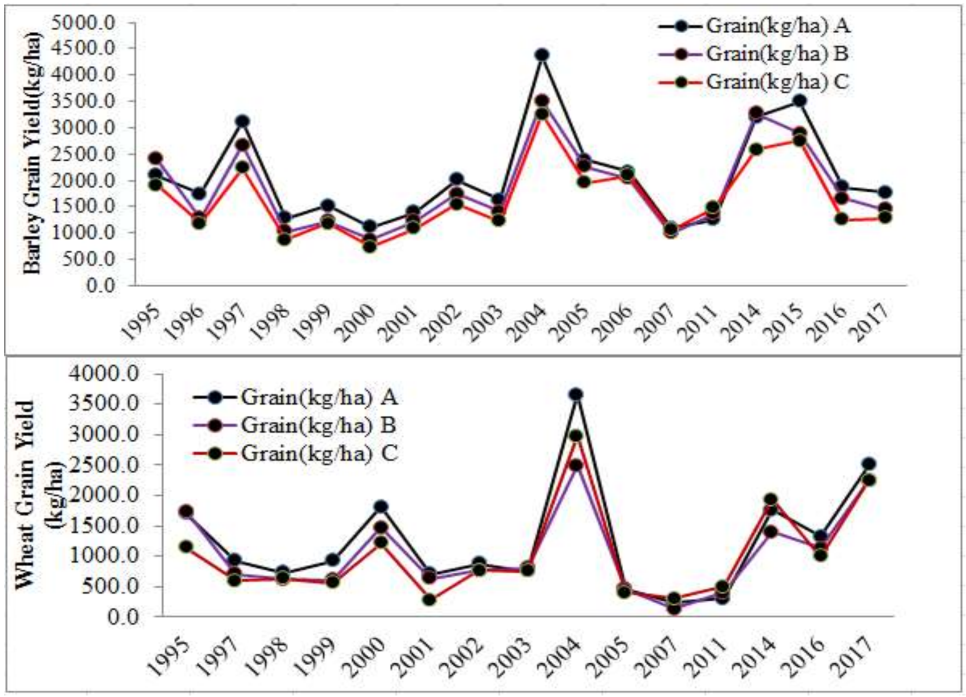

Figure 7. The long term response of Barley and Wheat yield for different locations of the terraces, (a = above / b = in between / c= below conservation structures)

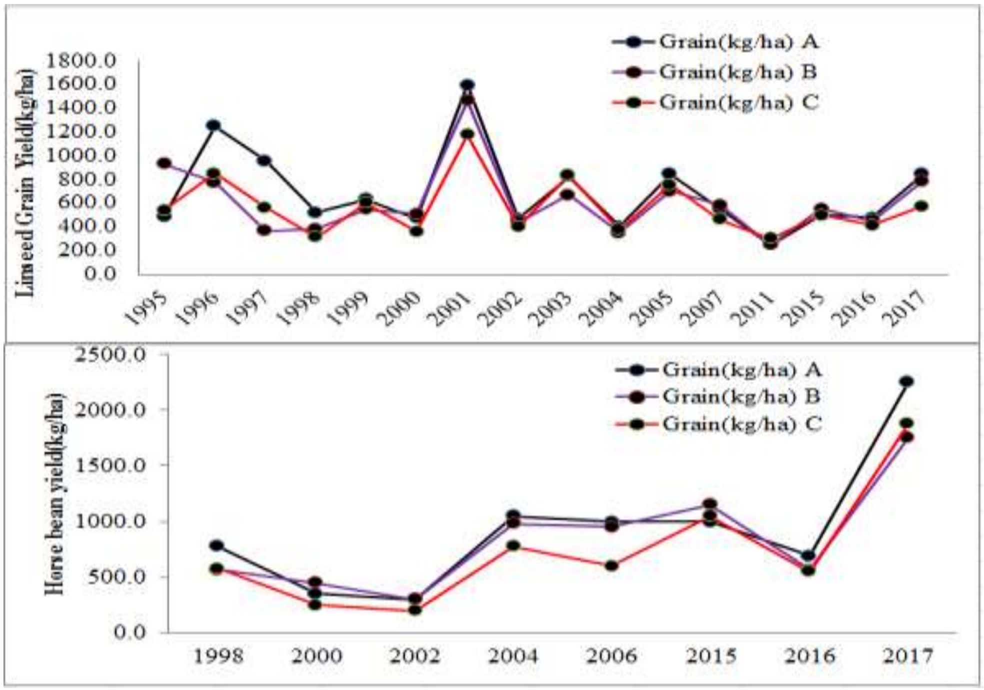

Figure 8. The long term response of Linseed and Horse bean yield for different locations of the terraces, (a = above / b = in between / c= below conservation structures)

The effects of diminishing topsoil in the upper zone of the conservation structure, and the resulting lower plant nutrient capacity immediately below the bunds were not systematically analyzed. Additional information, for example about soil depth and crop type can be found in the primary database.

Conclusion and Recommendation

Having realistic data in all hydrologic, climatic, sediment loss, crop production and land use change is the best thing in natural life. For having these realistic data on the mentioned parameters, actual field measurements are the best option because events may temporally and spatially varied. But in most countries including Ethiopia the data on hydrologic, sediment loss, climatic and crop production could not be collected and maintained properly for several reasons. Now even though it's impossible to measure hydrologic, sediment loss, climatic and crop production at every vulnerable spot in the country; it could be possible to saw the trends of these parameters at watershed level. Currently we could establish a well-structured, reliable and user's friendly data bank for rainfall, surface and atmospheric temperature, discharge, sediment loss and crop production potential and in the meantime we could provide a hydro-sedimentology characterization of a watershed.

On behalf this research paper compiles the analysis of spatial and temporal distribution of the rain fall; trends of run off and sediment loss and their relation and the influence of position of terraces on crop production. Based on the rainfall analysis the mean annual rainfall of the watershed is 1581mm and the distribution has bimodal characteristics which concentrated from March to May and July to September. The PCI value of the watershed is 1.07% which means the rainfall in the watershed have uniform spatial distribution. From the rainfall trend analysis result the rainfall of the watershed has insignificant variation (CV%=16.7) which is an indicator for less vulnerability to drought. The precipitation coefficient (%) value of the watershed indicates that July (PC=2.551) and August (PC=2.395) have big rain with high concentration; September (PC=1.068) have big rain with moderate concentration and these three months could contribute more than one twelve of total rainfall amount and January, February, October and November are dry months. The long term average runoff and sediment loss of the watershed is 417.7 mm and 1613.7 ton respectively. There was the decreased quantity of run off and sediment loss since 2000; it was expected to be the result of soil and water conservation intervention works applied in the watershed; whereas the increased trend of sediment loss starting from 2008 was the result of the oldness and destruction of applied soil and water conservation structures due to need of maintenance and other biological strengthen methods. The average surface and atmospheric temperature of the watershed is 14.2^0C and 12.6^0C. The result of on-farm yield data shows the impact of conservation structures on the crop productivity. All crops delivered statistically highest yield immediately above bunds and the lowest yield immediately below bunds. This is the result in which the bunds could trap the soil which comes from the upper parts and the accumulated soil expected to have plant nutrients that helps for better performance and production of crops.

Now Andit tid watershed has over 37 years of data, which should be useful to predict long term changes in a number of parameters that can be used to develop and manage the water and land resources in similar agro-ecologies. So the data helps the researcher to forecast possible climatic scenarios; to calibrate and validate hydrological models; to investigate the long-term impact of soil and water conservation interventions in ecosystem services and water storage capacity of the soil as well as to assess the soil health and crop productivity of soil and water conservation interventions in very fine manner.

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