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I) Soil fertility and Management of Problematic Soils

Economical optimum rates of N and P for food barley (*Hordeum vulgare* L.) production in the highlands of Central and North Gondar

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Abstract

Soils in the Ethiopian highlands have low levels of N and P nutrients for crop production. To address this problem and increase crop production, one of the solutions among others is to supply the deficient N and P nutrients through synthetic fertilizer. Therefore, a field experiment was conducted to find optimum nitrogen and phosphorus levels on yield of food barley at Debark, Dabat and Wegera districts, during the rainy seasons of 2019 and 2020. The treatments consisted factorial combinations of 4 rates of Nitrogen (46, 69, 92 and 115 kg ha^{-1} N) and 3 rates of Phosphorus (23, 46 and 69 kg ha^{-1} P_2O_5) arranged in randomized complete block design in 3 replications. Nitrogen showed a significant effect on plant height, spike length, above ground dry biomass and grain yield. The effect of Phosphorus was also significant on the above ground dry biomass. The maximum average grain yield (3150.83 kg ha^{-1}) was obtained at 115 kg ha^{-1} N. Finally, 23 kg ha^{-1} P_2O_5 combined with 92 kg ha^{-1} N are economical optimum rates for food barley production based on partial budget analysis. Therefore, it is indispensable to use this recommendation for the Central and North Gondar zone highlands.

Key words: Ethiopia; food barley; nitrogen; North Gondar highlands; phosphorus

Introduction

As in many other tropical and sub-tropical regions (Sanchez, 1976), soils in the highlands of Ethiopia, usually have low levels of essential plant nutrients and organic matter content, especially low availability of N and P has been demonstrated to be a major constraint to crop production in Ethiopia (Tekalign *et al*., 1988). This is largely a consequence of the cereal dominated mono-cropping system resulting with the continuous nutrient mining through removal by plants and no consideration for the replenishment through application of either mineral or organic fertilizer sources (Amsal *et al*., 1999).

The grain yield potential of released food barley varieties that are under production in Ethiopia ranges 2270 to 6100 kg ha^{-1} (Masreshaw, 2018). Although the importance of barley as a food and feed crop in Ethiopia and the efforts made so far to generate improved production technologies, its national average productivity (2177 kg ha^{-1}) has remained very low (CSA, 2019). For the past several years, farmers in the country had used blanket recommendation of only nitrogen and phosphorus fertilizer sources as an input to improve soil fertility and increase crop production including food barley. Similarly, the majority of farmers use fertilizers for their barley field in the Dabat, Debark and Wegera highlands (Daniel and Beyene, 2019). However, the blanket recommendation lacks the right rates of those fertilizer types in the specified locations.

There was no research conducted to determine site specific fertilizer rates recommendation on food barley productivity in the Central and North Gondar highlands. As a result, the farmers and development agents (DAs) rely on old fertilizer recommendation that is very general over the country. Therefore, there is a need to study the influence of different rates of N and P nutrients on the productivity of food barely, which provide economic optimum yield of food barley in the highlands of Central and Norther Gondar Zones; Ethiopia.

Materials and Methods

Study sites description

The field experiments were conducted in 2019 and 2020 in the main rainy season at Wegera, Dabat and Debark districts of Central and North Gondar administration zone in the Amhara

National Regional State, Ethiopia (Figure 1). According to the FAO soil classification, the dominant soil type of those areas is cambisols (FAO, 2015). The climatic data for the study districts were compiled for the last 5 (2016-2020) consecutive years. As shown in Figure 2 the areas received from 958 mm to 1620 mm total annual rainfall during the last 5 years (NASA, 2019).

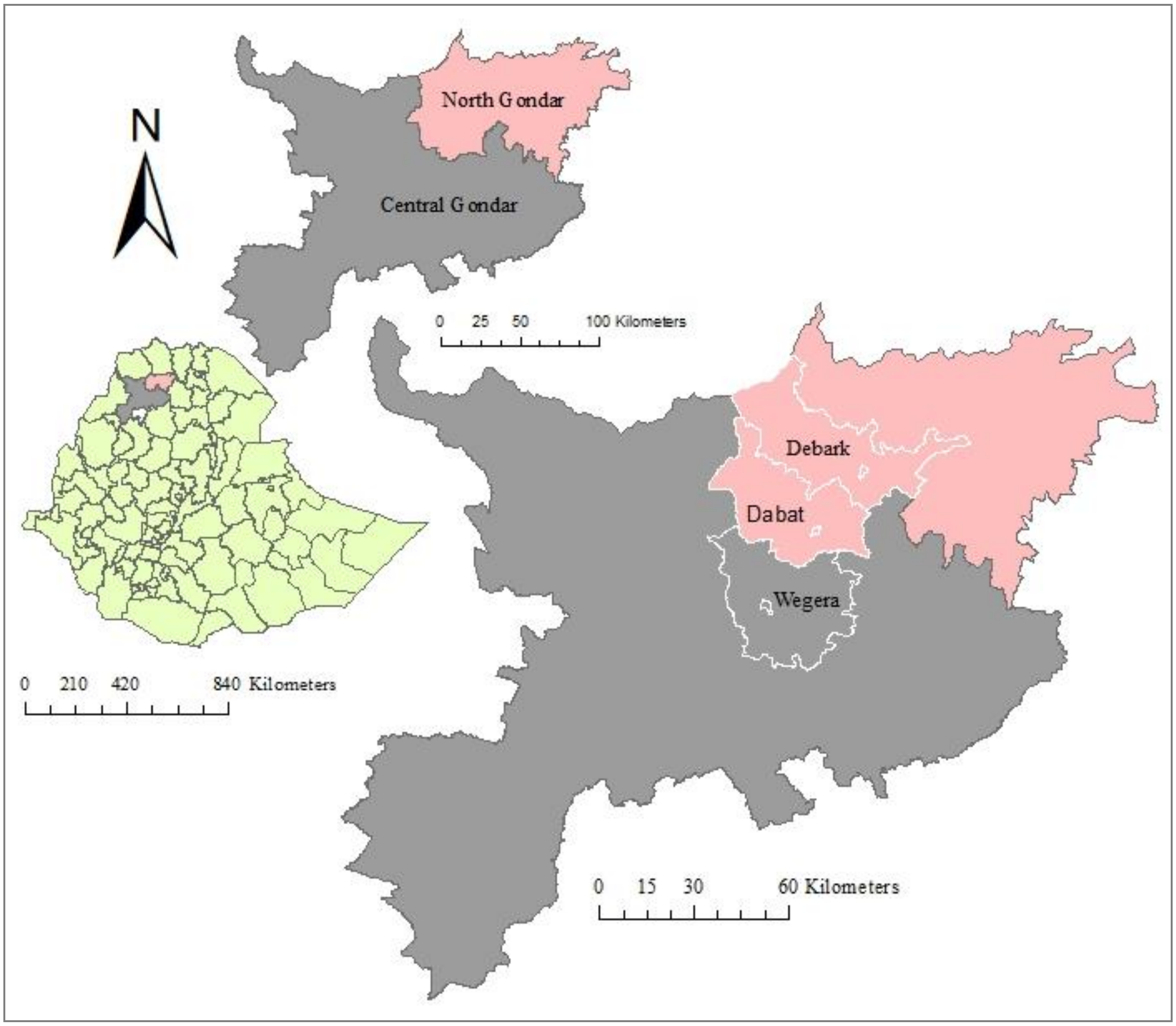

Figure 1. The map of Dabat, Debark and Wogera districts

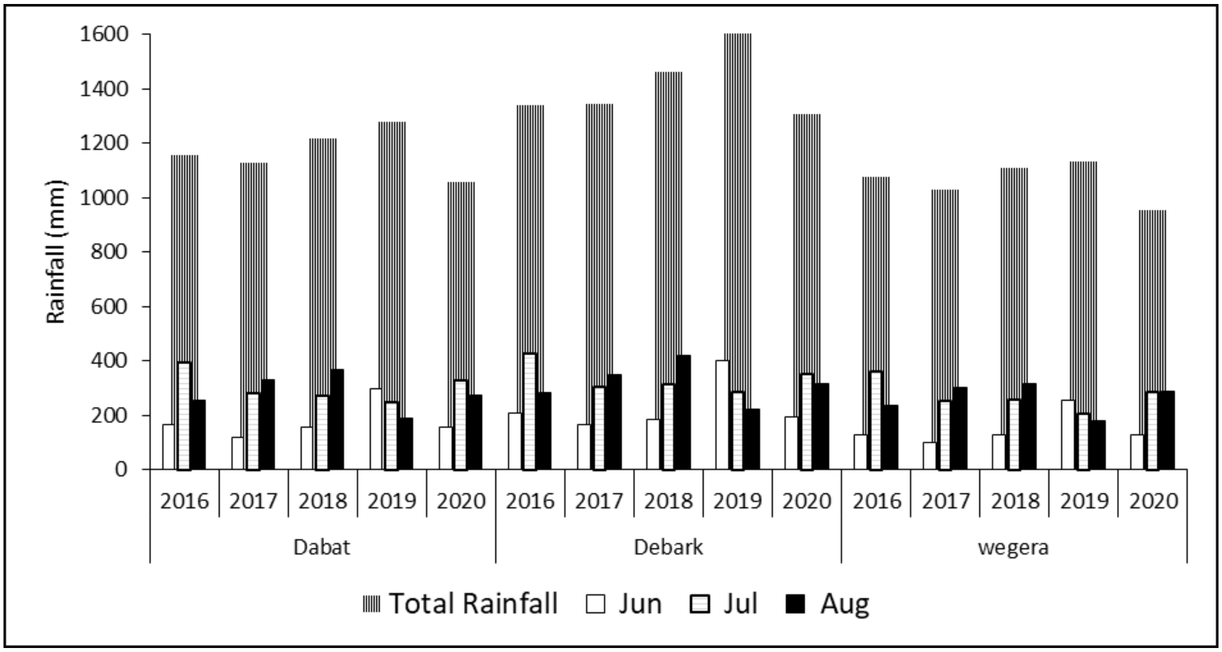

Figure 2. Jun, July, August**, and total rainfall at Dabat, Debark and Wegera districts**

Experimental Methods

In the first year, the experiment composed of factorial combination of four levels of N (46, 69, 92 and 115 kg ha^{-1}) and three levels of P_2O_5 (23, 46 and 69 kg ha^{-1}); besides one satellite treatment (0 N and 0 P) was observed. However, in the second year the experiment considered only factorial combination of four levels of N (46, 69, 92 and 115 kg ha^{-1}) and four levels of P_2O_5 (0, 23, 46 and 69 kg ha^{-1}); The treatments were laid out in randomized complete block design with three replications. The experiment was conducted on five sites; at Dabat (site1 and site 4), Debark (site 3 and site 5) and Wegera (site 2) districts in 2019. In addition, it was done on site 6 at Dabat district in 2020. Site 6 (2020) and site 1 (2019) located adjacently on the same farm land, and they can share similar soil properties.

The gross plot size was 3 m*3 m = (9 m^2) and spacing between plots and replication were 1 m and 1.5 m respectively. Triple Super Phosphate (TSP) was used as a source of phosphorus and urea was used as a source of nitrogen as indicated in the treatments. All doses of TSP fertilizer were drilled in furrows at the time of sowing, and half of N was added at planting and the remaining half after 45 days of planting. Debark 1 food barley variety was used with the seed rate of 125 kg ha^{-1}.

Physicochemical properties of the experimental soils:

Before planting, soil samples were collected from about 10 sub-sampling spots and 0-30 cm soil depths; then one composite soil sample was made for each experimental site. The soil samples were air dried ground and sieved for the determination of parameters of pH, total N, available P, the soil particle size distribution, Organic Carbon (OC) and cation exchange capacity (CEC). The distribution of soil particle size was determined by hydrometer method (Bouyoucos, 1951). The soil pH was measured with digital pH meter potentiometerically in supernatant suspension of 1:2.5 soil to distilled water ratio (Van Reeuwijk, 1992). The organic carbon (OC) was determined by the dichromate oxidation method (Walkley and Black, 1934). The total N in the soil was measured by the micro kjeldhal method (Jackson, 1958). Cation exchange capacity (CEC) was determined by 1M ammonium acetate method at pH 7 (Chapman, 1965). Available P was analyzed by Olsen method (Olsen *et al*., 1954). The soil samples were analyzed at Gondar soil testing laboratory.

According to Tekalign et al. (1991) the pH of site 1, site 3 and site 5 were moderately acidic soils; site 2 and site 4 were slightly acidic; the soil Organic Carbon (OC) content of all sites were moderate, except site 5 (low); total N from all sites were high, except site 3 (moderate); available P from site 1, site 2 and site 5 were very high; site 3 (high) and site 4 (medium); and Cation exchange capacity (CEC) from all sites were high (Table 1).

Table 1. The initial physico-chemical soil properties of the experimental sites (2019)

Experimental Sites	TN (%)	Av. P (ppm)	sand (%)	clay (%)	silt (%)	Textural Class	pH ($H_2$0)	OC (%)	CEC Cmol (+) /kg Ammon.Acet
Site 1	0.31	38.07	26.72	32	41.28	Clay loam	5.70	2.41	42.63
Site 2	0.27	73.29	26.72	32	41.28	Clay loam	6.24	1.91	50.20
Site 3	0.21	21.88	28.72	34	37.28	Clay loam	5.72	2.19	37.73
Site 4	0.35	10.68	24.72	44	31.28	Clay	6.08	2.49	40.90
Site 5	0.27	56.24	46.72	20	33.28	Loam	5.74	1.43	45.30

Data Collection and Analysis:

The following agronomic data were collected on 5 experimental sites in 2019 and at one site in 2020:

- Plant height and spike length: were recorded from 10 randomly selected plants from the net plot area at harvest.
- Above ground dry biomass: plants harvested close to the ground surface from the net plot were sun-dried in an open air, and weighed to determine the above ground biomass yield.
- Grain yield: It was determined after adjusting the actual grain yield at the appropriate moisture level of 12.5%.
- Thousand seeds weight: It was determined by weighing 1000 randomly selected grains and weighing with sensitive balance, and adjusted at moisture level of 12.5%.

The collected data were analyzed by SAS version 9.4 statistical software using General linear model (GLM) procedure after checking the compliance of the data with the assumptions of the statistical test. Comparisons among treatment means with significant difference for measured parameters were done using least significance difference (LSD) at 5% probability level. The partial budget analysis was done using the procedures outlined by CIMMYT (1988).

For economic analysis, the variable cost of fertilizers was taken at the time of planting. Yield from experimental plots was adjusted downwards by 10% for management difference between the experimental and farmers' field. The return was calculated as total gross return minus total variable cost. During planting time, field grain yield price of food barley was 22 birr kg^{-1}, the price of straw was 2 birr kg^{-1} and market price of urea was 15 birr kg^{-1}, which were used for variable cost determination. Net benefits and costs that vary between treatments were used to calculate marginal rate of return to invested capital as we move from a less expensive to a more expensive treatment. In this study, 100% return to the investments was used as reasonable minimum acceptable rate of return.

Marginal analysis was done by un-dominated treatments to make recommendation. Which is the process of calculating marginal rates of return (change in net benefit divided to change in total cost) between treatments, proceeding in steps from a lower cost treatment to that of next higher cost, and comparing those rates of return to the minimum rate of return (100%) acceptable to farmers. The purpose of marginal analysis is to reveal just how the net benefits from food barley yield increases as the amount of N application increases. If these values continue to fall, then the analysis can be stopped at the last treatment that has an acceptable rate of return compared to the treatment of next lowest cost (CIMMYT, 1988).

Result and Discussion

Effects of N and P on food barley

The analysis of variance (ANOVA) result showed that the effect of different N rates significantly ($P < 0.01$) affected grain yield of food barley at 5 experimental sites in 2019.

Table 2. Effects of N and P on average value of grain yield in kg ha^{-1} of food barley (2019)

Treatments	Site 1	Site 2	Site 3	Site 4	Site 5
N (kg ha^{-1})					
46	2039.6^{b}	2138.20^{c}	1511.70^{c}	1434.7^{b}	2393.90^{d}
69	2502.4^{b}	2418.40^{bc}	2079.20^{bc}	1692.3^{b}	2893.00^{c}
92	2515.2^{b}	3158.40^{a}	2686.80^{ab}	2341.7^{a}	3741.50^{b}
115	3073.9^{a}	2962.00^{ab}	3230.30^{a}	2650.6^{a}	4160.80^{a}
LSD (5%)	546.25**	633.50*	614.82**	393.54**	318.55**
P_2O_5 (kg ha^{-1})					
23	2432.7	2589.20	2241.70	2045.10	3123.80
46	2550.1	2486.30	2442.80	2056.10	3416.20
69	2615.5	2932.20	2446.50	1988.30	3351.90
LSD (5%)	NS	NS	NS	NS	NS
CV (%)	22.06	24.28	26.46	19.83	9.88
Satellite (0,0)	987.36	1505.28	689.78	1021.73	1685.57

All experimental sites showed progressive increase of grain yield in response to increased rates of nitrogen except site 2. However, there were no significant effect among P rates and their interaction with N (Table 2). The grain yield with no application of N and P (0, 0) fertilizers was ranged from 689.78 to 1685.57 kg ha^{-1}; but with the maximum N input (115 kg ha^{-1}) the grain yield ranged from 2650.6 to 4160.8 kg ha^{-1} (Table 2). While the ANOVA result showed that the interaction effect of different N and P rates (modified) significantly ($P < 0.05$) affected grain yield of food barley at one experimental site in 2020. Similar to the previous year experimental sites no statistically significant average grain yield differences were observed among application of 23, 46 and 69 kg ha^{-1} P_2O_5 rates (Table 3).

There is different grain yield response among experimental sites and additions of N fertilizer. All sites had more than soil P critical concentration (4.60 ppm) of food barely that determined by

Mulugeta *et al*. (2022) in Sinana district of Bale zone. As a result, recommendations to all sites are generally for maintenance of P in the optimum range (Douglas, 2011). Nevertheless, a single point of critical nutrient concentration is difficult to establish experimentally, the critical point may vary under different conditions (Dow and Roberts, 1982). Therefore, it looks desirable to deal with a critical nutrient range instead of a single concentration. According to critical nutrient ranges adopted by the Ethiopian Soil Information System (EthioSIS), the initial soil result in site 3 and site 4 were below the optimum critical P range (30 - 80 ppm), but all sites were within optimum levels of critical N range (0.15 - 0.3%) to most field crops (ATA, 2016). Generally, for soil test interpretations to be valid, it must be based on calibrations conducted under conditions similar to those where the test is used and must be calibrated for the specific crop to be grown. Therefore, local calibrations are desired (Douglas, 2011).

Our laboratory result of the soil was reported in the form of total N which exists in organic and inorganic forms. In the surface layer of most soils, over 90% of N occurs in organic forms (Silva et al., 2019). Most forms of organic nitrogen cannot be taken up by plants. In contrast, plants can readily take up mineral forms of nitrogen, including nitrate and ammonium. Although soil nitrogen supply is useful to estimate how much nitrogen from organic matter will become available to this crop, there is a significant difficulty with this measurement. Hence, the total N estimates the quantity of nitrogen released from organic matter without giving any information about when it will be available to the crop. Even though our soil nitrogen content was high the crop yield responded to the applied N fertilizer may be above explained reasons.

Table 3. The interaction effect of N and P on average value of grain yield in kg ha^{-1} of food barley at site 6 (2020)

Treatments	P_2O_5 (kg ha^{-1})				
N (kg ha^{-1})	0	23	46	69	Mean
46	982.2^{i}	1133.2^{ghi}	1671.8^{efgh}	1616.9^{efghi}	1351.0^{c}
69	1750.9^{efg}	1988.5^{def}	1996.5^{cdef}	1935.5^{def}	1917.8^{b}
92	1068.6^{hi}	2236.7^{bcde}	2161.1^{cde}	2641.1^{abc}	2026.9^{b}
115	1494.0^{fghi}	2819.1^{ab}	2461.6^{bcd}	3201.2^{a}	2494.0^{a}
LSD (5%)	649.94*				
CV (%)	20.01				
Mean	1323.9^{a}	2044.4^{b}	2072.8^{b}	2348.7^{b}	

The combined ANOVA was done for six sites excluding the level of 0 P_2O_5 from site 6; the result showed that the application of different N rates significantly ($P < 0.01$) increased plant height, spike length, above ground dry biomass and grain yield; but it was not influenced thousand seed weight of food barley. The tallest plant height (98.5 cm), the longest spike length (6.64 cm), the maximum above ground dry biomass (7974.19 kg ha^{-1}) and grain (3150.83 kg ha^{-1}) yield were recorded by application of 115 kg N ha^{-1} (Table 4). The result of the present study showed that application of 92 kg N ha^{-1} had added 23.8% grain yield of food barley over the previous N rate of recommendation (69 kg N ha^{-1}). Likewise, application of 115 kg N ha^{-1} had 39.4% yield increment over application of the previous recommendation (69 kg N ha^{-1}) to food barley. In agreement, Ketema and Mulatu (2018) reported that increased application of N on various varieties of food barley gave increased plant height, spike length, above ground dry biomass and grain yield. In contrast to the present finding, they also reported increased application of N significantly influenced thousand seed weight. Also, Wakene et al. (2014) reported that both N and P significantly influenced total dry biomass of barley but their interaction effect was not significant; the highest total dry biomass were recorded on plots received 120 kg N ha-1 (8780 kg ha-1) and 69 kg P2O5 ha-1 (8910 kg ha-1).

Table 4. The effect of N and P on average value of growth, yield and related components of food barley combined over years

Treatments	PH	SPL	BM	GY	TSW
N (kg ha^{-1})					
46	86.36^{d}	5.79^{d}	5333.89^{d}	1832.01^{d}	42.01
69	90.69^{c}	6.03^{c}	6259.82^{c}	2259.79^{c}	42.62
92	95.86^{b}	6.40^{b}	7295.18^{b}	2798.33^{b}	41.51
115	98.50^{a}	6.64^{a}	7974.19^{a}	3150.83^{a}	41.67
LSD (5%)	1.73**	0.18**	421.80**	162.21**	NS
P_2O_5 (kg ha^{-1})					
23	92.21	6.23	6580.39^{b}	2412.83	41.62
46	92.53	6.21	6559.34^{b}	2504.05	42.07
69	93.83	6.20	7007.58^{a}	2613.84	42.17
LSD (5%)	NS	NS	365.29*	NS	NS
CV (%)	6.13	7.47	18.25	20.28	6.01

PH= Plant height (cm), SPL=Spike Length (cm), BM= Above Ground Dry Biomass (kg ha^{-1}), GY=Grain Yield (kg ha^{-1}), TSW= Thousand Seed Weight (g), NS= Non Significant, *= Significant at 5%, and **= Significant at 1%

The combined ANOVA showed that there was no significant effect among P rates and their interaction with N, but above ground dry biomass yield significantly ($P < 0.05$) influenced by p rates (Table 4). The result showed that application of the previous P rate of recommendation (46 kg P ha^{-1}) gave grain yield that statistically at par with application of 23 and 69 kg P_2O_5 ha^{-1}. Similarly, Lake and Bezabih, (2018) reported increased application of P significantly influenced above ground dry biomass. They also found that increased application of P fertilizer to food barley gave increased plant height, spike length and grain yield. According to Cook and Davis (1957), soil test results on mineral soils show that phosphorus levels are building up in soils where crops are being regularly fertilized. Although the accumulation of phosphorus is rarely proportional, so that changes to the right rate of P fertilizer recommendation to crops become necessary to maintain soil P balance.

Partial Budget Analysis

The marginal rate of return (MRR) from this study showed that application of the three rates of N fertilizer (69, 92 and 115 N kg ha^{-1}) gave greater than 100% return (which was used as reasonable minimum acceptable rate of return) as compared with application of 46 N kg ha^{-1}.

Table 5. The partial budget analysis

N	AGY	Straw	GB	TVC	NB	D	MB	MC	MRR
46	1648.81	3151.69	42577.18	1500.00	41077.18	-			
69	2033.81	3600.03	51943.90	2250.00	49693.90	-	8616.71	750.00	1148.90
92	2518.50	4047.17	63501.26	3000.00	60501.26	-	10807.37	750.00	1440.98
115	2835.75	4341.02	71068.48	3750.00	67318.48	-	6817.22	750.00	908.96

N = N rate (kg ha^{-1}), AGY =Adjusted (10%) grain yield (kg ha^{-1}, Straw= straw yield (kg ha^{-1}), GB = gross benefit from grain and straw yield (birr ha^{-1}), TVC = total cost that vary (birr ha^{-1}), NB = net benefit (birr ha^{-1}), D = dominated, MB = Marginal Benefit, MC= Marginal Cost, MRR = marginal rate of return (%).

The maximum net benefit (67318.48 ETB) with MRR of 908.96% was obtained from application of 115 N kg ha^{-1} (Table 5). However, the maximum MRR of 1440.98% was obtained from application of 92 N kg ha^{-1} (Table 5). This means that for every 1.00 birr invested in N fertilizer application to food barley production, farmers can obtain an additional 14.41 birr in the North Gondar highlands.

Conclusion and Recommendation

Increased N application had significantly ($P < 0.01$) increased plant height, spike length, above ground dry biomass and grain yield of food barley, but not to thousands seed weight. However, there were no significant influences in all measured parameters among applied P rates, and their interaction with N rates, except significantly ($P < 0.05$) increased trend of above ground dry biomass has showed with increased P rates. Therefore, it is recommended to apply the lowest P fertilizer rate (23 kg ha^{-1} P_2O_5) to enhance food barley productivity and maintain availability of P in the soil. In addition, based on partial budget analysis, application of 92 kg ha^{-1} N is economically optimum fertilizer rate for food barley (Debark 1 variety) production in the Central and North Gondar zones.

References

Amsal Tarekegn, Tanner D. G. and Chanyalew Mandefro. 1999. A study of variety by management interaction in bread wheat varieties released in Ethiopia pp196-212 In: The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa, CIMMYT, Addis Ababa, Ethiopia.

ATA (Agricultural Transformation Agency). 2016. Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia.

Bouyoucos, G.S. 1951. Recalibration of the hydrometer methods for making mechanical analysis of soil. *Agronomy journal*, 43: 434-438. https://doi.org/10.2134/agronj1951.00021962004300090005x

Chapman, H.D. 1965. Cation exchange capacity in methods of soil analysis. Part 2. *Agronomy Monograph*, 9: 891-894.

Central Statistics Agency (CSA). 2019. The Federal Democratic Republic of Ethiopia, Central Statistical Agency agricultural sample survey 2018/19 (2011 E.C.) volume I report on area and production of major crops (private peasant holdings, Meher season). Statistical Bulletin no.589, Addis Ababa, Ethiopia, pp. 14.

Cook, R.L. and Davis, J.F. 1957. The Residual Effect of Fertilizer. Advances in Agronomy, 9(C):205-216. https://doi.org/10.1016/S0065-2113(08)60114-5

Daniel, T. and Beyene, D. 2019. The status and constraints of food barley production in the North Gondar highlands, North Western Ethiopia. Agriculture and Food Security, 8:3. https://doi.org/10.1186/s40066-018-0248-3

Douglas, B. 2011. Chapter 14: interpretation of soil testing results. Recommended soil testing procedures for the northeastern United states northeastern regional publication NO. 493, 3rd Edition.

Dow, A. I. and Roberts, S. 1982. Proposal: Critical Nutrient Ranges for Crop Diagnosis. Agronomy Journal, 74(2): 401-403. https://doi.org/10.2134/agronj1982.00021962007400020033x

Food and Agriculture Organization of the United Nations (FAO). (2015). World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps (World soil resources reports, 106). Rome, Italy: retrieved from: http://www.fao.org/3/i3794en/I3794en.pdf

Jackson, M.L. 1958. Soil chemical analysis. *Prentice Hall, Inc., Englewood Cliffs. N.J. Sixth Printing* 1970. PP. 498.

Ketema, N. and Mulatu, K. 2018. Response of Food Barley (*Hordeum vulgare* L.) Varieties to Rates of Nitrogen Fertilizer in Limo District, Hadiya Zone, Southern Ethiopia. Journal of Natural Sciences Research, 8(15): 17-31.

Lake, M. and Bezabih, W. 2018. "Response of Food Barley (*Hordeum Vulgare* L.) to Various Levels of P Fertilizer", International Journal of Research in Agriculture and Forestry, 5(2): 21-26.

Masreshaw, Y.H. 2018. Review on Barley Breeding and its Status in Ethiopia. International Journal of Research Studies in Agricultural Sciences (IJRSAS), 4:9 (13-21) DOI: http://dx.doi.org/10.20431/2454-6224.0409003

Mulugeta, E. Regassa, G. Daniel, A. Tesfaye, K. Girma, G. Tilahun, C. 2022. Soil Test Based Crop Response Phosphorus Calibration Study for Food barely Production in Sinana District of Bale Zone, Southeastern Ethiopia. American Journal of Environmental Science and Engineering. 6(2): 101-111. doi: 10.11648/j.ajese.20220602.13

NASA. (2019). NASA Langley Research Center (LaRC) POWER Project. https://power.larc.nasa.gov/data-access-viewer/

Olsen, S.R., Cole, V., Watanabe, F.S. and Dean, L.A. 1954. Estimations of available phosphorus in soils by extractions with sodium bicarbonate. *U.S. Dept. Of Agric. Cric.939*, USDA, Washington, DC.

Sanchez, P. A., 1976. Properties and Management of Soils in the Tropics. In : Effects of rates of nitrogen and varieties on nitrogen use in draft wheat . Japanese J. of Crop Sci. 48 (2): 279 – 282.

Silva, E. F. d., Melo, M. F., Sombra, K. E. S., Silva, T. S., de Freitas, D. F., Costa, M. E. d., Santos, E. P. d. S., Silva, L. F. d., Serra, A. P. and de Morais Cavalcante Neitzke, P. R. 2019. Organic Nitrogen in Agricultural Systems. In E. C. Rigobelo, and A. P. Serra (Eds.), Nitrogen Fixation. IntechOpen. https://doi.org/10.5772/intechopen.90242

Tekalign, M. Haque, I. and Kamara, G. S. 1988. Phosphorus status of some Ethiopia highland Vertisols. PP. 232-249. In: Jutz, S.C., I. Haque Mdntirc (eds.) Soils in Sub-Saharan Africa, ILCA, Addis Ababa, Ethiopia.

Tekalign, T. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Van Reeuwijk, L.P. 1992. Procedures for soil analysis.3rd edition. International Soil Reference and Information Center Wageningen (ISRIC). The Netherlands, Wageningen.

Wakene, T. Walelign, W. and Wassie, H. 2014. Effects of Nitrogen and Phosphorus Fertilizer Levels on Growth and Development of Barley (Hordeum vulgare L.) at Bore District, Southern Oromia, Ethiopia. American Journal of Life Sciences. 2(5): 260-266. doi: 10.11648/j.ajls.20140205.12

Walkley, A.J. and Black, I.A. 1934. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37: 29-38.

Effect of Potassium and micronutrient on Sorghum (*Sorghum bicolor* L. Moench) yield in the lowland areas of Eastern Amhara

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Abstract

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency developed soil fertility map (multi nutrient status and potassium status) for Amhara Region and demonstrated to farmers without research data. Field experiment was conducted in 2017/18 main cropping season at Kobo and Dawa-Chefa districts, east Amhara, to verify the response of sorghum to the application of potassium, boron and zinc containing fertilizers. The treatments were composed of NPS, NPSK, NPSZnB and NPSZnBK and arranged in a randomized completed block design with three replications. Nitrogen and phosphorus were adjusted to the location specific recommended rates using urea and NPS respectively. Potassium was applied as a straight fertilizer at the rate of 150 kg KCl ha^{-1}*. All other nutrients were applied at planting while nitrogen was applied in splits; half at planting and half at forty five days after planting. Girana1 sorghum variety was used as a test crop for both districts. Composite soil samples were collected from 0-20 cm depth to determine selected soil parameters following standard laboratory procedures. Agronomic data were also collected and subjected to analysis of variance using SAS software and mean separation was done using least significant difference at 5%. The available phosphorus (33 to 45 ppm) and exchangeable potassium (4.9 to 5.6 cmol*$_C$*kg*$^{-1}$*) contents of the soil in both districts were very high. While the total nitrogen and organic matter contents were low for both districts. In addition, sorghum grain yield was not significantly affected by the application of potassium, boron and zinc containing fertilizers at Kobo and Dawa-Chefa districts. Moreover, in support of the crop response and soil analysis, the soil fertility map developed for the exchangeable potassium content (excluding the K:Mg) showed that more than 70% of Kobo and 99% of the Dawa-Chefa have optimum and more exchangeable potassium content. Therefore, special attention should be given to improve the soil organic matter content and nitrogen fertilizer management to boost sorghum yield. Moreover, the soil fertility map of the region as well as of the study districts should be refined and improved based on reliable data.*

Keywords: Fertilizer, Grain yield, Kobo, Potassium, Sorghum, Total nitrogen

Introduction

The agriculture sector in Ethiopia is dominated by smallholders, who until recently used little technology and rely predominantly on traditional practices. Soil fertility is highly depleted from time to time due to many factors among others loss of the top soil by erosion, nutrient leaching, continuous residue removal, competing use of organic residues for different purposes. However, the status of the soil fertility of the country in general and of the region in particular was not known. Ethiopian Agricultural Transformation Agency was established since 2012 and brought soil fertility to the front and make an issue by the policy makers. MoANR and ATA developed soil fertility map of the country and regions since 2014 to 2016. The soil fertility map of Amhara region was finalized in 2016 identifying seven fertilizer types for the region.

Sorghum (*Sorghum bicolor* L. Moench) is the most important cereal crop in Ethiopia, Amhara region, North and South Wollo zones in area coverage and total production. In Amhara region, sorghum ranked second in area coverage following teff and third in total production following maize and teff (CSA, 2017/18). In North Wollo zone and Oromo special zone it ranked first both in area coverage and total production (CSA, 2016/17). Kobo and Dawa-Cheffa districts are the potential areas of the North Wollo zone and Oromo special zone where sorghum is largely produced (Aleminew *et al.,* 2015*)*. However, the yield attained per hectare was and is by far below the national and regional average as well as the attainable yield (CSA, 2016/17 and CSA, 2017/18) due to poor soil fertility and nutrient management coupled with moisture stress.

Based on the initial soil fertility map, different blended fertilizers and K were demonstrated on farmers field by MoANR and ATA since 2014. The final soil fertility and potassium status maps developed by Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency (MoANR and ATA, 2016) showed that Amhara soils are 47% deficient in NPSZnB, 46% in NPSB, 94% in K and 100% in N. The map also showed that soils of Kobo district are 95% deficient in potassium, 45% deficient in NPSZnB, 35% deficient in NPSZn, 15% deficient in NPSB and 5% deficient in NPS and Dawa-Chefa district is 95% deficient in potassium, 75% deficient in NPSB and 20% deficient in NPS. Farmers in the country and the region were advised by the Ministry and ATA to apply new blended/compound fertilizers based on the fertility maps to the specific locations and 100 kg KCl ha^{-1} to all cultivated lands in Amhara region without research data. However, the previous and recent research reports didn’t support the recommendations (Murphy, 1968; Tadele *et al.*, 2008; Tadele *et al*, 2018). Therefore, the present investigation was undertaken to examine the crop response to potassium, boron and zinc fertilizers in relation to soil fertility map of the districts.

Material and methods

Description of the study sites

The research was conducted at Kobo and Dawa-Cheffa districts (where sorghum is widely grown) in the Eastern Amhara region in 2017/18 main cropping season. Kobo is located 540 km Northeast of Addis Ababa and 420 km east of Bahir Dar the national and regional capitals respectively. The geographical location of Kobo district lies between 12^{o} 08’N latitude and 39^{o} 28’E longitude at the elevation of 1468 m above sea level. The district receives a mean annual rainfall of 630 mm, and the mean maximum and minimum temperatures of 29 ^{0}C and 15^{0}C respectively with considerable year to year variation. The area is characterized by seasonal moisture stress and erratic rainfall. Dawa-Cheffa is also located about 325 km away from Addis Ababa to the Northeastern direction and 595 km east of Bahir Dar. The geographical location of the district lies between 10°01’ to 11°25’ N latitude and 39°41’ to 40°24’ E longitude with an altitude ranges from 1000 to 2500 meters above sea level. The district receives mean maximum temperature of 33°C and minimum temperature of 12°C. The mean annual rainfall of the area ranges from 600 to 900 mm with a long heavy rainy season from June to September and a short rainy season from March to May.

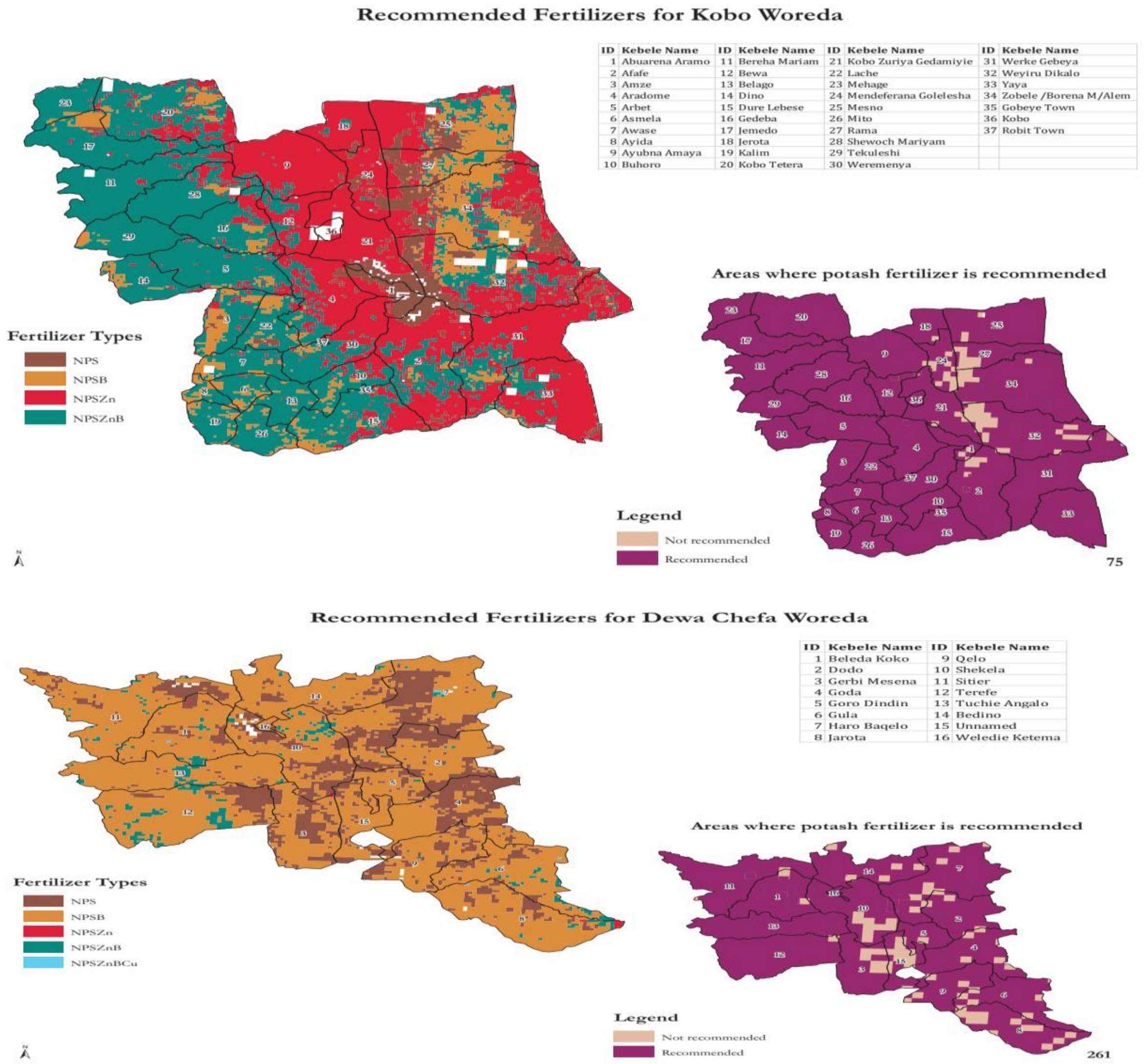

Figure1. Soil fertility maps of Kobo and Dawa-Cheffa district respectively (source; ATA and MoANR, 2016).

Treatment setup

The treatments used for the research were:

1. NPS
2. NPSK
3. NPSBZn
4. NPSKBZn

Treatments were arranged in a randomized complete block design replicated three times. The site specific recommended NP which was adjusted by urea and NPS were used uniformly for all treatments for both districts. Nitrogen, 69 kg ha^{-1} and 69 kg ha^{-1} P_2O_5 were used for both districts. The rate of KCl was 150 kg ha-^{1}. Nitrogen was applied by splitting half at planting and half at knee height. The whole rates of phosphorous and potassium chloride was applied at planting. Foliar application of B and Zn fertilizer at a rate of 1 kg ha^{-1}. Borax and 1 kg/ha Zinc Sulphate was used. The plot size was 24 m^2 (4.8m by 5m) for both districts. The space between plots and replications were 1m each. Soil and crop management practices were applied during the growth period of the crop uniformly to all treatments. Girana one Sorghum variety was used as a test crop for both districts with a spacing of 75 cm between rows and 15cm between plants.

Soil Sampling and Analysis

Composite soil samples were collected from 0-20 cm depth from each farm before planting. The collected Samples were air-dried and ground to pass a 2 mm sieve for the determination of most soil parameters except total nitrogen and organic carbon which were determined from samples passed through 0.5 mm sieve. Soil texture was determined by hydrometer method (Bouyoucos, 1962). The pH of the soils was measured in water (1: 2.5 soils to water) (Page et al., 1982). The organic carbon content of the soil was determined following Walkley and Black procedures (1934). The total nitrogen was also determined by Kjeldahl method (Bremner and Mulvaney, 1982). The available soil phosphorus was determined by the Olsen method (1954). While exchangeable potassium was extracted by ammonium acetate at pH 7 (Sahlemedhin and Taye, 2000) and determined by Atomic Absorption Spectrometer.

Agronomic data collection

The whole plants were harvested from the net plots excluding the border rows, sun dried and dry biomass per plot and per hectare was determined. Then the harvest was manually threshed and the grain was separated from the straw and grain yield per plot and hectare was determined. The moisture content of the grain was measured using moisture tester during threshing and the final yield was adjusted to 12.5% moisture content

Data analysis

All collected data were subjected to the analysis of variance using SAS version 9.3 and means were separated using least significant difference (LSD) at 5% significance level.

Results and Discussion

Soil physico-chemical properties of the study sites

The analysis of variance showed that the soils of both district were clay in texture (Table 1). The soil total nitrogen content ranges from 0.08% to 0.1% and 0.1% to 0.25 % for Dawa-Cheffa and Kobo respectively. Based on the classification made by Tekalign, (1991), the total nitrogen content for Dawa-cheffa was low and for Kobo was medium. The soil organic matter content for soils of Dawa-Cheffa ranges from 0.7% to 2.8 % and classified as low to medium level while that of soils of Kobo ranges from 0.88% to 2.2%, and categorized under low content (Berhanu, 1980). The available phosphorus was ranged from 33.0 ppm to 45.05 ppm for both districts indicating that the available phosphorus content very high in both districts (Marx et. al. 1999, Landon, 1991). The exchangeable potassium also ranges from 4.97 to 5.6 $cmol_c kg^{-1}$ for Dawa-cheffa and 5.1 to 5.6 $cmol_c kg^{-1}$ for Kobo. The level of exchangeable potassium for the both districts was very high (FAO, 2006) and hence crop response to potassium fertilizer is questionable. The soil reaction (pH) of the two districts was ranging from 6.6 to 6.8 and 6.5 to 6.8 for Dawa-Cheffa and Kobo study areas respectively. The soil reaction of both districts was neutral and suitable for any agricultural activity.

Table 1: Soil physic-chemical properties of the study sites before planting

Site	pH	OM (%)	Available P (ppm)	T.N (%)	Ex. K($cmol_c kg^{-1}$)	Textural class
Dawa-Cheffa	6.6-6.8	0.7-2.8	33.55-45.05	0.08-0.10	4.962-5.60	Clay
Kobo	6.5-6.8	0.88-2.2	33.85-44.45	0.10-0.25	5.081-5.60	Clay

Note: pH = power of Hydrogen; OM = organic matter; T.N = total nitrogen; P = phosphorus; Ex.K = exchangeable potassium

Effect of potassium and micro nutrients on straw and grain yields of sorghum

The overall results of this research showed that there was no statistically significant straw and grain yield differences ($p > 0.05$) among and between the treatments for both districts (Table 2,3,4 and 5). The result is in line with the previous validation study made at the same locations by Abebe and his friends (under publication) and Tadele et al., (2008) and Tadele et al., (2018) who reported that there was no significant crop responses to the application newly intrduced fertilizer products (K, B and Zn) to the country in general and Amhara region in particular including. The soil analysis results also showed that the level of potassium was above the critical limit which strength the yield response (Table 1). In addition, the soil fertility status map for both districts showed that exchangeable potassium excluding K:Mg ratio was optimum and more than optimum for more than 90% of the districts (MoANR and ATA, 2016). Adequate plant nutrition with micronutrients depends on many factors including the ability of the soil to supply these nutrients, rate of absorption of the nutrients to functional sites and nutrients mobility within the plants. In support of our result, EFMA, (2003) stated that in soils with adequate amounts of potassium readily available to plant uptake was higher and there may be no response to the application of the nutrient. However, if the nutrients are insufficiently available in the soil, many scholars reported that the response to their application could have resulted in higher grain and biomass yields (Nataraja et al., 2006; Chaudry et al. 2007; Dash et al., 2015; Gitte et al., 2005; Nadim *et. al*., 2011; Sultana et al., 2016*;* and Choudhary et al., 2017).

Table 2. Effect of treatments on grain yield (kg ha^{-1}) at Kobo

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Mean
NPS	5025	2688	1971	5182	3717
NPSK	5046	3628	2010	4745	3830
NPSBZn	5058	3272	3014	4797	4035
NPSKBZn	4880	3841	2344	4929	3993
LSD (5%)	NS	NS	NS	NS	NS
CV (%)	20.0	19.1	23.2	8.9	21.2

Table 3. Effect of treatments on biomass yield (kg ha^{-1}) at Kobo

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Mean
NPS	10103	6322	5747	12205	8594
NPSK	10250	6369	5544	11522	8421
NPSBZn	10070	6459	5583	12632	8916
NPSKBZn	9394	6275	5923	12272	8460
LSD (5%)	NS	NS	NS	NS	NS
CV (%)	15.6	18.7	15.6	21.2	20.3

Table 4. Effect of treatments on grain yield (kg ha^{-1}) at Dawa-Cheffa

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Mean
NPS	4412	6860	3373	5690	3342	4852
NPSK	4754	6189	3397	4907	3587	4567
NPSBZn	4190	6520	3320	5803	3701	4707
NPSKBZn	4084	6845	3169	5682	3950	4763
LSD (5%)	NS	NS	NS	NS	NS	NS
CV (%)	14.9	10.5	10.3	11.2	9.5	13.4

Table 5. Effect of treatments on biomass yield (kgha^{-1}) at Dawa-Cheffa

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Mean
NPS	8719	13414	8564.1	16516	9587	11360
NPSK	10573	16269	6982	14898	10614	11867
NPSBZn	8788	11973	6813	12784	11397	10351
NPSKBZn	10318	12848	7047	16428	12080	11744
LSD (5%)	NS	NS	NS	NS	NS	NS
CV (%)	20.4	15.2	19.3	14.3	24.9	17.98

Conclusion and Recommendation

In general, the result indicated that application of potassium, zinc and boron containing fertilizers to the soils of these districts didn’t have impact on yield increment. Hence, capitalizing mainly on the application of crop and site specific recommended nitrogen and phosphorus are still remaining central to the yield increment in both districts. Moreover, improvement of the soil organic matter base is also helps the improvement of nitrogen and phosphorus and other macro and micro nutrients. Moreover, the soil fertility status map developed for the region by MoANR and ATA in 2016 should be revised based on the feedbacks from the research system in a larger scale. However, the status of these nutrients should be monitored periodically for they could be yield limiting sometimes in the future if the soil is not well maintained.

References

Amare Aleminew, Adane Legas, Mekonnen Misganaw and Mulugeta Mamo. 2015. Yield Response of Sorghum to Timing of Urea Fertilizer Application in Eastern Amhara Region, Ethiopia. World Journal of Agricultural Sciences 11 (3): 144-150.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal 54:464-465.

Bremner, J. M., and Mulvaney, C. S. 1982. Nitrogen-total. In Methods of soil analysis. Part 2. Chemical and microbiological properties, (methodsofsoilan2) (pp. 595–624).

Brhane Hagos, Mamo Tekaligne, Teka Kassa. 2017. Potassium Fertilization and its Level on Wheat (Triticum aestivum) Yield in Shallow Depth Soils of Northern Ethiopia. J Fertil Pestic 8: 182. doi:10.4172/2471-2728.1000182.

Chaudry, E.H., Timmer, V., Javed, A.S. and Siddique, M.T. 2007. Wheat response to micronutrients in rain-fed areas of Punjab. Soil & Environ. 26: 97-101.

Choudhary, S.K., Jat, M.K. and Mathur, A.K. 2017. Effect of micronutrient on yield and nutrient uptake in sorghum. Journal of Pharmacognosy and Phytochemistry, 6(2), pp.105-108.

Dash A.K., Singh H.K., Mahakud T., Pradhan K.C. and Jena D. 2015. Interaction Effect of Nitrogen, Phosphorus, Potassium with Sulfur, Boron and Zinc on Yield and Nutrient Uptake by Rice Under Rice – Rice Cropping System in Inceptisol of Coastal Odisha. Int. Res. J. Agric. Sci. Soil Sci. 5(1):14-21

Gitte, A.N., Patil, S.R. and Tike, M.A. 2005. Influence of zinc and boron on biochemical and yield characteristics of sunflower. Indian Journal of Plant Physiology 10 (4), pp. 400-403.

Hagos Birhane, Tekaligne Mamo, and Kassa Teka, 2017. “Optimum potassium fertilization level for growth, yield and nutrient uptake of wheat (Triticum aestivum) in Vertisols of Northern Ethiopia,” *Cogent Food Agric.*, vol. 3, no. 1, pp. 1–8, 2017.

Haile, Wassie And Tekaligne Mamo. 2013. The effect of potassium on the yields of potato and wheat grown on the acidic soils of Chencha and Hagere Selam in Southern Ethiopia. IPI, e-ifc No. 35

Mandal, A., Patra, A.K., Singh, D., Swarup, A., and Masto, R.E. 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Bioresource. Technology 98: 3585-3592.

Marx, E. S. Hart, J. and R. G. 1996. Stevens, “Soil Test Interpretation Guide,” *Oregon State Univ. Serv.*

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia (MoANR and ATA). 2016. Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia.

Murphy, HF. 1968. A Report on Fertility Status of Some Soils of Ethiopia. HSIU/College of Agriculture. Alemaya. Experiment Station Bull No. 44. 1968. 9.

Nadim, M.A., Awan, I.U., Baloch, M.S., Khan, E.A., Naveed, K., Khan, M.A., Zubair, M. and Hussain, N. 2011. Effect of micronutrients on growth and yield of wheat. Pak. J. Agri. Sci, 48(3), pp.191-196.

Nataraja, T.H., A.S. Halepyati, B.T. Pujari and B.K. Desai. 2006. Influence of phosphorus levels and micronutrients on the physiological parameters of wheat. Karnataka J. Agri. Sci. 19**:** 685–687.

Page J.R., Miller, R.H., Keeney, D.R., Baker, D.E. and Roscoe, E.J.R. 1982. Methods of soil Analysis. II. Chemical and microbiology properties 2nd (eds.) Wisconsin, USA.

Sahlemedhin S. And Taye B., 2000. Procedures for Soil and Plant Analysis. National Soil testing center, Addis Ababa, Ethiopia

Sultana, S., Naser, H.M., Akhter, S. and Begum, R.A. 2016. Effectiveness of soil and foliar applications of zinc and boron on the yield of tomato. Bangladesh Journal of Agricultural Research, 41(3), pp.411-418.

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet, Birhanu Agumas, Mengstu Muchie, Tesfaye Feyisa and Desalew Fentie, 2018 .Crop response to balance nutrient application in north western Ethiopia. Blue Nile Journal of Agricultural Research 1(1), pp1-14.

Tadele Amare, Tesfaye Feyisa and Yihenew G/Selassie. 2008. Response of maize, malt barely and tomato to potassium. In: Birru Yitaferu, Teshome Tessema, Zewdu Ayalew (eds.). Procedings of the third Annual Regional Conference on Completed Research activities on soil and water management, Forestry and Agricultural Mechanization 1-4 September 2008, Amhara regional agricultural research institute ARARI, Bahirdar, Ethiopia, pp 67-75.

Tekalign Tadesse. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Walkley, A., & Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37, 29–38.

Zia, M.S., Gill, M.A., Aslam, M. And Hussain, M.F. 1991. Fertilizer use efficiency in Pakistan. Progressive farming, (11): 35-8

Response of Sorghum (Sorghum bicolor L. Moench) to Potassium, Zinc and Boron nutrients in Wag-Lasta, Eastern Amhara Region, Ethiopia

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Abstract

Unlike studies on validation the effect of new fertilizer products on major cereal crops, the final soil fertility map developed by Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency revealed that 94% of the arable land in Amhara region is deficient in potassium. Based on the map and few studies without data, application of 100 kg KCl ha^{-1} *was recommended and demonstrated to the farmers. Thus, this experiment was conducted in 2017/18 main cropping season to verify the response of sorghum to potassium, zinc and boron containing fertilizers in Wag-Lasta, Northeastern Amhara Region. The treatments were: NPS, NPSK, NPSZnB and NPSZnBK, (N and P were adjusted to the location specific recommendation using urea and NPS respectively). All nutrients were applied at planting except nitrogen which was applied in split (half at planting and half at knee height). Potassium was applied as a straight fertilizer at the rate of 150 kg KCl ha*$^{-1}$*. The treatments were arranged in a randomized completed design with three replications. Composite soil samples were collected from 0-20 cm depth to determine some soil parameters following standard procedures. All agronomic data were collected and subjected to the analysis of variance using SAS software and significant means were separated using least significant difference (LSD) at 5%. Analysis of variance revealed that application of potassium, zinc and boron containing fertilizers had no significant effect (P>0.05) on sorghum yield and yield components at all locations. The laboratory results also indicated that the exchangeable potassium content of the soils of the study sites lies between high to very high. The result disagrees with the soil fertility map which showed more than 98% of potassium deficiency and more than 80% NPSZnB deficiency at Wag_Lasta. Hence, currently, application of the recommended nitrogen and phosphorous fertilizers rates with organic inputs can significantly increase the yield of sorghum at Wag-Lasta.*

Key words*:* fertilizer, grain yield, potassium, sorghum, zinc

Introduction

Agriculture in Ethiopia contributes 34% to the GDP, 90% to the export commodity and 85% employment opportunity (UNDP, 2018). However, the sector is not effective due to low soil fertility and inappropriate nutrient management practices. The history of fertilizer use in Ethiopia dates back to the early 1950s (*Murphy, 1968).* For the last half a century, Ethiopian agriculture solely depended only on urea and di-ammonium phosphate (DAP). The soil fertility map of Ethiopia developed by Ministry of Agriculture and Natural Resources and Agricultural Transformation in 2016 indicated multi nutrient deficiency (including N, P, K, S, B, and Zn) and recommended different fertilizer formulations containing these nutrients (MoANR and ATA, 2016). Based the soil fertility map, new fertilizer products were introduced to Ethiopia and widely demonstrated to the farmers. The soil fertility map indicated that soils of Wag-Lasta were nearly 80 % deficient in NPSZnB, 47% in NPSB and 98% in K. Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency widely advocated and demonstrated the application of new fertilizer products based on the soil fertility map and 100 kg KCl ha^{-1} to each parcel of land under crop production without proved scientific evidences. However, the result of nutrient omission trials and validation studies on new fertilizers across the region on different crops indicated that potassium and new fertilizer products had no effect on the yields of the studied crops, (Tadele *et al*., 2008; Tadele *et al*., 2018).

Sorghum (*Sorghum bicolor* L.) Moench] is a viable food grain for many of the World’s most food insecure people who live in marginal areas with poor and erratic rains and often poor soils. Sorghum is a major staple food crop, ranking third after teff and maize in Ethiopia, second after teff in Amhara region and first in Waghemra in area coverage. However, the current sorghum yield at Waghemra (1.5 t ha^{-1}) is by far below the national (2.5 t ha^{-1}) and regional (2.4 t ha^{-1}) average (CSA, 2016/17). This low yield is attributed to moisture stress and poor soil fertility (*Wortmann* et al.*, 2006)*, inappropriate inorganic fertilizer management (Workat and Merssie, 2018). Hence, to improve the yield of this important crop to Waghemra, appropriate application of inorganic fertilizers and verification of the recommended blend and straight fertilizer types and rates is highly important.

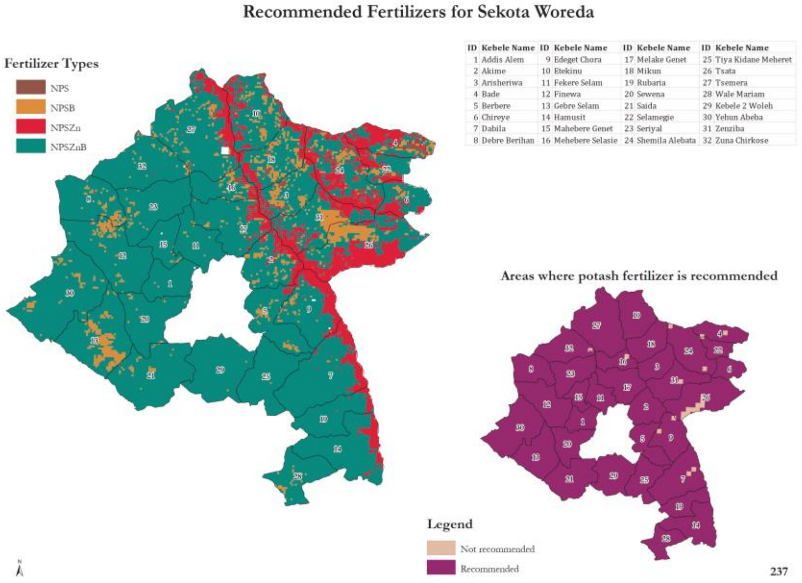
Therefore, this study was conducted to verify the response of sorghum to potassium, zinc and boron containing fertilizers.

Materials and methods

Description of the study area

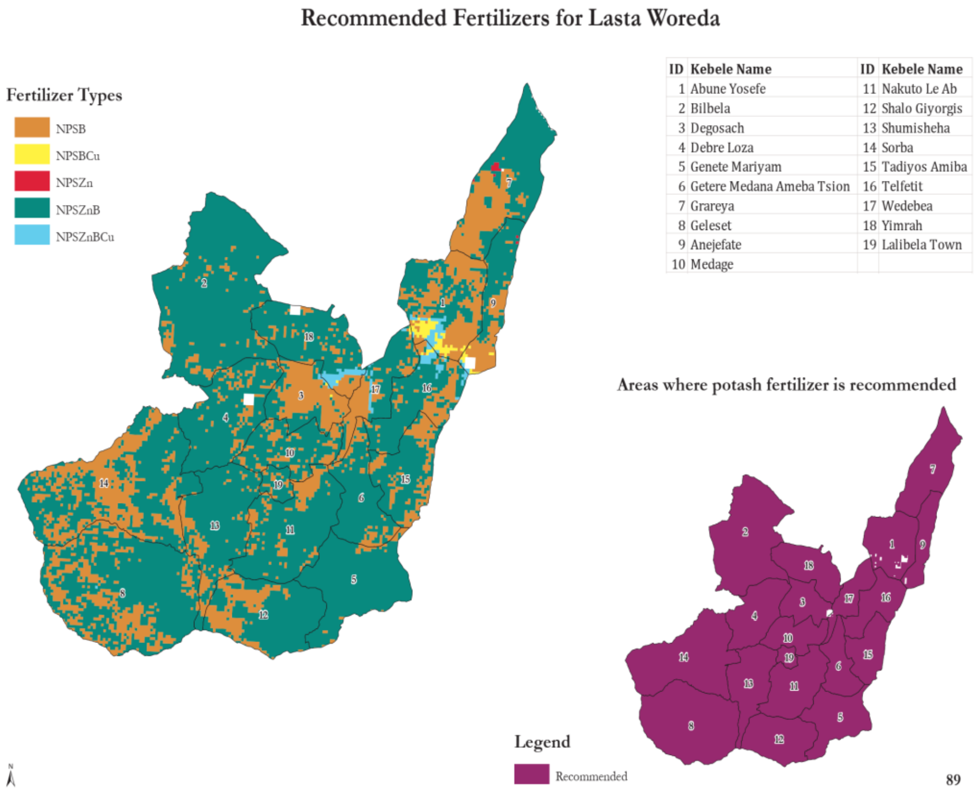
The research was conducted in 2017 main cropping season in Sekota and Lasta districts in Northeastern Amhara region. The geographically Sekota district is located at $12^0$43’38’’N latitude and $39^0$01’08’’E longitude with an altitude of 1915 meters above sea level and Lasta district is located in 11^o 58’ 50.15’’ N latitude and 38^o 59’ 03.22’’E longitude with altitude of 1966 meters above sea level. The districts have uni-modal rainfall occurring in June to August. The districts receive 674mm (Sekota) and 818mm (Lasta) rainfall per annum. The maximum and minimum average temperature of Sekota was 27^0C, 13 ^{0}c and of Lasta was 25 ^{0}C, 14 ^{0}C.

The dominant soil type at Sekota was Eutric Cambisols while at Lasta were Eutric Cambisols and Vertic Cambisols. The farmers use to plow their land by a traditional oxen drawn local implement (Maresha) since many centuries. The farming system of the districts was crop livestock mixed farming.



ID	Kebele Name	ID	Kebele Name	ID	Kebele Name	ID	Kebele Name
1	Addis Alem	9	Edeget Chora	17	Melake Genet	25	Tiya Kidane Meheret
2	Akime	10	Etekinu	18	Mikun	26	Tsata
3	Arisheriwa	11	Fekere Selam	19	Rubaria	27	Tsemera
4	Bade	12	Finewa	20	Sewena	28	Wale Mariam
5	Berbere	13	Gebre Selam	21	Saida	29	Kebele 2 Woleh
6	Chireye	14	Hamusit	22	Selamegie	30	Yehun Abeba
7	Dabila	15	Mahebere Genet	23	Seriyal	31	Zenziba
8	Debre Berihan	16	Mehebere Selasie	24	Shemila Alebata	32	Zuna Chirkose

Figure1: Soil fertility map of Sekota district (MoANR and ATA, 2016)


Recommended Fertilizers for Lasta Woreda

Areas where potash fertilizer is recommended

ID	Kebele Name	ID	Kebele Name
1	Abune Yosefe	11	Nakuto Le Ab
2	Bilbela	12	Shalo Giyorgis
3	Degosach	13	Shumisheha
4	Debre Loza	14	Sorba
5	Genete Mariyam	15	Tadiyos Amiba
6	Getere Medana Ameba Tsion	16	Telfetit
7	Grareya	17	Wedebea
8	Geleset	18	Yimrah
9	Anejefate	19	Lalibela Town
10	Medage		

Figure 2: Soil fertility map of Lasta district (MoANR and ATA, 2016).

Experimental design and treatments

The treatments were comprised of NPS, NPSK, NPSZnB and NPSZnBK, arranged in randomized complete block design with three replications. Nitrogen and phosphorous were adjusted to the location specific rates using urea and NPS. The recommended N and P for sorghum at Sekota was 46 kg N and 23 kg P_2O_5 ha^{-1} and at Lata was 23 kg N and 23 kg P_2O_5 ha^{-1}. Except nitrogen, all nutrients were applied basally at planting while N was applied in split; half at planting and half at knee height. Potassium was applied at a rate of 150 kg KCl ha^{-1} while B and Zn were applied as blend (NPSZnB).

The gross plot size was 18.75m^2 (3.75 m X 5 m) and consisted of 5 rows. A distance of 1m was left for both between plots and blocks. Spacing of 75 cm by 15 cm was used between rows and plants, respectively. The tested sorghum variety was Miskir. All recommended agronomic crop management was done for all treatments uniformly in their own appropriate time.

Agronomic data Collection

The average plant height was measured by taking five random representative plant samples from each plot measuring the height from ground to tip of head by tape meter and the average was recorded as plant height. Sorghum head length was also measured using tape meter from five randomly selected representative heads and the average was recorded as head length. The above ground dry biomass and grain yields were measured after harvesting the whole plants from the net plots leaving the border rows to avoid border effect, sun drying until constant weight was attained and then biomass yield was determined in kg per plot and then finally converted to t ha^{-1}. The grain yield was determined after manually separating the grains from the straw and recorded as grain yield in kg per plot and in kg per hectare. The moisture content of the grain was measured by moisture tester and finally the actual grain yield was adjusted to standard moisture content 12.5%.

Soil sample collection, preparation and analysis

Representative composite soil samples were collected before planting from 0-20 cm soil depth from each trial site using augur soil sampler. Each composite sample was made of five sub-samples. The soil samples were air dried, passed through 0.5 mm sieve for total nitrogen and organic carbon determination and through 2 mm sieve for the other soil parameters. Labeled and submitted to the laboratory for nutrient analysis following the standard laboratory procedures.

Soil reaction (pH) was measured from filtered suspension of 1:2.5 soil to water ratio using a glass electrode attached to a digital PH meter (Van Reeuwijk, 1992). Soil Organic carbon was determined following the wet digestion method as described by *Walkley and Black (1934*). Percentage of soil organic matter was determined by multiplying soil organic carbon value by 1.724. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method (Jackson, 1958). Available phosphorus was determined following the Olsen method (*Watanabe and Olsen, 1965*). Exchangeable potassium extracted by ammonium acetate at PH 7 method (Sahilmedihen and Taye, 2000). Sulfur was also determined by Turbidity method and soil texture determined by hydrometer method.

Data analysis

All data were subjected to analysis of variance using SAS software version 9.0 and significant treatment means were separated using the Fisher’s Least Significant Differences test at 5% level of significance.

Results and Discussion

Soil physic chemical properties analysis result at planting

The analysis of variance revealed that mean soil pH of the trial sites ranged from 5.8 to 6.1 (Table 1) which is moderately acidic but suitable to most crop types except to the most sensitive ones (Tekalign, 1991).

Table1. Soil data before planting

Site	PH	EC	%OC	%OM	%TN	Av.P ppm	Exch.K $Cmol_ckg^{-1}$	S. ppm	Textural class
Tiya	6	0.12	0.80	1.38	0.03	4.79	1.26	6.53	sandy loam
Q/Abeba	6.1	0.14	0.49	0.84	0.05	23.24	0.86	7.82	sandy loam
Sayda	6	0.12	0.47	0.81	0.02	8.40	0.88	7.54	sandy loam
Shumsha	5.8	0.14	0.49	0.84	0.04	15.68	1.35	5.34	sandy clay loam
Rubariya	5.8	0.12	0.45	0.77	0.04	7.43	0.85	5.02	sandy loam
Woleh	5.8	0.14	0.37	0.64	0.04	7.37	0.84	6.74	loamy sand

The mean total nitrogen content of the soils of the study sites was very low (Tekalign (1991*)* while Available phosphorus content of the study sites vary from very low to high range according to Cottenie (1980) with the majority in the low range (Table 1). In addition, soil organic carbon (SOC) content was in a very low to low range (Tekalign, 1991). The soils of the study sites need soil organic matter improvement through the application of organic manure, compost, crop residue management and crop rotation. Moreover, the soil exchangeable potassium content of the study sites ranged from high to very high (FAO, 2006*)* indicating that the response of crops to its application is less likely. Soil textural class was in both districts was good for crop production. But, due to its low water holding capacity it couldn't store water for a long time in dry land areas.

Table 2. Effect of potassium, Zinc and Boron fertilizers on plant height and head length of sorghum at Sekota district

	F/selm		Rubariya		Sayda		Tiya		Woleh	
Trts.	PH.cm	HL.cm	PH.cm	HL.cm	PH.cm	HL.cm	PH.cm	HL.cm	PH.cm	HL.cm
NPS	157.97	18.56	164.07	18.4	90.81	12.55	134.65	17.33	147.8	21.07
NPSK	152.17	17.88	160.07	18.46	101.41	13.26	142.05	16.81	155.48	19.87
NPSZnB	158.22	18.24	166.17	20.4	86.18	12.75	141.2	17.46	150.4	21
NPSZnBK	149.12	18.46	156.27	17.92	91.51	12.73	138.18	17.13	158.12	19.51
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.62	2.48	3.1	4.02	5.61	9.47	2.84	1.48	7.8	5.6

Effect of potassium, boron and zinc fertilizers on plant height and head length

Potassium, zinc and boron fertilizer had no significant effect ($p > 0.05$) on plant height and head length of sorghum in Sekota and Lasta districts (Table 2 and 4). The biological data confirms the soil data indicated Table 1 that there was no response due to the application of K for it is sufficiently available in the soil. But, hadn't potassium available in the soil, the growth of the crops get stunted and the yield will highly reduce. In addition, Zinc and boron play great role for plant growth and development but in the case of experimental fields they had no significant effect on the growth and development of sorghum. Our finding is contrasting with the findings of Saif *et al..,*(2017), who reported significant increase in sorghum plant height due to boron and salinity and their interactions The present study also disagrees with the report made by Bayu *et al.,* (2006) as cited by (Menamo, (2016). Unlike our study, Pholsen and Somsungnoen*, (*2005) also reported that an increase in N and K rates significantly increased most growth parameters of sorghum plants. The response due to application of potassium in the previous studies was in soil where potassium was not sufficiently available unlike to our study sites. Therefore, application of potassium to a soil with high and very contents may lead to the reduced uptake of other cations including calcium and magnesium.

Table 3. Effect of potassium, Zinc and Boron fertilizer on grain yield of sorghum at Sekota district

	F/selam	Rubriya	Sayda	Tiya	Woleh
Trts	GY. Kgha-^{1}	GY. kgha-^{1}	GY. kgha-^{1}	GY. kgha-^{1}	GY. kgha-^{1}
NPS	1480	2670	960	1420	3230
NPSK	1370	2560	620	1570	3070
NPSZnB	1240	2610	510	1460	2910
NPSZnBK	1230	2.00	720	1450	3100
LSD (5%)	NS	NS	NS	NS	Ns
CV (%)	5.87	4.5	16.19	4.01	4.8

Table 4. Effect of potassium, Zinc and Boron fertilizer on plant height and head length of sorghum at Lasta district

	G/Mariam		Q/abeba 1		Q/abeba2		Shumsha	
Trts.	PH.cm	HL.cm	PH.cm	HL.cm	PH.cm	HL.cm	PH.cm	HL.cm
NPS	159.39a	18.83	140.47	18.82	131.1	17.4	158.4	21.26
NPSK	146.27b	17.93	146.47	20.16	131.3	16.16	171.31	22.53
NPSZnB	146.47b	17.33	143.27	17.36	126.36	17.4	164.91	22.26
NPSZnBK	147.53b	17 43	145.87	18.9	132.84	17.2	149.96	18.58
LSD 5%	7.4	NS	NS	NS	NS	NS	16.05	NS
CV (%)	6.9	3.68	2.6	4.4	2.31	2.82	2.75	9.1

Effect of potassium, boron and zinc containing on sorghum grain yield

Application of potassium, zinc and boron containing fertilizers had no statistically significant effect on sorghum grain yield at Sekota and Lasta districts (Table. 3 and 5). Relatively higher grain yield was obtained from the application of NPS fertilizer in most experimental fields. Whereas relatively lower grain yield was obtained from the application of NPS combined with K, B and Zn. Our finding was in agreement with the soil analysis result which showed no deficiency of these nutrients. The pH values of the collected soil samples was in a range suitable for most crops and the micro nutrients under investigation are sufficiently available and are not in a range limiting crop yield (Table 1). The overall yield was low except at Shumsha, Rubariya and Woleh due to poor soil fertility status and moisture deficit. But, the yield at Shumsha and Rubariya was similar with the yield reported by Workat and Merssie, (2018) (3.8 and 2.96 t ha^{-1}) by applying 23 kg N and 23 kg P_2O_5 ha^{-1} for Shumsha, and 46 kg N and 23 kg P_2O_5 ha^{-1}.

Though potassium, boron and zinc have numerous advantages in plant anatomy, physiology and yield, their application to sorghum had no significant effect on the increment of grain yield at Wag_Lasta was because the nutrients are found in sufficient amount and may antagonize with other macro and micro nutrients if applied excessively. Therefore, the farmers in the study area and similar agro ecologies can improve the sorghum yield by proper application of the recommended nitrogen and phosphorus rates for the sites together with organic fertilizer sources for the sub region is known for its moisture stress, poor organic matter base, poor soil fertility, and continuous biomass removal due to free grazing and other competitive uses of the residue. The finding is in agreement with the previous studies (Tadele *et al*., 2008; Tadele *et al*., 2018). Our nutrient omission trial conducted at Dehana and Lasta districts showed that application of 72 kg K_2O ha^{-1} or 120 kg KCl ha^{-1}) had insignificant effect on teff and wheat yield. Similarly, Yihenew *et al*., 2007), investigated that the response of potato tuber yield to potassium levels had negative relationship with soil K status in western Amhara Region,

Table 5. Effect of potassium, Zinc and Boron fertilizer on grain yield of sorghum at Lasta district

	G/Mariyam	Q/abeba1	Q/abeba2	Shumsha
Trts	GY. kgha^{-1}	GY. kgha^{-1}	GY. kgha^{-1}	GY. kgha^{-1}
NPS	1710a	1080	1200	3300
NPSK	1040b	1240	860	4010
NPSZnB	940b	910	940	2860
NPSZnBK	1406a	1140	1090	3160
LSD (5%)	0.3	NS	NS	NS
CV (%)	8.4	11.75	14.16	8.43

Our result is also contradicting with soil fertility map of Sekota and Lasta districts, which showed 98% deficiency in potassium and 80% deficient in NPSZnB. This implies that the amount of K, Zn and B available in the soil is adequate to provide for optimum crop growth, development and yield, in the areas. In addition, our result was not in line with that of Redai et al., (2018); Gebrekorkos, et al., (2017*)*, who reported application of the blended fertilizers significantly increased sorghum grain yield of in Tigray Region.

On the other hand, many scholars reported that sorghum yield increment was merely due to the application of appropriate rates of nitrogen and phosphorus than the application of other nutrients (Nebyou and Muluneh, 2016; Legesse and Gobeze, 2015; Gebrekidan, 2003; Berhane, 2012; Ashiono *et al*., 2005).

Conclusion and Recommendation

Application of K Zn and B containing fertilizers had insignificant effect on plant height, head length and grain yield of sorghum, in Sekota and Lasta districts indicating that application of these nutrients to sorghum had no advantage than incurring additional costs to the farmers and the regional government for no return. Even, studies indicated that there is no or low response of lowland crops to phosphorus application. But, until further investigation is made on the response of crops to phosphorus application in the lowlands of Amhara region, application of the site and crop specific nitrogen and phosphorus rates together with organic fertilizers should be made to increase crop yield and feed the highly increasing population of the region. Moreover, since the soil fertility map widely disagreed with the field fact for it was developed not based on our own nutrient critical levels, developing our own nutrient critical levels should be top priority and refinement of the map to a larger scale should also be mandatory. The potassium map should also be corrected based only on the exchangeable potassium data avoiding the K:Mg ratio which couldn’t serve our purpose. Furthermore, periodic monitoring of these nutrients is crucial for they may be yield limiting in the future.

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References

Anjum, S.A., M.F. Saleem, M. Shahid, A. Shakoor, M. Safeer, I. Khan, A. Farooq, I. Ali and U. Nazir. 2017. Dynamics of soil and foliar applied boron and zinc to improve maize productivity and profitability. *Pakistan Journal of Agricultural Research*, 30(3): 294-302.DOI | http://dx.doi.org/10.17582/journal.pjar/2017.30.3.294.302

Ashiono, G.B., Gatuiku, S., Mwangi, P. and Akuja, T.E. (2005). Effects of nitrogen and phosphorus application on growth and yield of dual-purpose sorghum in the dry highlands of Kenya. *Asian Journal of Plant Sciences*, 4(4): 379-382,

Asnakew Woldeab., Tekalign Mamo. (1991). Soil fertility management studies on wheat in Ethiopia. Debre Zeit Agricultural Research Center, Ethiopia.

Barber, S., 1984. Soil Nutrient Bioavailability: Mechanistic Approach. John Wiley and Sons. Inc., New York, USA. 398p.

Bekele Muluneh. 2018. Effects of different levels of potassium fertilization on yield, quality and storage life of onion (Allium cepa L.) at Jimma, Southwestern Ethiopia. J Food Sci Nutr. 2018;1(2):32-9.

Berhanu Debele, 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.

Brady, N. C. 1984. The nature and properties of soils. 9th ed. Macmillan Publishing Company, New York.

Brady, N.C. and R. R. Weil. 2002. The Nature and Properties of Soils. Thirteenth Edition. Pearson Education Asia. Delhi, India. 960P.

Birhane Hagos, Mamo Tekalign and Teka Kassa. 2017. Potassium Fertilization and its Level on Wheat (*Triticum aestivum*) Yield in Shallow Depth Soils of Northern Ethiopia. J Fertil Pestic 8: 182. doi:10.4172/2471-2728.1000182

Central Statistical Agency (CSA)**.** 2017. Report on area and production of crops. Statistical Bulletin 578. Addis Ababa.

Cottenie, A., 1980. Soil and plant testing as a basis of fertilizer recommendations. FAO Soil Bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome, Italy.

Eyob Tilahun, Kebebew Kibret, Tekalign Mamo, Hailu Shiferawu. 2015. Assessment and Mapping of some soil Micronutrients status in agricultural Land of Alicho-Woriro Woreda, Siltie zone, Southern Ethiopia. MSc thesis.

Jackson, M.L. 1958. Soil chemical analysis. Prentice Hall, Inc., Englewood Cliffs. N.J. Sixth Printing 1970. 498pp.

Jones, J.B. 2003. Agronomic Handbook: Management of Crops, Soils, and Their Fertility. CRC Press LLC, Boca Raton, Florida, USA. 482p.

FAO (Food and Agriculture Organization). 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome, Italy.

Fageria, N. K., Moreira, A. and dos Santos, A. B. 2013. National Rice and Bean Research Center of EMBRAPA, Santo Antonio de Goi as, Brazil ´ 2National Soybean Research Center of EMBRAPA, Londrina, Brazil.

Gebremeskel Gebrekirkos, Yemane Gebere Egziabiher and Solomon, H. 2017. Response of Sorghum (*Sorghum bicolor* (L.) Moench) varieties to blended fertilizer on yield, yield component and nutritional content under irrigation in Raya valley, Northern Ethiopia. *International Journal of Agriculture Biosci*, **6(3)**: 153-162

Kafkafi, U. W. and S. Genbaum. 1971. Effect of Potassium Nitrate on Growth, Cation Uptake and Water Requirement of Tomato Grown in Sand Culture. *Israel J. Agri.Res*., 21: 13-20

Legesse Hidoto and Gobeze, Loha. 2015. Growth and grain yield response of sorghum (*Sorghum*

Bicolor L. Moench) varieties to moisture conservation practices and NP Fertilizer at moisture stress area of Amaro, Southern Ethiopia. *Ashese Journal of Agricultural Science*, 1: 001-005,

Menamo, M. 2016. The Effect of Application of Different Rate N-P Fertilizers Rate on Yield and Yield Attributes of Bread Wheat in Case of Chancha, 6(5), 63–66.

Mengel, K. and E.A. Kirkby. 1996. Principles of Plant Nutrition, Panama Publishing Corporation, New Delhi, India, 314p.

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia. 2016. Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia: 297 pages.

Murphy, H.F. 1968. A report on fertility status and other data on some soils of Ethiopia. Collage of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture, Alemaya, Ethiopia: 551p.

Nadim, M.A., Awan, I.U., Baloch, M.S., Khan, E.A., Naveed, K. and Khan, M.A. 2012. Response of wheat (Triticum aestivum L.) to different micronutrients and their application methods. Journal of Animal and Plant Science, 22(1), pp.113-119.

Olsen, S.R., C.V. Cole, F.S. Watanabe and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium carbonate. USDA Circular 939: 1-19.

Redai Weldegebriel, Tesfay Araya and Yemane G.Egziabher. 2018. Effect of NPK and blended fertilizer application on Yield, Yield Component and its profitability of Sorghum (Sorghum bicolor (L.) Moench) varieties under rainfed condition in north western Tigray, Ethiopia

Saif, A., Alkhamisi, L., Hamid, C. Ali, L., Saleem, K., Nadaf, L., Ahmed, N., Al-Bakri, L., Rashid , S., Al-Maamari and Choudri, B. 2017. Influence of boron on sorghum (Sorghum bicolor L.) forage yield under different water salinity levels in Oman

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet, Birhanu Agumas, Mengistu

Muchie, Tesfaye Feyisa and Desalew Fentie, 2018. Crop response to balance nutrient application in north western Ethiopia. Blue nile journal of agricultural research (1), pp1-14.

Tadele Amare, Tesfaye Feyisa and Yihenew G/Selassie. 2008. Response of maize, malt barely and tomato to potassium. In: Birru Yitaferu, Teshome Tessema, Zewdu Ayalew (eds.). Procedings of the third Annual Regional Conference on Completed Research activities on soil and water management, Forestry and Agricultural Mechanization 1-4 September 2008, Amhara regional agricultural research institute ARARI, Bahirdar, Ethiopia, pp 67-75.

Tekalign Tadesse. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Van Reeuwijk, L.P. 1992. Procedures for soil analysis.3rd edition. International Soil Reference and Information Center Wageningen (ISRIC). The Netherlands, Wageningen.

Workat Sebine and Merssie Mengesha. 2018. Response of nitrogen and phosphorus fertilizer rate for sorghum (Sorghum bicolor L. Moench) production in Wag-Lasta area of Ethiopia.

Yihenew G. Selassie, Tesfaye Feyisa and Tadele Amare. 2006. Soil K Status and K Requirement of Potato Growing on Different Soils of Western Amhara, Proceedings of the 2nd Annual Regional Conference on Completed Natural Resources Management Research Activities (18-19 September 2007)

Verification of Potassium and Micronutrients on yield of bread Wheat (*Triticum aestivum*) in Jamma and Meket districts of East Amhara

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Abstract

The final soil fertility status map developed for Amhara region by Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency in 2016 indicated 100% of the soils of Jamma and Meket districts are deficient in potassium and other new fertilizer combinations. However, previous studies showed that there was no response to these nutrients. Therefore, this study was conducted in Eastern Amhara, at Meket and Jamma districts in 2017 cropping season to verify the response of bread wheat (Dinkenesh variety) to potassium, Boron and Zinc containing fertilizers. The experiment consists of four treatments including: NPS, NPSK, NPSBZn and NPSKBZn arranged in a randomized complete block design replicated three times. Nitrogen and phosphorus were adjusted by urea and NPS to the recommended rate of location and the crop and were uniformly applied to all treatments. Potassium was applied as a straight fertilizer at the rate of 150 kg KCl ha^{-1}*. Nitrogen was applied in two splits half at planting and half at tillering, while the other nutrients were applied at planting. Composite soil samples were collected from 0-20 cm depth for the determination of selected soil properties. All collected agronomic and soil data were subjected to the analysis of variance using SAS version 9.0 (2004) and significant means were separated using least significant difference (LSD) at 5% level. The exchangeable potassium contents ranged from 1.70 to 5.81 cmol*$_c$*kg*$^{-1}$* for Meket and 4.86 to 6.00 cmol*$_c$*kg*$^{-1}$* for Jamma and lies in a very high category. The available phosphorus contents also ranged from 23.1 ppm to 31.2 ppm for Meket and from 39.4 ppm to 54.8 ppm for Jamma and placed in a very high category. Whereas, the total nitrogen and organic matter contents were in a low category for most samples and in medium category for a few. The difference among the treatments in sorghum grain and biomass yields was not statistically significant (*$p > 0.05$*) indicating that special attention should be given for the improvement of nitrogen and organic matter contents than potassium, boron and zinc to increase sorghum yield. The soil fertility status map should also be improved to a better scale.*

Key words: Boron, fertilizer, potassium, soil fertility map, zinc

Introduction

Ethiopia is endowed with abundant agricultural resources and has diverse ecological zones. The two dominant agricultural systems in Ethiopia are the mixed agriculture of the highlands, where both crops and livestock production are integrated, and pastoralism in the lowlands. Agriculture in Ethiopia accounts for about 34.8% of the gross domestic product (GDP) (CIA World Facebook, 2019). However, the production and productivity of the country is highly affected by poor soil fertility resulted in severe deforestation, top soil erosion, over grazing and mining of nutrients. To curb the situation there is a positive response to the applications of nitrogen and phosphorous fertilizers for most crops under all agro ecologies. However, there has been a lack of crop response to potassium and new fertilizer blends (Murphy, 1968; Tadele et al, 2008; Tadele et al., 2018). Contrary to the reports from the aforementioned authors, the final soil fertility status map developed by MoANR and ATA, (2016), showed that 94% of the soils of Amhara Region are deficient in potassium content. Tena and Beyene (2011) also reported that potassium was deficient in Ethiopian soils. The soil fertility status map shows that Jamma soils are 100% deficient in potassium and 100% deficient in NPSB and NPSZnB while soils of Meket were 99% deficient in potassium and 99% deficient in NPSB and NPSZnB (MoANR and ATA, 2016).

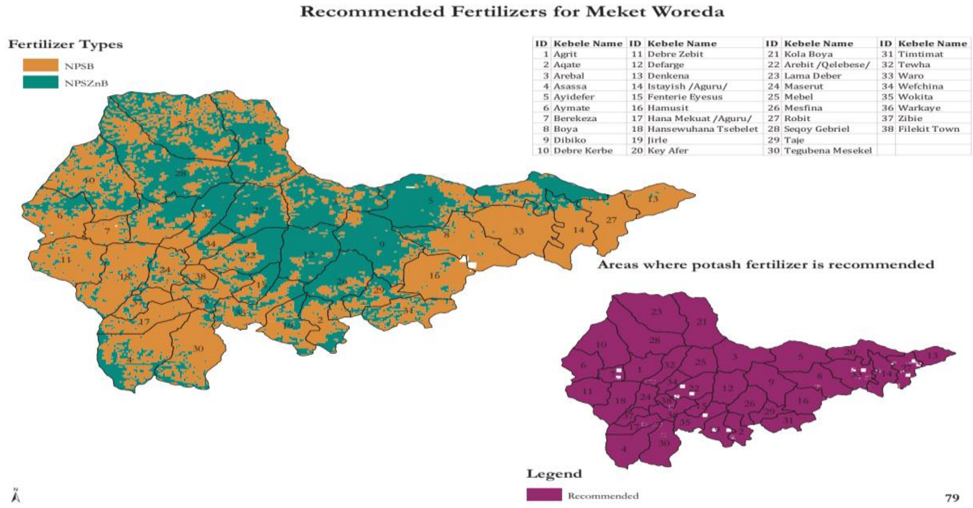
Different scholars reported that Ethiopian soils are not deficient in potassium and micro nutrients and rich enough to supply the crop demand (Tadele *et al*., 2018; Abebe *et al.,* 2019, under publication). Blended fertilizers which contain potassium were introduced in different ways to the country starting from 2014 as a balanced fertilizer (Birhane et al, 2017) to all areas of the region including Jamma and Meket districts. MoANR and ATA recommended the application of 100 kg KCl ha^{-1} throughout the districts regardless of crop type and agro-ecology without proven scientific evidence. Based on this the farmers were directed to apply 100 kg KCl ha^{-1} to his land for no return.

Hence, Amhara Agricultural Research Institutes developed a regional project to verify the responses of different crops including bread wheat to potassium, boron and zinc containing fertilizers.

Material and methods

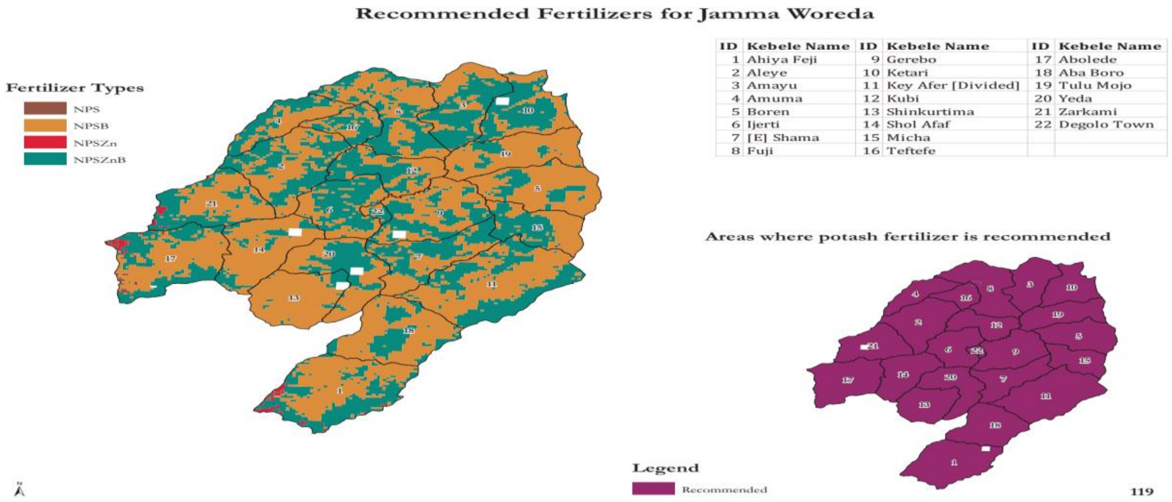
Study site

The research was conducted on farmers' field at Meket and Jamma districts in the Eastern Amhara region in 2017/18 main cropping season. Jamma is located about 520 km away from the capital city, Addis Ababa via Dessie, in the north east direction. The geographical location of the district lies between 10° 23' to 10° 27' N latitudes and 39° 07' to 39° 24' E longitudes and altitude of 2630 meters above sea level in South Wollo Zone of the Amhara National Regional State. The dominant soil type of the district is Vertisols. The soil is characterized by poor drainage and difficulty to work, but high potential for wheat production with proper soil management. The mean annual rain fall of the district was 868 mm and the mean minimum and maximum temperatures were 9°C and 21.6°C respectively. While Meket is located in the western parts of North Wollo Zone at a distance of about 740 km away from Addis Ababa via Dessie. The geographic position of the district lies 11° 54' to 12° 00' N Latitude and 38° 50' to 39° 10' E longitude at an altitude of 2650 meter above sea level. The mean annual rain fall ranges from 790 to 1250 mm with the annual average rain fall of 1105 mm. The mean minimum and maximum temperatures of the district were 12°C and 24°C respectively. The dominant soil type is Regosols followed by Leptosols and acidic in reaction. Alike Jamma, Meket also receives a unimodal type of rain fall.



ID	Kebele Name	ID	Kebele Name	ID	Kebele Name	ID	Kebele Name
1	Agrit	11	Debre Zebit	21	Kola Boya	31	Timtimat
2	Aqate	12	Defarge	22	Arebit /Qelebese/	32	Tewha
3	Arebal	13	Denkena	23	Lama Deber	33	Waro
4	Asassa	14	Istayish /Aguru/	24	Maserut	34	Wefchina
5	Ayidefer	15	Fenterie Eyesus	25	Mebel	35	Wokita
6	Aymate	16	Hamusit	26	Mesfina	36	Warkaye
7	Berekeza	17	Hana Mekuat /Aguru/	27	Robit	37	Zibie
8	Boya	18	Hansewuhana Tsebelet	28	Seqoy Gebriel	38	Filekit Town
9	Dibiko	19	Jirle	29	Taje		
10	Debre Kerbe	20	Key Afer	30	Tegubena Mesekel		

Figure 1. Fertilizer recommended areas of Meket district (Source, MoANR and, ATA 2016).



ID	Kebele Name	ID	Kebele Name	ID	Kebele Name
1	Ahiya Feji	9	Gerebo	17	Abolede
2	Aleye	10	Ketari	18	Aba Boro
3	Amayu	11	Key Afer [Divided]	19	Tulu Mojo
4	Amuma	12	Kubi	20	Yeda
5	Boren	13	Shinkurtima	21	Zarkami
6	Ijerti	14	Shol Afaf	22	Degolo Town
7	[E] Shama	15	Micha		
8	Fuji	16	Teftefe		

Figure 2. Fertilizer recommended areas of Jamma district (Source: MoANR and ATA, 2016).

Treatment setup

The treatments were composed of NPS, NPSK. NPSBZn and NPSKBZn arranged in a randomized complete block design (RCBD) with three replications. The site and crop specific recommended nitrogen and phosphorus for Meket were 69 kg N ha^{-1} and 69 kg P_2O_5 ha and for Jamma were 115 kg N ha and 69 kg P_2O_5 ha^{-1}. The recommended N and P were uniformly applied to all plots. Potassium was applied at the rate of 150 kg KCl ha^{-1}. Nitrogen was applied in two splits half at planting and half at tillering while phosphorus and potassium were applied at planting. Foliar application of B and Zn fertilizers was done at a rate of 1 kg Borax ha^{-1} and 1 kg Zinc sulphate ha^{-1} at fifth week after planting.

The plot size was 25 m^2 (5 m * 5m) for Meket and 24 m^2 (4.8 m * 5m) for Jamma. At Jamma broad bed furrow with 80cm by 40cm was used. The space between plots and replications were 0.5m and 1 m respectively. Soil and crop management were applied uniformly to all plots. The test bread wheat variety was Dinkenesh with a seed rate of 125 kg ha^{-1}.

Soil Sampling and Analysis

Composite soil samples at a depth of 0-20 cm were collected from each farm at planting. Samples were air-dried and ground to pass through 2 mm sieve (for the determination of most soil properties) and 0.5 mm sieve (for the determination of total N). Soil texture was determined by hydrometer method (Bouyoucos, 1962). The soils pH was measured with a glass electrode in water (1: 2.5 soils to water ratio) (Page et al., 1982). The organic carbon content of the soil was determined following Walkley and Black procedures (Walkley and Black, 1934). The total nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982). The available soil phosphorus was determined by the Olsen method (1954) and Exchangeable potassium was extracted by ammonium acetate at pH 7 (Sahlemedhin and Taye, 2000) and determined by Atomic absorption spectrometer.

Agronomic data collection

Plant height was measured at maturity from five random plant samples of the harvestable rows from the ground to the tip of the spike. The harvestable rows were harvested at full maturity, sun dried and weighed to determine the above ground biomass in kg per plot and then converted to kg per hectare. Then the grains were separated from the straws and grain yield in kg per plot was determined and then converted to kg per hectare. The moisture content of the grain was collected simultaneously with the grain yield and finally the grain yield was adjusted to 12.5% moisture content.

Data analysis

The collected data were subjected to analysis of variance using SAS statistical software (SAS version 9.0) to evaluate the degree of variations between treatments using. Significant mean differences were separated using least significant difference at 5% level.

Results and discussion

Physico-chemical properties of the soils of the study sites

The results of soil analysis showed that the texture of the soils of both districts was clay. The total nitrogen ranged from 0.1% to 0.2% and 0.08% to 0.15 % for Meket and Jamma respectively, and it is in a low to medium in content (Tekalign, 1991). In addition, the soil organic matter content of Meket ranged from 1.6% to 3.8% (low to medium content) and of Jamma ranged from 0.67% to 1.55% (low content) (Berhanu, 1980). Moreover, the available phosphorus content of soils of Meket ranged from 23.05 ppm to 31.15 ppm and for Jamma ranged from 39.4 ppm to 54.8 ppm (Table 1). For both study sites the availability of phosphorous content is categorized as very high (Marx et al., 1999). The exchangeable potassium content of the soils at Meket was in a range of 1. 7 to 5.8 $cmol_ckg^{-1}$ and of soils at Jamma were from 4.9 to 6.0 $cmol_ckg^{-1}$. The level of potassium for the two districts was also very high (FAO, 2006) and hence crop response to potassium is very unlikely. The soil reaction (pH) of the two districts was ranging from 5.9-6.3 (moderately acidic) for Meket and 6.4-6.8 (moderately acidic to neutral) for Jamma (Table 1).

Table 1: Soil physico-chemical properties of the study sites before planting

District	pH	OM (%)	Available P (ppm)	T.N (%)	Ex. K ($cmol_ckg^{-1}$)	Textural class
Meket	5.9-6.3	1.60-3.80	23.05-31.15	0.10-0.20	1.70-5.81	Clay
Jamma	6.4-6.8	0.67-1.55	39.40-54.80	0.08-0.15	4.86-6.00	Clay

Note: pH = power of Hydrogen; OM = organic matter; T.N = total nitrogen; P = phosphorus; Ex.K = exchangeable potassium

Effect of potassium, boron and zinc containing fertilizers on bread wheat biomass and grain yields

The analysis of variance showed that there was no statistically significant difference ($p > 0.05$) between the treatments for both districts (Table 2, 3, 4 and 5). This finding is in line with the previous studies done at the same locations and other parts of the region to validate the initial soil fertility status map and also with studies made in nutrient refining conducted in the region (Abebe *et al.*, 2019 under publication; Tadele *et al.*, 2018). The non-significant response of the biomass and grain yields of bread wheat to these nutrients is also supported by the soil analysis result which showed very high potassium content result in the soils of both districts and less likely response to their application (Table 1). Adding potassium, boron and zinc fertilizers did not bring any observable yield advantage over recommended NP fertilizers. Our finding is in agreement with Birhane et al., (2017) who reported non-significant yield difference among potassium rates up to 150 kg ha^{-1}.

Table 2. Effect of treatments on grain yield ($kgha^{-1}$) at Jamma

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm5	Mean
NPS	2991	3014	3798	2834	2925	3112
NPSK	3043	3213	3565	2657	3054	3106
NPSBZn	2663	3179	3569	2922	2823	3032
NPSKBZn	2986	3186	3799	2684	3305	3192
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	13.1	5.66	8.4	12.88	11.02	14.0

Table 3. Effect of treatments on biomass yield ($kgha^{-1}$) at Jamma

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm5	Mean
NPS	7722	7611	9556	7111	7889	7978
NPSK	7556	8000	8611	6778	7944	7778
NPSBZn	6833	8056	9278	7444	7444	7811
NPSKBZn	7611	7722	9222	6833	8611	8000
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	12.93	6.36	7.9	9.76	11.51	13.74

Table 4. Effect of treatments on grain yield (kg ha^{-1}) at Meket

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Mean
NPS	2885	3011	3787	1943	2906	2906
NPSK	2485	3611	3979	2136	2964	3035
NPSBZn	3070	2944	3883	1877	2550	2865
NPSKBZn	2722	3033	3882	2091	2679	2881
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	24.32	17.62	4.88	20.12	13.79	27.74

Table 5. Effect of treatments on biomass yield (kgha^{-1}) at Meket

Treatment	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Combined
NPS	8174	7275	10116	5159	7855	7716
NPSK	7391	8588	10652	5870	8290	8158
NPSBZn	8841	7333	9812	5696	6826	7701
NPSKBZn	8087	8529	10638	5768	7739	8152
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	20.8	17.45	4.42	12.5	13.52	24.59

In addition, our finding didn’t support the soil fertility status map developed for the districts (MoANR and ATA, 2016) as well as the application of 100 kg KCl ha^{-1} to each parcel of agricultural land all over the country and the region recommended by ATA and MoANR. Our finding was also not in line with the findings of Wassie and Tekalgn (2013) who reported 41% yield increment over the control due to the application of potassium fertilizer. Unlike our finding, Piri, (2012) reported yield increment due to the foliar application of micronutrients may be attributed to sufficient micro nutrient content in the soils of the study areas.

For soils deficient in potassium, zinc and boron, crop yield increased through proper application of these nutrients (Chaudry et al., 2007; Dash et al., 2015; Gitte et al., 2005; Nadim et al., 2012; Nataraja et al., 2006; Sultana et al., 2016). Among the micronutrients, Zinc (Zn) and Boron (B) played key role in pollination and seed setting processes. So, their deficiency can cause poor seed formation and subsequent yield reduction. However, this effect was not observed in our study. The importance of potassium and other micronutrients including zinc and boron for crop production is clear. However, currently wheat is not responding to the application of these nutrients and resulted in no biological and economic benefits for the famers in the study districts and similar soil and agro-ecologies. The response to potassium may be attributed to the highest amount of potassium available in the soil resulting in no yield response due to the application of additional potassium to the soil (Table 1).

Furthermore, the exchangeable potassium status map developed by MoANR and ATA, (2016) excluding the K:Mg ratio showed that 99% of soils at Jamma had exchangeable potassium contents being optimum and above and 85% of soils at Meket had exchangeable potassium to be optimum and above approving the insignificant yield increment due to the application of potassium and micro nutrients. Therefore, the map developed by MoANR and ATA for the region should be improved based on the feedback from the research system.

Application of potassium, zinc and boron fertilizers are therefore incurring additional cost to the farmers for no yield advantage over the application of nitrogen and phosphorus.

Conclusion and Recommendation

The overall result of this research showed that application of K, B and Zn containing fertilizers did not bring significant yield increment over the crop and site and crop specific recommended nitrogen and phosphorus fertilizers. This indicates that application of recommended nitrogen fertilizer without the addition of K, B and Zn fertilizers is required to increase production and productivity of wheat in the study districts. So that K, B and Zn were not potentially yield limiting nutrients in the study sites and these nutrients were sufficient to support good crop growth for wheat in both areas where these experiments were conducted.

This study confirmed that for this time no need of potassium, Zinc and Boron fertilizer in the aforementioned study areas. Moreover, crop response to new fertilizers and the soil fertility status must be monitored as they will be expected to be yield limiting in the future.

References

Berhanu Debele. 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land use planning and regulatory department, Ministry of Agriculture. Addis Ababa, Ethiopia

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal, 54, 464–465.

Birhane Hagos, Mamo Tekalegn, Teka Kassa. 2017. Potassium Fertilization and its Level on Wheat (Triticum aestivum) Yield in Shallow Depth Soils of Northern Ethiopia. J Fertil Pestic 8: 182. doi:10.4172/2471-2728.1000182.

Chaudry, E.H., Timmer, V., Javed, A.S., and Siddique, M.T. 2007. Wheat response to micronutrients in rain-fed areas of Punjab. Soil & Environ. 26: 97-101.

Dash, A.K., Singh, H.K., Mahakud, T., Pradhan, K.C. and Jena, D. 2015. Interaction Effect of Nitrogen, Phosphorus, Potassium with Sulphur, Boron and Zinc on Yield and Nutrient Uptake by Rice Under Rice – Rice Cropping System in Inceptisol of Coastal Odisha . Int. Res. J. Agric. Sci. Soil Sci. 5(1):14-21

Gitte, A.N., Patil, S.R. and Tike, M.A. 2005. Influence of zinc and boron on biochemical and yield characteristics of sunflower. *Indian journal of plant physiology*, *10*(4), pp.400-403.

Haile Wassie and Mamo Tekaligne. 2013. The effect of potassium on the yields of potato and wheat grown on the acidic soils of Chencha and Hagere Selam in Southern Ethiopia. International Potash Institute Research Findings, 35, pp.3-8.

International Potash Institute (IPI), 2016. Technical manual on potash fertilizer.

Mandal, A., A.K. Patra, D. Singh, A. Swarup and R.E. Masto. 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Bioresour. Technol. 98: 3585-3592.

Marx, E. S. Hart, J.and Stevens, R. G. 1996. “Soil Test Interpretation Guide,” *Oregon State Univ. Serv.*

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia. 2016. Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia: 297 pages.

Murphy, H. F. 1968. A report on fertility status and other data on some soils of Ethiopia. Experimental Station Bulletin No. 44. Hailesilassie College of Agriculture. Oklahoma State University, 551P.

Nadim, M.A., Awan, I.U., Baloch, M.S., Khan, E.A., Naveed, K. and Khan, M.A. 2012. Response of wheat (Triticum aestivum L.) to different micronutrients and their application methods. *Journal of Animal and Plant Science 22*(1), pp.113-119.

Nataraja, T.H., A.S. Halepyati, B.T. Pujari and B.K. Desai. 2006. Influence of phosphorus levels and micronutrients on the physiological parameters of wheat. *Karnataka J. Agri. Sci.* 19**:** 685–687.

Olsen, S. R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington: United States Department of Agriculture.

Page J.R., Miller, R.H., Keeney, D.R., Baker, D.E. and Roscoe, E.J.R. 1982. Methods of soil Analysis. II. Chemical and microbiology properties 2nd (eds.) Wisconsin, USA.

Piri, I. 2012. Effect of phosphorus fertilizer and micronutrients foliar application on sorghum yield. Annals of Biological Research, 3(8), pp.3998-4001.

Sultana, S., Naser, H.M., Akhter, S. and Begum, R.A. 2016. Effectiveness of soil and foliar applications of zinc and boron on the yield of tomato. *Bangladesh Journal of Agricultural Research*, *41*(3), pp.411-418.

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet, Birhanu Agumas, Mengstu Muchie, Tesfaye Feyisa and Desalew Fentie. 2018. Crop response to balance nutrient application in north western Ethiopia. Blue Nile Journal of Agricultural Research (1), pp1-14.

Tadele Amare, Tesfaye Feyisa and Yihenew G/Selassie. 2008. Response of maize, malt barely and tomato to potassium. In: Birru Yitaferu, Teshome Tessema, Zewdu Ayalew (eds.). Proceedings of the third Annual Regional Conference on Completed Research activities on soil and water management, Forestry and Agricultural Mechanization 1-4 September 2008, Amhara regional agricultural research institute ARARI, Bahir Dar, Ethiopia, pp 67-75.

Tena, W. and Beyene, Sheleme. 2011. Identification of growth limiting nutrient (s) in alfisols: Soil physico-chemical properties, nutrient concentrations and biomass yield of maize. American Journal of Plant Nutrition and Fertilization Technology, 1(1), pp.23-35.

Walkley, A., and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37, 29–38.

Influence of nitrogen and phosphorus on yield and quality of malt barley (*Hordeum distichon* L.) under irrigation in West Amhara, Ethiopia

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Abstract

Under most soils, landscapes, and agro-ecologies nitrogen and phosphorus nutrients are deficient and one of the options to improve crop productivity is using the synthetic fertilizers that contain nitrogen and phosphorus nutrients. A two year on-farm research was conducted to determine the economical and biological optimum levels of NP fertilizers on grain yield and quality of malt barley (Hordeumdistichon L.) under irrigation in North West Amhara. The experiment was conducted from 2019-2020 at two districts (Mecha and Gugusashekudad) and had 5 rates of N (0, 46, 69, 92 and 115) kg and 3 rates of P (23, 46 and 69) kg P2O5 ha-1with one negative (0,0) pilot treatment which was arranged in RCBD with three replications. IBON (174/03) with 100 kg ha-1 seed rate and Urea for N and TSP for P source were used. All dose of P was applied at planting; whereas N was applied in three splits equally at planting, tillering and booting stage of the crop. The trial was irrigated with seven days of irrigation interval using 40cm furrow width. One composite soil sample for each site was collected at 0-20 cm depth before planting to understand the state of soil fertility. Maximum grain yield of 3337 and 2284.3 kg ha-1 was attended on 92/23 N/ P2O5 kg ha-1 and 115/23 N/ P2O5 kg ha-1 fertilizer combinations at Mecha and Gugusashikudad districts, respectively. Grain and biomass yields of malt barley showed a significant response for nitrogen fertilization at both districts. Similarly, at Gugusashikudad district, nitrogen showed a significant difference on protein contents. However, sole phosphorus and its interaction with nitrogen were insignificant on the yields and protein contents. Application of 92 and 115 kg N with 23 kg P2O5 ha-1 showed the highest net benefit (66,839 ETB ha-1) and (44,285 ETB ha-1) and takes as the first optimum economical profitable rates with yield advantages of 64% and 194.5% from the control treatment in Mecha and Gugusashikudad districts, respectively. Therefore, for seed production, it is better to use 92 and 115 kg N with 23 kg P2O5 ha-1 at Mecha and Guagusashikudad districts, respectively. However, for malt purpose 69 and 46 kg N with 23 kg P2O5 ha-1are recommended at Mecha and Guagusashikudad districts, respectively.

Keywords: Nitrogen, phosphorus, Fertilizer, Malt barley, Protein content

Introduction

Ethiopia is the second largest barley producer in Africa, next to Morocco, accounting for about 25% of the total barley production in the continent (FAO, 2014). It is the fifth important cereal crop next to teff, maize, sorghum and wheat in the country with a mean productivity of2.1 ton ha^{-1} (CSA, 2017). More than 4 million smallholder farmers involved barley production (CSA, 2016). Malt barley *(Hordeumdistichon L.)* in Ethiopia is predominantly grown between 2200-3000 m a.s.l(Asmare Yallew *et al.*, 1998). It is one of the most important crops for food, feed, malt and income generation for many smallholder in the highlands of Ethiopia (Bayeh and Berhane, 2011).

However, the productivity is about 2 ton ha^{-1}. ORDA, 2008b estimated that about 15,945 ton of malt barley produced annually in Ethiopia. However, the combined annual malt barley consumption of the six breweries in the country is estimated about 48,330 ton and is more than threefold which demand to increase the production capacity of malt barely. Accordingly, about 60% of the malt demand of factories is met through imports (ORDA, 2008a). Low soil fertility and poor agronomic practices are among the major constraints responsible for the low productivity of malting barley in Ethiopia (Gete Zelleke *et al.*, 2010).

Most Ethiopian soils are nitrogen and phosphorus deficient (Taye *et al.*, 2002). Synthetic NP fertilizer application is one the options to improve the productivity of malt barley and hence satisfy the demands of factories with local production than importing. Nitrogen is critically important to plants since it is a fundamental part of the chlorophyll molecule and is essential in the formation of amino acids and proteins. Phosphorus is an essential structural constituent of various bio chemicals such as nucleic acid (DNA and RNA enzymes and coenzymes). Deficiency of nitrogen and phosphorus are still one of the factors accountable for low malt yield production in Ethiopia(Khan et al., 2017). Hence, good soil fertility management practices is paramount important for all barley production systems (Bayeh and Berhane, 2011). Therefore, this research was initiated to determine the economical and biological optimum NP fertilizer rate for seed and malt production under irrigation in North West Amhara, Ethiopia.

Materials and methods

The study was conducted at two districts (Mecha and Gugusa-Shekudad) which are 525km and 435km far away from Addiss Ababa; the capital city of Ethiopia in the north-west direction. According to Ethiopian traditional agro-ecological classification, Mecha district is classified under WeyinaDega (1800 to 2400 m.a.s.l) and Gugusa-Shekudad under Dega (Mekonnen, 2015).

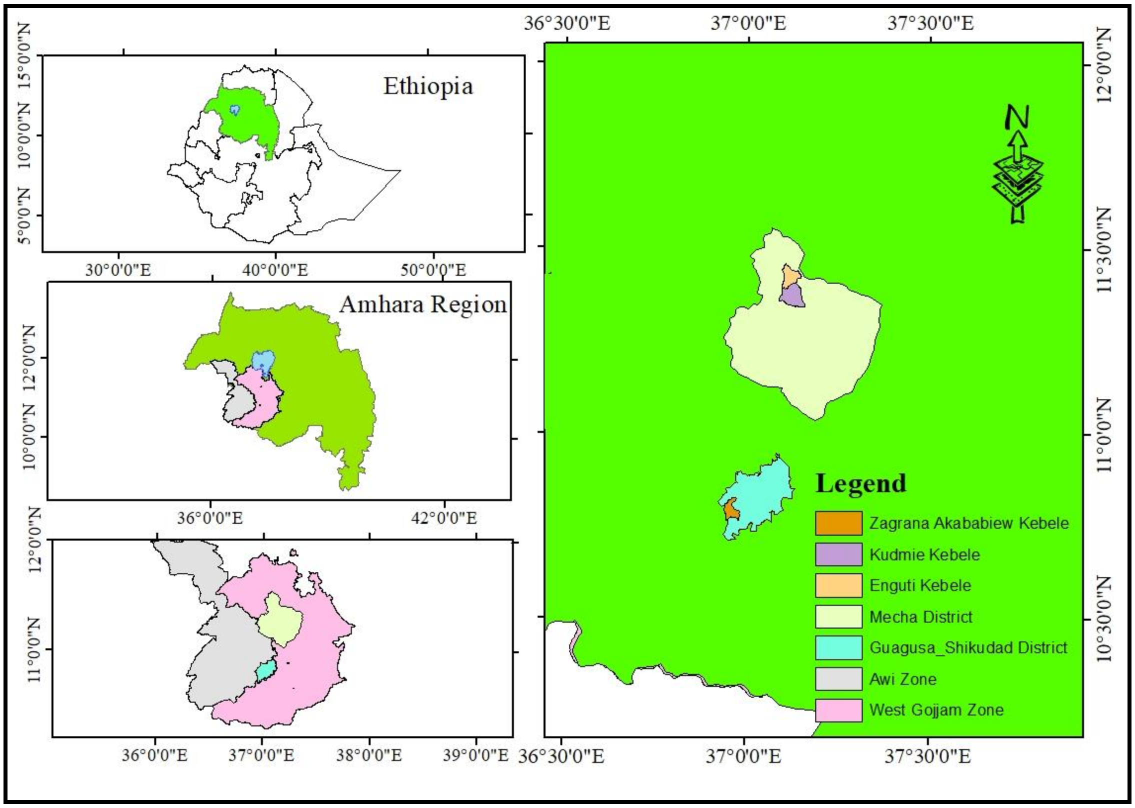

Figure 1. Map of the study areas

A factorial experiment with 5 rates of nitrogen (0, 46, 69, 92 and 115 kg ha^{-1}) and 3 rates of phosphorus (23, 46 and 69 kg P_2O_5ha^{-1}) was used. One treatment with no fertilizer (control) was used as pilot. A randomized complete block design (RCBD) with three replications was used. The experiment was conducted for two consecutive years (2019-2020). The spacing was 1.5m, 0.5m and 0.2m between replications, plots and rows, respectively. Gross plot size was 3.2 m width and 2m length (6.4m^2).

The water was applied in furrows with 40cm furrow width at7 days irrigation interval. IBON (174/03) variety with 100 kg ha^{-1} seed rate was used. Urea (46-0-0) and TSP (0-46-0) were used as a source of nitrogen and phosphorus, respectively. All amount of phosphorus was applied at planting and nitrogen fertilizer was applied in three splits that was at planting (1/3), tillering (1/3) and booting (1/3) stages.

Soil sampling, Preparation and Analysis

One composite soil sample before planting was taken from five points following the Non-Systematic pattern (X- pattern sampling) technique at the depth of 0-20 cm for each site. The sampled soils were air dried and sieved (≤2 mm) for analysis of soil pH, Organic carbon (OC), Cation Exchange Capacity (CEC), Available phosphorus (AP), and total nitrogen (TN). The soil analysis was conducted at Adet Agricultural Research Center's Soil Laboratory. From this, soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Sahilemedihin and Taye (2002). AP was analyzed following Olsen method (Olsen, 1954); while TN was analyzed following the Kjeldahl method (Bremner and Mulvaney, 1982). Wet oxidation method was used to determine soil OC while cation exchanges capacity (CEC) was determined using ammonium acetate method. Following this, at Table 1 indicated parameter values were obtained.

As shown in Table 1, the soil pH at all experimental sites ranges from strongly acidic (4.5-5.2) to moderately acidic (5.3-5.9) according to the scale of Tekalign Tadese (1991). Soil OC values was also ranged from moderate to high (1.5-3%) according to Tekalign Tadese (1991), whereas CEC readings ranged from moderate to high (12-40 $Cmol_{(+)}$/kg) (Hazelton and Murphy, 2007). The TN found to be in high ranges (0.12-0.25%) according to Tekalign Tadese, 1991. On the other hand, AP at two sites ranged from (5-10ppm) which is medium range while at other sites it was >10 ppm which is at high rating range (Olsen, 1954).

Table 1.Selected soil properties for the experimental sites before plant

Soil parameters	Mecha 2019		Mecha 2020		Gugusashekudad 2019		Gugusashekudad 2020	
	Farm 1	Farm 2	Farm1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2
pH (H_2O)	5.29	5.54	5.12	5.09	5.95	5.29	5.32	5.68
OC (%)	2.49	2.63	2.07	1.96	2.63	2.76	2.25	2.37
CEC (mg/100g)	15.54	19.42	26.28	27.22	21.7	15.06	28.02	27.16
Total N	0.175	0.258	0.190	0.185	0.247	0.161	0.171	0.188
AP (ppm)	10.17	7.79	6.80	14.44	10.28	12.26	10.84	11.01

Data collection and analysis

Agronomic data like plant height, spike length, harvest index (HI) and all biological yields (grain + above ground biomass) were collected at harvest. The grain yield was adjusted to 12.5% of moisture content. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). Least significant difference (LSD) was used for mean separation comparison at 5% probability. The partial budget analysis was done following CIMMYT(1988) procedure. For the partial budget analysis, farm gate prices of the malt barley and the cost of fertilizers were considered to their specific area. Based on this, 1kg malt barley grain, 1 ton straw, 1 kg Urea and 1 kg NPS fertilizers were considered as 20 ETB, 1000 ETB, 14 ETB and 14.5 ETB, respectively.

Results and Discussion

Yield response to applied N and P

At Mecha both grain and biomass yields of malt barley linearly increased as nitrogen level increased for both two consecutive cropping seasons (Table 2) which is in line with the findings of Snežana *et al. (*2011) and Meharie and Kindie (2019). Although both yields (grain + biomass) in two cropping seasons showed an incremental trend with N levels, this increment showed a decreasing incremental rate after 46 kg N ha^{-1}. In this district, only in the first cropping season (2019), both grain and biomass yields showed a highly significant difference ($p<0.0001$) among treatments due to nitrogen fertilization. But, there was no significant difference between P-rates for both grain and biomass yields. This might be related to the available soil P with better temperature in the growing season.

Both nitrogen and phosphorus fertilizer applications didn’t show statistical significant differences and showed irregular trends on protein contents of malt barley in both experimentation periods as shown in Table 4. But from malt quality perspective, all readings in the first cropping season were above critical level (>11.5%) whereas, in the second cropping season it was below critical level of 11.5% based on Atherton (1984) standardization (Table 4).

Table 2.Yield response of malt barley to N and Pat Mecha district

	Grain yield (kg ha^{-1})			Biomass yield (kg ha^{-1})		
N Levels	2019	2020	Combined	2019	2020	Combined
0	1241.4	2087.2	1579.7	2707.9	5868.5	3972.6
46	2619.2	2347.4	2510.7	4746.1	7153.0	5708.7
69	2805.9	2730.1	2775.6	4907.1	7448.2	5923.3
92	2889.9	2868.9	2881.7	5092.6	7917.2	6222.0
115	2885.2	2975.1	2921.4	5463.7	8091.1	6513.7
LSD (0.05)	496.7	811.2	430.2	952.6	1990.9	1171.0
P_2O_5 levels						
23	2598.2	2685.7	2633.2	4777.6	7312.9	5791.5
46	2339.2	2566.7	2430.2	4431.1	7562.5	5683.0
69	2528.2	2553.9	2538.7	4542.0	7010.7	5529.0
LSD (0.05)	384.7	628.5	333.2	737.9	1542.1	907.1
P level (5%)	NS	NS	NS	NS	NS	NS
CV (%)	30.1	37.9	33.2	31.3	33.2	40.5
P level (N)	**	NS	**	**	NS	**
P level (P_2O_5)	NS	NS	NS	NS	NS	NS
P level N* P_2O_5	NS	NS	NS	NS	NS	NS

In Guagusa-Shikudaddistrict, both grain and biomass yields of malt barley showed a highly significant difference ($P<0.0001$) among treatments with linear increment in both cropping season due to nitrogen fertilizer application and this result was in line with the findings of De. Ruiter (1999) and Sainju *et al.* (2013). Similar to Mecha district, phosphorus as well as the interaction of nitrogen and phosphorus didn't show any significant difference among treatments on the yield and protein contents (Table 3) at Guagusa-Shikudad district. In this district also increment of both grain and biomass yields due to nitrogen fertilization showed a decreasing rate after 46 kg N ha^{-1}.

In this district similar to biological yields, protein content of malt grain showed highly significant difference ($P<0.0001$) among treatments due to nitrogen fertilizer application with linear increment in 2019 cropping season (Table 4). In this cropping season, all protein contents of grain showed above the critical level (>11.5) based on Atherton (1984). However, in the second cropping season the protein content didn't show any significant response for both nitrogen and phosphorus rates and below the critical protein content. Even though the two fertilizers had no significant response on the protein content values of the malt grains in this cropping season, all readings showed below the critical protein content value (<11.5) which is at acceptable range of malt quality (Atherton, 1984).

Table 3.Yield response of malt barley to N and P at Guagusa- Shikudad district

	Grain yield (kg ha^{-1})			Biomass yield (kg ha^{-1})		
N Levels	2019	2020	Combined	2019	2020	Combined
0	1304.4	907.9	1106.4	3055.6	2199.2	2627.4
46	1752.4	1508.5	1631.0	3634.3	2824.6	3229.4
69	1982.2	1617.0	1799.1	4236.3	3309.9	3773.1
92	2154.9	1514.4	1835.2	4537.3	3726.4	4132.5
115	2381.2	1757.1	2068.6	5000.5	4455.6	4728.6
LSD (5%)	439.8	508.1	342.9	751.2	965.0	624.7
P_2O_5 levels						
23	1864.4	1538.9	1701.0	3902.6	3465.1	3684.4
46	1838.7	1314.9	1576.2	4083.5	3278.4	3680.9
69	2041.7	1530.7	1786.2	4292.3	3166.4	3728.8
LSD (5%)	340.8	393.6	265.6	580.0	747.5	483.8
P level (N*P)	NS	NS	NS	NS	NS	NS
CV (%)	34.6	27.6	43.6	52.4	43.9	36.3
P levels (N)	**	**	**	*	**	**
P levels (P)	NS	NS	NS	NS	NS	NS
P levels (N*P)	NS	NS	NS	NS	NS	NS

Demisie *et al.* (2015) and Derebe *et al.* (2018) reported similar result with our finding. Nitrogen fertilizer resulted a highly significant difference ($p<0.0001$) among treatments on both grain and biomass yields of malt barley from the two years combined analysis result at each district with a linear increment (Table 2 and 3). But this increment is in a decreasing rate as nitrogen rate increase on both biological yields. Similar to separate years' result; sole phosphorus and interaction of N and P fertilizers didn't show any statistical significant difference of grain and biomass yields (Table 2 and 3). The non-responsiveness of phosphorus fertilizers on biological yields of barley may be due to high phosphorus nutrient accumulation in the soil system. The accumulation may be occurred due to continuous phosphorus containing fertilizer application as fertilizer sources for the last 50 and more years. By its nature, mobility of phosphorus nutrient from soil system is too low relative to nitrogen. This is also justified by phosphorus soil data found in the experimental fields ranged from medium to high ranging. In contrast of this, whatever the nitrogen level is high in the soil, application of nitrogen as fertilizer sources showed a significant response on biological yields of barley. This may be due to the fact that, the amount of nitrogen determined in the soil was TN and may not be fully available for plant nutrition during plant growth period.

As shown in combined ANOVA results of each district, protein content showed a significant difference among treatments due to nitrogen fertilization only at Guagusa-Shikudad district. Beside of this, application of nitrogen up to 92 kg N ha^{-1} at Mecha and 46 kg N ha^{-1} at Guagusa-Shikudad district, protein values found less than 11.5% and this is under acceptable malt quality rage (Atherton, 1984) (Table 4). From yield potential perspective, both grain and biomass yields showed nearly a 20% yield penalty per hectare due to furrow spacing in both districts compared to the rainy season.

Table 4. Response of protein contents (%) of malt barley to N and P

	Mecha			Guagusa-Shekudad		
N Levels	2019	2020	Combined	2019	2020	Combined
0	10.8	9.7	10.4	11.9	10.0	10.9
46	11.6	10.1	11.0	12.0	10.2	11.1
69	11.8	10.3	11.2	12.5	10.6	11.6
92	11.7	9.7	10.9	13.0	10.3	11.6
115	12.5	10.0	11.5	13.5	10.4	11.9
LSD (5%)	1.4	1.5	1.1	0.5	0.8	0.7
P_2O_5 levels						
23	11.5	9.6	10.8	12.5	10.2	11.3
46	11.9	10.3	11.2	12.8	10.4	11.6
69	11.6	10.0	10.9	12.4	10.3	11.4
LSD (5%)	1.1	1.2	0.8	0.4	0.6	0.6
CV(%)	18.2	18.6	19.4	6.2	11.8	13.7
P level (N)	NS	NS	NS	**	NS	*
P level (P)	NS	NS	NS	NS	NS	NS
P level (N*P)	NS	NS	NS	NS	NS	NS

Partial budget analysis

All biological yields (grain and biomass) of malt barley showed a highly significant difference ($p<0.0001$) among location/districts, which subjects to the analysis of the partial budget for each district separately. Based on CIMMYT (1988) partial budget analysis principle as shown in (Table 5 and 6), 92 kg N with 23kg P_2O_5 and 115 kg N with 23 kg P_2O_5 ha^{-1}showed the highest net benefit values (66,839and 44,285 Birr/ha) and takes as the first optimum economical profitable rates for Mecha and Gugusa-Shikudad districts, respectively. The above combined fertilizer rates gave 64% and 194.5% yield advantages over the control (without fertilizer) at Mecha and Gugusa-Shikudad districts, respectively.

Table 5. Partial budget analysis for Mecha district

N kg ha^{-1}	P_2O_5 kg ha^{-1}	NPS kg ha^{-1}	Urea kg ha^{-1}	GY (kg ha^{-1})	STY (t ha^{-1})	GI	N Fertilizer cost	P fertilizer cost	TVC	NB	Dominance
0	0	0	0	1862	3.6	40851	0	0	0	40851	
0	23	60.5	0	1936	2.9	41575	0	878	878	40697	D
0	46	121.1	0	1465	2.6	31861	0	1755	1755	30106	D
46	23	60.5	75	2518	3.2	53551	1050	878	1928	51624	
46	46	121.1	50	2539	3.5	54330	700	1755	2455	51875	
69	23	60.5	125	2695	3.2	57128	1750	878	2628	54500	
0	69	181.6	0	1474	2.0	31443	0	2633	2633	28810	D
46	69	181.6	25	2690	3.1	56939	350	2633	2983	53956	D
69	46	121.1	100	2957	3.6	62789	1400	1755	3155	59634	
92	23	60.5	175	3337	3.4	70167	2450	878	3328	66839	
69	69	181.6	75	2911	2.9	61077	1050	2633	3683	57394	D
92	46	121.1	150	2641	3.3	56144	2100	1755	3855	52288	D
115	23	60.5	225	3055	3.5	64643	3150	878	4028	60616	D
92	69	181.6	125	2913	3.6	61826	1750	2633	4383	57443	D
115	46	121.1	200	2893	3.7	61524	2800	1755	4555	56969	D
115	69	181.6	175	3066	3.9	65205	2450	2633	5083	60123	D

N	P_2O_5	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	0	40851	
46	23	1928	51624	559
46	46	2455	51875	48
69	23	2628	54500	1523
69	46	3155	59634	973
92	23	3328	66839	4180

1kg grain=20 ETB, 1t straw=1000 ETB, 1kg Urea=14 ETB, 1kg NPS=14.5 ETB

Where: *GY=grain yield, STY= straw yield, GI=gross income, TVC=total variable costs, NB=net benefits, MRR=marginal rate of return, ETB= Ethiopian birr*

Table 6. Partial budget analysis for Gugusa-Shikudad district

N kg ha^{-1}	P_2O_5 kg ha^{-1}	NPS kg ha^{-1}	Urea kg ha^{-1}	GY(kg ha^{-1})	STY (t ha^{-1})	GI	N Fertilizer cost	P fertilizer cost	TVC	NB	Dominance
0	0	0	0	652.3	2.0	15037	0	0	0	15037	
0	23	60.5	0	1073.8	1.4	22903	0	878	878	22025	
0	46	121.1	0	1129.3	1.7	24243	0	1755	1755	22488	
46	23	60.5	75	1560.6	1.6	32795	1050	878	1928	30867	
46	46	121.1	50	1694.9	1.9	35774	700	1755	2455	33319	
69	23	60.5	125	1921.3	2.2	40611	1750	878	2628	37984	
0	69	181.6	0	1210.8	1.6	25826	0	2633	2633	23193	D
46	69	181.6	25	1775.4	1.5	36982	350	2633	2983	33999	D
69	46	121.1	100	1892.6	2.0	39817	1400	1755	3155	36661	D
92	23	60.5	175	1908.7	2.4	40551	2450	878	3328	37223	D
69	69	181.6	75	1738.0	1.9	36700	1050	2633	3683	33017	D
92	46	121.1	150	1593.3	2.4	34272	2100	1755	3855	30417	D
115	23	60.5	225	2284.3	2.6	48313	3150	878	4028	44285	
92	69	181.6	125	2159.5	2.3	45495	1750	2633	4383	41112	D
115	46	121.1	200	1798.2	2.9	38879	2800	1755	4555	34324	D
115	69	181.6	175	2301.8	2.7	48698	2450	2633	5083	43615	D

N	P_2O_5	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	0	15037	
0	23	878	22025	796
0	46	1755	22488	53
46	23	1928	30867	4861
46	46	2455	33319	465
69	23	2628	37984	2706
115	23	4028	44285	450

1kg grain=20 ETB, 1t straw=1000 ETB, 1kg Urea=14 ETB, 1kg NPS=14.5 ETB

Where: *GY=grain yield, STY= straw yield, GI=gross income, TVC=total variable costs, NB=net benefits, MRR=marginal rate of return, ETB= Ethiopian birr*

Conclusions and recommendations

In this study, application of nitrogen fertilizer showed a significant response on biological yields (grain + biomass) at both districts with linear increment. However, sole phosphorus and interaction of nitrogen and phosphorus fertilizers didn't show any statistical significant difference on biological yields (grain + biomass) and malt qualities of malt barley among treatments at each district. Application of 92 kg N with 23 kg P_2O_5 and 115 kg N with 23 kg P_2O_5 ha^{-1} showed the highest net benefit values (66,839 and 44,285 Birr/ha) as the first optimum economical profitable rates with the yield advantages of 64% and 194.5% from the control treatment at Mecha and Gugusa-Shikudad districts, respectively. The effect of nitrogen on malt quality of barley grain was found at acceptable range (<11.5) up to 69 N ha^{-1} at Mecha and 46 kg N ha^{-1} at Gugusa-Shikudad districts, respectively. Accordingly, for the objective of seed production, it is better to use 92 kg N with 23 kg P_2O_5 at Mecha and 115 kg N with 23 kg P_2O_5 ha^{-1} at Gugusa-Shikudad districts and areas having the same agro ecology and soil fertility status under irrigation. However, for malt barley it is better to use 69 and 46 kg N with 23 kg P_2O_5 ha^{-1} fertilizers at Mecha and Guagusa-Shikudad districts, respectively.

References

Asmare Yallew, Alemu Hailiye, Alemayehu Assefa, Melkamu Ayalew, Tessema Zewudu, B. A. and H. H. (1998). Barley based farming system in the high lands of Ethiopia. Ethiopian Agricultural Research Organisation. Addis Ababa, Ethiopia. In F. A. & W. S. (eds.). In: Chilot Yirga (Ed.), Barley production practices in Gojam and Gondar (pp. 67–89). Addis Ababa, Ethiopia.

Atherton MJ. (1984). Quality requirements: malting barley, In: EJ Gallagher, Cereal Production. *Butter worths in association with Royal Dublin Society, Dublin*. pp 113-130.

Bayeh M. and Berhane. L. (2011). Barley research and development in Ethiopia—an overview. In G. S. (eds). In: Mulatu B (Ed.), Barley research and development in Ethiopia. Holleta Ethiopia.

Bremner, J. M. and C. S. Mulvaney. (1982). Nitrogen-total, In A. L. Page ed. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. *Agronomy 9. Madison, Wisconsin*. 595-624.

Central Statistical Agency (CSA). (2016). Agricultural sample survey report on area and production of major crops. Addis Ababa, Ethiopia.

Central Statistical Agency (CSA). (2017). Agricultural sample survey. Report on area and production of major crops (private peasant holdings, Meher season). Volume I, Statistical bulletin. Addis Ababa, Ethiopia.

CIMMYT. (1988). From agronomic data to farmer recommendations. An economic training manual . Compeletly revised Edition. Mexico.

De Ruiter, J. M. (1999). Yield and quality of malting barley (Hordeum vulgare L. ‘Valetta’) in response to irrigation and nitrogen fertilisation. *New Zealand Journal of Crop and Horticultural Science*, *27*(4), 307–317. https://doi.org/10.1080/01140671.1999.9514110

Demisie Ejigu, Tamado Tana, and Firdissa Etich. (2015). Effect of Nitrogen Fertilizer Levels on Yield Components and Grain Yield of Effect of Nitrogen Fertilizer Levels on Yield Components and Grain Yield of Malt Barley (Hordeum vulgare L .) Varieties at Kulumsa , Central Ethiopia. *Journal of Crop Science and Technology*, (January).

Derebe Terefe, Temesgen Desalegn and Habtamu Ashagre. (2018). Effect of Nitrogen Fertilizer Levels on Grain Yield and Quality of Malt Barley (Hordeum Vulgare L .) Varieties at Wolmera District , Central Highland of Ethiopia. *International Journal of Research Studies in Agricultural Sciences*, *4*(4), 29–43.

FAO. (2014). Food and Agriculture Organization (FAO) *: Rome, Italy.*

Gete Zelleke, Getachew Agegnehu, Dejene Abera and Shahidur R. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. Addis Ababa, Ethiopia.

Hazelton P. and Murphy B. (2007). Interpreting soil test results: What do all the numbers mean? *(2nd Editio). CSIRO.* 152.

Khan K., Sharif, M., Azeem I., Ibadullah, Khan A.A., Ali S., K. I. and K. A. (2017). phosphorus solubility from rock phosphate mixed compost with sulphur application and its effect on yield and phosphorus uptake of wheat crop. *Open Journal of Soil Science.*, *7*, 401-429.

Meharie Kassie and Kindie Tesfaye. (2019). Malting Barley Grain Quality and Yield Response to Nitrogen Fertilization in the Arsi Highlands of Ethiopia. *J. Crop Sci. Biotech*, *2019*(10), 225–234.

Olsen, Sterling Robertson, C.V. Cole, F. S. W. and L. A. D. (1954). Estimation of available phosphorus in soils by extraction with sodium carbonate.

ORDA (Organization for Rehabilitation and Development in Amhara). (2008). Malt barley value chain study. Options for growing a new channel in Amhara region.Bahir Dar, Ethiopia.

ORDA (Organization for Rehabilitation and Development in Amhara). (2008). Baseline survey of six malt barley potential woredas of north and south Gondar zones of the

Amhara region, Ethiopia. Bahir Dar Ethiopia.

Sainju, U. M., Lenssen, A. W., & Barsotti, Joy L. (2013). Dryland malt barley yield and quality affected by tillage, cropping sequence, and nitrogen fertilization. *Agronomy Journal*, *105*(2), 329–340. https://doi.org/10.2134/agronj2012.0343

SAS Institute. (2002). A Business Unit of SAS. SAS Institute Inc, Cary, NC. 2751. USA.

Snežana J., Đorđe G., Radojka ., Sveto R., Nikola . and Ik. J. (2011). Effects of nitrogen fertilization on yield and grain quality in malting barley. *10*(84), 19534–19541. https://doi.org/10.5897/AJB11.2633

Taye Bekele, Yesuf Assen, Sahlemedhin Sertsu, Amanuel Gorfu, Mohammed Hassena, D.G. Tanner, Tesfaye Tesemma, and Takele Gebre. (2002). Optimizing fertilizer use in Ethiopia: Correlation of soil analysis with fertilizer response in Hetosa Wereda, Arsi Zone. Addis Ababa. *Sasakawa-Global, 2000*.

Tekalign Tadese. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. *Working Document No. 13. Addis Ababa, Ethiopia.* (No. 13).

Increasing the productivity of food barley ((*Hordeum vulgare* L.*)* through nutrient management in the highlands of West Amhara, Ethiopia

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Abstract

Nitrogen and phosphorus are the most yield limiting nutrients and are deficient in the soil and can be corrected primarily by applying in synthetic form. Hence, a two year on-farm research was conducted to determine the optimum rates of NP fertilizer on food barley (Hordeum vulgare L.*) in Northwest Amhara during 2020 to 2021 production seasons at two response domain districts (Yilmana-Densa and Farta- Laie-Gainet). The experiment was conducted using two treatment combination setups for two years. For the first year (2020) the experiment had 5 rates of N (23, 46, 69, 92 and 115 kg ha-1) and 3 rates of P (46, 69 and 92 kg ha-1 P2O5). While in the second year (2021); the treatment combination were slightly modified in to 4 rates of N (69, 92, 115 and 138 kg ha-1) and 4 rates of P (0, 23, 46 and 69 kg ha-1 P2O5). In both years, one pilot treatment (zero input) was used for the purpose of partial budget analysis. Except the pilot treatment the two nutrient levels combined in factorial arrangement in each cropping season. A randomized complete block design (RCBD) with three replications was used. HB-1307 variety with 125 kg ha-1 seed rate, Urea for N and TSP for P source were used. All dose of P was applied at planting; whereas N was applied in two equal splits that were at planting and tillering stage of the crop. One composite soil sample from each testing site in each cropping year was collected at 0-20 cm depth before plating to understand the soil fertility status of each experimental site. Based on the two year combined analysis, both grain and biomass yields of food barley showed highly significant response to nitrogen fertilization at each response domain district. However, sole phosphorus application and its interaction with nitrogen didn't show any statistical significant difference on biological yields (grain + biomass) of food barley. Application of 115 kg N with 69 kg P2O5 and 115 kg N with 46 kg P2O5 ha-1 gave the highest net benefit values (55,012 and 76,342 Birr/ha) and takes as the first optimum economical profitable rates for Yilmana-Densa and Farta-Laie-Gainet response domain districts, respectively. The above combined fertilizer rates gave 224.7% and 81.7% yield advantages over the control (zero input) at Yilmana-Densa and Farta-Laie-Gainet districts, respectively.*

Keywords: Nitrogen, phosphorus, food barley, Yilmana Densa and Farta-Laie-Gainet

Introduction

Barley (*Hordeum vulgare* L.) is grown as commercial crop in about one hundred countries world-wide and is the fourth most important cereal crop after wheat, rice and maize. Russia, Canada, Germany, Ukraine and France are the major barley producers accounting nearly half of the total world production. Worldwide, barley grown on 57 million hectares which accounts a total of 138 million tones grain production with 2.4 tone (t) ha^{-1} productivity (FAO, 2009). Ethiopia is the second largest barley (*Hordeum vulgare L.*) producer in Africa next to Morocco, accounting for about 25% of the total barley production in the continent (FAO, 2014) and takes as a center of origin and wide range of diversity (Vavilov, 1951).

In Ethiopia barley is the fifth important cereal crop next to tef, maize, sorghum and wheat with a mean productivity of 2.1t ha^{-1} (CSA, 2017) and accounted 10% of the total annual cereal production (CSA, 2008). More than 4 million smallholder farmers involved on barley production (CSA, 2016) in Ethiopia. Based on CSA (2011) report, the national and regional (Amhara Region) area coverage of barley was estimated about 1,047,000 and 328,000 hectares with a productivity of 1.63 and 1.3 t ha^{-1}, respectively. While, the total area coverage for South Gonder and West Gojjam Zones were estimated about 35,861 and 24,649 hectares with productivity of 1.3 and 1.1 t ha^{-1}, respectively.

Within this truth, Ethiopian soils are not potentially productive due to topsoil erosion, soil acidity, significant depletion of soil OM, macro and micro-nutrients, soil salinity and depletion of the basic soil properties (Gete *et al.*, 2010). As ICARDA (2008) stated, the most important factors that reduce yield of barley in Ethiopia are poor soil fertility, water logging, drought, frost, soil acidity, diseases and insects and weed competition. Specifically Ethiopian soils are nitrogen and phosphorus deficient and takes as the most yield limiting nutrients for many crops including for food barley (Taye *et al.*, 2002). Therefore, synthetic NP fertilizer application is one of the options to improve the productivity of many crops including food barley using site-specific fertilizer modification in different times.

As Adamu *et al*. (1993) mentioned, agronomic trials on barley was started in the late 1960s under the Institute of Agricultural Research (IAR). After this, different economical NP rates were recommended for barley production by different researchers and research centers in different times. From this, for Arsi, Shewa and Bale district the recommended N/P_2O_5 on Nitisols and Vertisols were 25/45 and 20/55 kg ha^{-1}, respectively. However, for other districts across the country, 30/45 and 20/40 N/P_2O_5 kg ha^{-1} were taken as a general recommendation on Nitisols and Vertisols, respectively (Fana, in press). AARC (2002) was also reported different NP fertilizer rate recommendations for barley production at different districts that was available from 1997-2003. Based on this, the recommended N/P_2O_5 values at Laie-Gainet (92/46), Enarge-Enawga, Machakel and DebayTilatgin (46/46), Gozamen and Chiliga (69/69), Estie (69/23) and Wogera (69/46) kg ha^{-1}. Based on Minale *et al*. (2011) report, economical recommended NP fertilizer rates for barley production at Fartta and Huleteju-Enebssie were 69/23 and 46/23 N/P_2O_5 kg ha^{-1} with 150% and 131% yield advantage over the control, respectively. This indicates that, the economical optimum recommendations were given before ten years and update of the level of most yield limiting nutrients is too much necessary for the production of optimum economical barley yield. Therefore, this research was initiated to determine the economical optimum NP fertilizer rates for food barley production in the highlands of North Western Amhara.

Materials and methods

The study was conducted at two districts which are Yilmana-Densa and Farta-Laie-Gainet. Both districts located in the north direction from the capital city of Ethiopia (Addiss Ababa). According to Ethiopian traditional agro-ecological classification, Yilmana-Densa district is found under *Weyina dega* (1800 to 2400 m.a.s.l) while, Farta-Laie-Gainet is found under Dega classification (Mekonen, 2015).

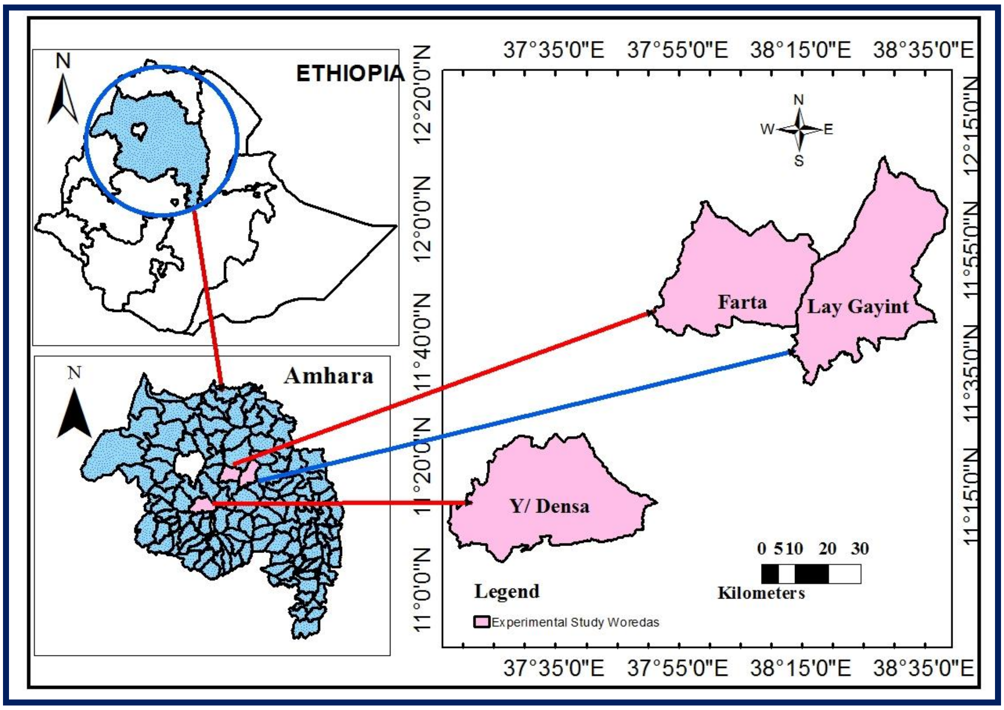

Figure 2. Map of the study districts

Experimental procedure and treatment set up

The experiment was conducted at fourteen farmers' fields in two consecutive years (2020 to 2021) with two treatment combination setups. During the first year (2020) experimentation, the experiment had 5 rates of N (23, 46, 69, 92 and 115 kg ha^{-1}) and 3 rates of P (46, 69 and 92 kg ha^{-1} P_2O_5). While in the second year (2021); the above treatment combinations were slightly modified in to 4 rates of N (69, 92, 115 and 138 kg ha^{-1}) and 4 rates of P (0, 23, 46 and 69 kg ha^{-1} P_2O_5). In both years, one negative pilot treatment (zero input) was used which didn't include under ANOVA analysis but only used for the purpose of partial budget analysis. Except the pilot treatment the two nutrient levels combined in factorial arrangement in each cropping season.

A randomized complete block design (RCBD) with three replications was used. The spacing was 1.5m, 0.5m and 0.2m between replications, plots and rows, respectively. The net harvestable area was also (5.2m^2). **HB-1307** variety with 125 kg ha^{-1} seed rate as well as Urea (46-0-0) and TSP (0-46-0) were used as a source of nitrogen and phosphorus nutrients, respectively. All amount of phosphorus was applied at planting and nitrogen fertilizer was applied in two equal splits that were at planting and at crop tillering stage. All the agricultural practices were implemented manually using human man power.

Soil sampling, Preparation and Analysis

One composite soil sample before planting was taken at the depth of 0-20 cm for each site in each year. Soil pH, Organic carbon (OC), Cation Exchange Capacity (CEC), Available phosphorus (AP) and total nitrogen (TN) were analyzed at Adet Agricultural Research Center's Soil Laboratory. From this, soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Sahilemedihin and Taye (2002). AP was also analyzed following Olsen method (Olsen, 1954); while TN was analyzed following the Kjeldahl method (Bremner and. Mulvaney, 1982). Wet oxidation method was used to determine soil OC. The CEC determined using ammonium acetate method.

Following this, at Table 1 indicated parameter values were obtained. Soil pH values of the testing sites found from strongly to moderately acidic ranges based on the scale of (Tekalign Tadese, 1991) which is under optimum pH value (5-6) for barley growth and development (Table 1). Except one testing site, at Farta-Laie-Gainet district in 2020 (site 4), available phosphorus values were found medium range (5-15ppm) based on (Landon, 1991) nutrient rating scale (Table 1). While, soil OC and TN values found at moderate (1.5-3%) and high (0.12-0.25%) levels based on Tekalign Tadese (1991), respectively (Table 1). All CEC readings also found at high rating (25-40 Cmol$_{(+)}$ kg^{-1}) according to Landon (1991) and

(Hazelton P. and Murphy B., 2007). Based on the analyzed soil parameter values, we can see that all the testing sites had optimum growth media for food barley production.

Table 7.Selected soil properties for the experimental sites before planting

2020								
	Farta-Laie-Gainet				Yilmana Densa			
Parameters	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2		
pH (pH_2O)	5.7	5.4	5.4	5.5	5.1	5.2		
Ava P (ppm)	13.1	9.1	13	16.3	6.2	6.6		
OC (%)	2.017	1.78	1.782	1.91	1.879	1.408		
TN (%)	0.175	0.165	0.137	0.179	0.190	0.148		
CEC Cmol $_{(+)}$ kg ha^{-1}	31.6	31.5	39.4	36.7	30.2	36.3		
2021								
Parameters	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
pH (pH_2O)	5.1	5.7	5.4	5.1	5.1	5.3	5.5	5.3
Ava P (ppm)	12.2	13.6	14.5	13.7	6.2	5.1	7.4	9.4
OC (%)	1.548	2.321	1.287	1.349	1.87	1.50	1.24	0.897
TN (%)	0.169	0.183	0.167	0.165	0.12	0.115	0.12	0.151
CEC Cmol $_{(+)}$ kg ha^{-1}	26.7	30.1	33.6	29.6	29.2	29.7	36.7	29.3

Data collection and analysis

Agronomic data like plant height, spike length, harvest index (HI) and all biological yields (grain + above ground biomass) were collected at harvest. The grain yield was adjusted to 12.5% of moisture content. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). Least significant difference (LSD) was used for mean separation at 5% probability whenever there is difference between treatments. The partial budget analysis was done following CIMMYT (1988) procedure for the economic. The partial budget analysis was done based on the consideration of treatment combinations which were found in the two-years experimentation but not on the basis of the individual year treatment arrangement. For partial budget analysis fertilizer costs (urea and NPS) were taken as variable costs. While grain and straw yields considered as farmer gate price income. Based on this, 1kg barley grain, 1 t straw, 1 kg Urea and 1 kg NPS fertilizers were considered as 20 ETB, 1000 ETB, 14 ETB and 15 ETB, respectively.

Results and Discussion

Response of barley grain and biomass yields to nitrogen and phosphorus

In the two districts (Farta-Laie-Gainet and Yilmana Densa) both grain and biomass yields of food barley increased linearly as nitrogen level increased (Table 2-4) which is in line with the findings of Snežana *et al., (*2011) and Meharie and Kindie (2019). In addition to increasing trend of agronomic yields, both grain and biomass yields showed a highly significant difference ($p<0.0001$) among the treatment means due to nitrogen fertilization.

However, except at one site in Yilmana Densa district, application of phosphorus fertilizer didn't show statistically significant difference on both grain and biomass yields of food barley in this cropping season. Similarly, interaction effect of the two fertilizers (N and P) didn't show statistical significant response on food barley agronomic yields at both districts (Table 2-4). This might be showed that, all the phosphorus amounts used were above critical P-requirement for food barley production at each testing site. Therefore, the result subjected for a slightly treatment modification in the second year experimentation.

Table 8. Grain yield (kg ha^{-1}) response for NP at Farta-Laie-Gainet district in 2020

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
23	3037	2685	1394	2548	2416
46	3547	3328	1776	2668	2830
69	4092	3678	2154	3176	3275
92	4594	4052	2319	3236	3550
115	5151	4360	2712	3569	3948
LSD (0.05)	732	400	359	485	446
P level (N)	**	**	**	**	**
Phosphorus (P_2O_5)					
46	3928	3676	2077	3115	3199
69	3869	3474	1994	3010	3087
92	4456	3712	2141	2993	3326
LSD (0.05)	567	310	278	355	346
P level (P_2O_5)	NS	NS	NS	NS	NS
P level (N* P_2O_5)	NS	NS	NS	NS	NS
CV (%)	18.6	11.5	17.9	15.7	29.9

Table 9. Biomass yield (kg ha^{-1}) response for NP at Farta-Laie-Gainet district in 2020

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
23	8440	6795	3205	7650	6523
46	9701	8419	4252	7649	7505
69	11026	9081	5342	9402	8713
92	11560	10149	6090	9338	9284
115	13205	10983	6688	9893	10192
LSD (0.05)	2106	1180	893	1254	1223
P level	**	**	**	*	**
Phosphorus (P$_2$O$_5$)					
46	10372	9346	5090	8974	8446
69	10154	8782	4949	8756	8160
92	11833	9128	5308	8628	8724
LSD (0.05)	1632	914	692	972	948
P level	NS	NS	NS	NS	NS
P level (N*P)	NS	NS	NS	NS	NS
CV (%)	20.3	13.5	18.1	14.8	31.1

Table 10. Grain & biomass yields (kg ha^{-1}) response for NP at Yilmana Densa districts in 2020.

	Grain yield			Biomass yield		
N kg ha^{-1}	Site 1	Site 2	Combined	Site 1	Site 2	Combined
23	1127	1609	1368	3291	4402	3846
46	1515	1675	1595	4060	4615	4338
69	1754	2245	2000	4829	6068	5449
92	2246	2282	2264	5769	6368	6068
115	2670	2567	2619	6581	7265	6923
LSD (0.05)	344	342	267	747	990	672
P level	**	**	**	**	**	**
Phosphorus (P$_2$O$_5$)						
46	1678	2003	1841	4487	5513	5000
69	1772	2161	1967	4718	5923	5321
92	2137	2063	2100	5513	5795	5654
LSD (0.05)	266	265	207	578	767	520
P level	**	NS	*	**	NS	*
P level (N*P)	NS	NS	NS	NS	NS	NS
CV (%)	19.2	17.1	20.4	15.8	17.9	18.9

From second year experimentation, at Farta-Laie-Gainet district, the grain yield of food barley linearly increased as nitrogen level increased up to application of 115 N kg ha^{-1} at each testing sites (Table 5) which is in line with the findings of Meharie and Kindie (2019). Even though this trend showed liner increment, the increment is in a decreasing order. As shown in Table

5, grain yield of food barley showed highly significant response ($p<0.001$) among treatment means due to the applied nitrogen fertilizer at two testing sites (1 and 2) and combined of the district. However, application of phosphorus fertilizer didn't show statistical significant difference on grain yield of the test crop except at one testing site (site 4). Similar to the first year result, interaction effect of the two nutrient rates didn't show any statistical significant response on barley grain yield at all experimental sites. This shows that there is no need of phosphorus applications in the testing districts. However, phosphorus sources might be necessary as nutrient banks on the soil system and may be important to apply the minimum rate.

Table 11. Grain yield (kg ha^{-1}) response for NP at Farta-Laie-Gainet district in 2021

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
69	4555	2097	2530	2703	2971
92	4845	2463	3017	2872	3299
115	5473	2610	3092	2983	3540
138	5658	2914	2944	2979	3624
LSD (0.05)	489	343	766	381	498
P level	**	**	NS	NS	*
Phosphorus (P_2O_5)					
0	4787	2452	2786	2582	3152
23	5260	2642	3088	2793	3446
46	5196	2511	2921	3067	3424
69	5287	2480	2788	3095	3413
LSD (0.05)	489	343	766	381	498
P level	NS	NS	NS	*	NS
P level (N*P)	NS	NS	NS	NS	NS
CV (%)	11.4	16.4	31.8	15.9	36.8

Biomass yield of the testing crop showed an overall increasing trend even though some irregularities shown at site 3 and 4 testing sites (Table 6). Exception of one testing site (site 3), biomass yield of food barley also showed a significant difference among treatment means due to nitrogen fertilizer application. In contrast of nitrogen response, phosphorus fertilizer did show statistically significant difference only at one testing site (site 2) on biomass yield of food barley. As shown in the analyzed ANOVA (Table 6), combined biomass yield of food barley in the district didn't show any statistical significant difference among treatment means neither due to nitrogen nor phosphorus fertilizer application. Interaction effect of the two fertilizers also didn't show a significant difference on biomass yield of barley in the combined ANOVA result.

Table 12. Biomass yield (kg ha^{-1}) response for NP at Farta-Laie-Gainet district in 2021

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
69	9872	4311	5881	4055	6030
92	10289	5769	6410	5705	7043
115	10930	6202	6378	5673	7296
138	11795	5929	6811	5320	7464
LSD (0.05)	1545	845	1519	1133	1126
P level	NS	**	NS	*	NS
Phosphorus (P2O5)					
0	10096	5897	6218	4519	6683
23	11218	6058	6651	4808	7183
46	10449	5529	6282	5913	7043
69	11122	4728	6330	5513	6923
LSD (0.05)	1545	845	1519	1133	1126
P level	NS	*	NS	NS	NS
P level (N*P)	NS	**	NS	NS	NS
CV (%)	17.3	18.3	28.7	26.3	40.2

Similar to the first year, in Yilmana-Densa district, the grain yield of food barley linearly increased as the applied nitrogen fertilizer increased at each testing site (Table 7) which is in line with the findings of Meharie and Kindie (2019). The minimum and the maximum grain yield were recorded at the minimum and maximum nitrogen rates used, respectively. As shown in Table 7, the grain yield showed highly significant difference ($p<0.001$) among treatment means due to nitrogen fertilization at all testing sites which is similar with the findings of De. Ruiter (1999) and Sainju *et al,* (2013). As shown in the combined ANOVA result, grain yield of food barley also showed a statistical significant difference among treatment means due to nitrogen fertilization (Table 7).

In contrast to Farta-Laie-Gainet district and the first year result of Yilmana densa, grain yield of food barley showed high response for phosphorus fertilizer rate and recorded a highly significant difference ($p<0.0001$) among the treatment means. The mean difference observed was among the treatments received 0, 23 and 69 kg ha^{-1} phosphorus rates except in site 1 and 3. But similar to the first year result, there was no a statistical mean difference between the treatments that received 46 and 69 kg ha^{-1} phosphorus levels. However, including the combined analysis result, interaction effect of the two fertilizers still didn’t show any statistical significant difference on the grain yield of food barley at all testing sites similar to Farta-Laie-Gainet district.

Table 13. Grain yield (kg ha^{-1}) response for NP at Yilmana Densa district in 2021

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
69	2616	1861	1850	1855	2045
92	2931	2298	2081	2231	2385
115	3143	2602	2380	2225	2587
138	3275	2839	2704	2684	2876
LSD (0.05)	425	287	280	493	217
P level	*	**	**	*	**
Phosphorus (P_2O_5)					
0	2579	1876	2018	1729	2051
23	2975	2284	2192	1976	2357
46	3056	2722	2336	2612	2681
69	3355	2719	2469	2677	2805
LSD (0.05)	425	287	280	493	217
P level	**	**	*	**	**
P level (N*P)	NS	NS	NS	NS	NS
CV (%)	17.1	14.4	14.9	26.4	21.8

Similar to Farta-Laie-Gainet district, biomass yield of the testing crop in Yilmana-Densa district showed an overall increasing trend even though some irregularity shown at the two testing sites (site 1 and 2) (Table 8). But in contrast of the first district, the combined analysis result showed a significant difference among treatment means on biomass yield of food barley for both nitrogen and phosphorus fertilizer rates used. But similar to first year result, the interaction effect of the two fertilizers had no a statistical significant difference among the biomass yields (Table 8).

Table 14. Biomass yield (kg ha^{-1}) response for NP at Yilmana-Densa districts in 2021

N kg ha^{-1}	Site 1	Site 2	Site 3	Site 4	Combined
69	6314	3654	3878	4199	4511
92	6603	4744	4519	4615	5120
115	6378	6378	5321	4968	5761
138	7821	5417	6987	5833	6514
LSD (0.05)	1381	1207	1343	1538	717
P level	NS	**	**	NS	**
Phosphorus (P_2O_5)					
0	6314	4968	4872	3718	4968
23	6506	4744	4647	4679	5144
46	6859	5192	5481	5833	5841
69	7436	5289	5705	5385	5954
LSD (0.05)	1381	1207	1343	1538	717
P level	NS	NS	NS	*	*
P level (N*P)	NS	NS	NS	NS	NS
CV (%)	24.5	28.7	31.2	37.7	32.5

When we see the two year combined analysis results at each district, grain yield of food barley increased linearly as nitrogen fertilizer rate increased. That is the minimum and maximum grain yields recorded on the treatments which received minimum and maximum nitrogen levels, respectively. Similar to the separate year ANOVA result, nitrogen fertilization makes highly significant difference ($p<0.001$) among the treatment means of grain yield at each district. However, sole phosphorus and its interaction with nitrogen couldn't make any statistical significant difference on the grain yield of food barley at both districts (Table 9). It is important to remind for the readers, all the above statements in this paragraph wants to explain for the nitrogen and phosphorus rates which are found in the two-year experiment combination as nutrient levels but not considering the nutrient levels which was existed either of the two experimental year nutrient level combination.

Similar to grain yield, ANOVA of biomass yield showed an increasing trend without a turning point as the applied nitrogen rate increased. As shown in table 10, the two-year ANOVA result for biomass yield also showed a significant difference among the treatment means due to nitrogen fertilization. However, the sole phosphorus application and the interaction of the two fertilizers had no any significant response among the treatment means.

Table 15. Combined grain yield (kg ha^{-1}) values at the two study districts

	Yilmana Densa		Farta-Laie-Gainet		Combined over year	
N kg ha^{-1}	2020	2021	2020	2021	Yilmana Densa	Farta-Laie-Gainet
69	1993	2226	3216	2965	2148	3091
92	2161	2654	3571	3409	2490	3490
115	2474	2853	3850	3621	2726	3735
LSD (0.05)	338	316	528	677	246	419
P level	*	**	*	NS	**	**
Phosphorus (P_2O_5)						
46	2176	2539	3561	3376	2418	3468
69	2243	2616	3531	3287	2492	3409
LSD (0.05)	276	258	431	553	201	342
P level	NS	NS	NS	NS	NS	NS
P level (N*P)	NS	NS	NS	NS	NS	NS
CV (%)	18.4	21.3	25.8	35.3	21.5	30.2

Consistently non responsiveness phosphorus fertilizers on biological yields of food barley at the study districts may be due to high phosphorus nutrient accumulation in the soil system. The accumulation probably happens due to continuously phosphorus nutrient application as fertilizer sources for the last 50 and more than years. In fact, by its nature, lose of phosphorus nutrient from soil system is too low relative to nitrogen and other nutrients. This is why because most of our phosphorus soil data found from medium to high ranging. In contrast of this, whatever the nitrogen level is high or low in the natural soil, application of nitrogen in the form of fertilizer showed highly significant response on biological yields of barley. This may be indicated that, the amount of nitrogen level found in the natural soil is not fully available for plant nutrition during its growth period due to unjustified reasons.

Table 16. Combined biomass yield (kg ha^{-1}) values at the two study districts

	Yilmana Densa		Farta-Laie-Gainet		Combined over year	
N kg ha^{-1}	2020	2021	2020	2021	Yilmana Densa	Farta-Laie-Gainet
69	5353	4792	8590	6226	4979	7408
92	5833	5705	9263	6811	5748	8037
115	6571	6042	9968	7372	6218	8670
LSD (0.05)	864	1060	1442	1530	750	1139
P level	*	*	NS	NS	**	*
Phosphorus (P_2O_5)						
46	5748	5513	9327	6934	5591	8130
69	6090	5513	9220	6672	5705	7946
LSD (0.05)	705	867	1177	1249	612	930
P level	NS	NS	NS	NS	NS	NS
P level (N*P)	NS	NS	NS	NS	NS	NS
CV (%)	17.5	33.4	26.9	39.0	28.4	35.1

Partial budget analysis

All biological yields (grain + biomass) of food barley showed a highly significant difference ($p<0.0001$) between districts, which subjected us to analyzed the partial budgets for each district separately. Based on CIMMYT (1988) partial budget analysis principle as shown in Table 11 and 12, 115 kg N with 69 kg P_2O_5 and 115 kg N with 46 kg P_2O_5 ha^{-1} showed the highest net benefit values (55,012 and 76,342 Birr/ha) and takes as the first optimum economical profitable rates for Yilmana Densa and Farta-Laie-Gainet districts, respectively. The above combined fertilizer rates gave 224.7% and 81.7% yield advantages over the control (zero input) at Yilmana-Densa and Farta-Laie-Gainet districts, respectively. For Farta-Laie-Gainet district, the economical profitable recommended phosphorus rate in this study overlaid with the rate recommended by (AARC, 2002).

Table 17. Partial budget analysis for Yilmana Densa district

N kg ha^{-1}	P_2O_5 kg ha^{-1}	NPS kg ha^{-1}	Urea kg ha^{-1}	GY (kg ha^{-1})	STY (t ha^{-1})	GI	Urea cost	NPS cost	TVC	NB	Dominance
0	0	0	0	798	0.99	16942	0	0	0	16942	
69	46	121	100	2139	2.86	45640	1400	1816	3216	42424	
69	69	182	75	2158	2.80	45956	1050	2724	3774	42182	D
92	46	121	150	2487	3.37	53104	2100	1816	3916	49188	
92	69	182	125	2493	3.15	53004	1750	2724	4474	48531	D
115	46	121	200	2628	3.29	55851	2800	1816	4616	51235	
115	69	182	175	2825	3.69	60185	2450	2724	5174	55012	

N	P_2O_5	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	0	16942	
69	46	3216	42424	792
92	46	3916	49188	966
115	46	4616	51235	292
115	69	5174	55012	677

NB: 1kg grain=20 ETB, 1t straw=1000 ETB, 1kg Urea=14 ETB, 1kg NPS=15 ETB

Where: GY=grain yield, STY=straw yield, GI=gross income, TVC=total variable costs, NB=net benefits, MRR=marginal rate of return, ETB=Ethiopian birr

Table 18. Partial budget analysis for Farta-Laie-Gainet district

N kg ha^{-1}	P_2O_5 kg ha^{-1}	NPS kg ha^{-1}	Urea kg ha^{-1}	GY(kg ha^{-1})	STY (t/ha)	GI	urea cost	NPS cost	TVC	NB	Dominance
0	0	0	0	1965	2.72	42022	0	0	0	42022	
69	46	121	100	3058	4.34	65497	1400	1816	3216	62281	
69	69	182	75	3123	4.30	66766	1050	2724	3774	62993	
92	46	121	150	3536	4.92	75634	2100	1816	3916	71718	
92	69	182	125	3443	4.18	73045	1750	2724	4474	68571	D
115	46	121	200	3811	4.73	80958	2800	1816	4616	76342	
115	69	182	175	3659	5.14	78325	2450	2724	5174	73152	D

N	P_2O_5	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	0	42022	
69	46	3216	62281	630
69	69	3774	62993	128
92	46	3916	71718	6140
115	46	4616	76342	661

NB: 1kg grain=20 ETB, 1t straw=1000 ETB, 1kg Urea=14 ETB, 1kg NPS=15 ETB

Where: GY=grain yield, STY=straw yield, GI=gross income, TVC=total variable costs, NB=net benefits, MRR=marginal rate of return, ETB=Ethiopian birr

Conclusions and recommendations

In general, relative to Yilmana-Densa district, higher biological yields (grain + biomass) at Farta-Laie-Gainet district were observed. This made a confirmation of how much high altitude areas have a higher potential for barley production and productivity than low and mid land areas. From the two years experiment, application of N-fertilizer showed significant response on biological yields (grain + biomass) at both districts with linear increment. However, sole P and interaction of N and P fertilizers didn't show any significant change on biological yields (grain + biomass) of food barley among treatments at each district. Application of 115/69 and 115/46 N/P_2O_5 kg ha^{-1} showed the highest net benefit values (55,012 and 76,342 Birr/ha) and takes as the first optimum economical profitable rates with the yield advantages of 224.7% and 81.7% from the control (zero input) treatment at Yilmana-Densa and Farta-Laie-Gainet districts, respectively. From cumulative result, both grain and biomass yields of the food barley showed more response for the applied nitrogen fertilizer rather than the applied phosphorus fertilizer at each district. Therefore, we confidently recommended that anyone can be maximized the production of food barley by applying the above mentioned nutrient levels with the integration of other food barley production technologies.

References

AARC. (2002). Adet Agricultural Research Center. Progress Report of the period *2000/2001 and 2001/2002.* Adet, Ethiopia.

Adamu Molla, Amsal Tarekegn, Amanuel Gorfu, Yeshanew Ashagrie and Zewdu Yilma. (1993). Barley Research in Ethiopia: Past work and Future Prospects. Proceedings of the First Barley Research Review Workshop, 16-19 October 1993, Addis Abeba: IAR/ICARDA. Addis Abeba, Ethiopia. In IN: Hailu Gebre and Joop van Leur (eds) (Ed.), *Food barley Agronomy* (p. pp 68-84.).

Bremner, J. M. and C. S. Mulvaney. (1982). Nitrogen-total, In A. L. Page ed. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. *Agronomy 9. Madison, Wisconsin*. 595-624.

*Central Statistical Agency (*CSA*).* (2008). *Area and Production of Crop (Private Peasant Holdings, Meher Season). Statistical Bulletin 331.* Addis Ababa, Ethiopia.

Central Statistical Agency (CSA*).* (2011). *Agricultural sample survey report.* Addis Ababa, Ethiopia.

Central Statistical Agency (CSA*)*. (2016). Agricultural sample survey report on area and production of major crops. Addis Ababa, Ethiopia.

Central Statistical Agency (CSA). (2017). Agricultural sample survey. Report on area and production of major crops *(private peasant holdings, Meher season). Volume I, Statistical bulletin*. Addis Ababa, Ethiopia.

CIMMYT. (1988). From agronomic data to farmer recommendations. An economic training manual . *Compeletly revised Edition.* Mexico.

De Ruiter, J. M. (1999). Yield and quality of malting barley (Hordeum vulgare L. 'Valetta') in response to irrigation and nitrogen fertilisation. *New Zealand Journal of Crop and Horticultural Science*, *27*(4), 307–317. https://doi.org/10.1080/01140671.1999.9514110

Fana, P. (n.d.). Barley Response to Fertilizer Application in Ethiopia: *A Review. Proceeding*.

FAO. (2009). (Food and Agricultural Organization) http://apps. Fao.Org/faostat default.jsp. Access date: 16 Feb 2010.

FAO. Food and Agriculture Organization (2014). *Rome, Italy*.

Getahun, M. (2015). Characterisation of agricultural soils in cascape intervention woredas of Amhara region.

Gete Zelleke, Getachew Agegnehu, Dejene Abera and Shahidur R. (2010). Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. Retrieved from http://www.ifpri.org/publication/fertilizer-and-soil-fertility-potential-ethiopia

Hazelton P. and Murphy B. (2007). Interpreting soil test results: What do all the numbers *mean? (2nd Editio). CSIRO. 152.*

ICARDA. *(International Center for Agricultural Research in Dry Areas)* (2008).. Barley improvement production, Allepo, Syria.

Landon J.R. (1991). A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and sub Tropics. *Longman Scientific & Technical Publ., Harlon.*

Meharie Kassie and Kindie Tesfaye. (2019). Malting Barley Grain Quality and Yield Response to Nitrogen Fertilization in the Arsi Highlands of Ethiopia. *J. Crop Sci. Biotech, 2019*(10), 225–234.

Minale Liben, Alemayehu Assefa and Tilahun Tadesse. (2011). Grain yield and malting quality of barley in relation to nitrogen application at mid- and high altitude in Northwest Ethiopia.

Journal of Science and Development, *1*(1), 75–88.

Olsen, Sterling Robertson, C.V. Cole, F. S. W. and L. A. D. (1954). Estimation of available phosphorus in soils by extraction with sodium carbonate.

Sainju, U. M., Lenssen, A. W., & Barsotti, Joy L. (2013). Dryland malt barley yield and quality affected by tillage, cropping sequence, and nitrogen fertilization. *Agronomy Journal*, *105*(2), 329–340. https://doi.org/10.2134/agronj2012.0343

SAS Institute. (2002). A Business Unit of SAS. *SAS Institute Inc, Cary, NC. 2751. USA*.

Snežana J., Đorđe G., Radojka ., Sveto R., Nikola . and Ik. J. (2011). Effects of nitrogen fertilization on yield and grain quality in malting barley. *10*(84), 19534–19541. https://doi.org/10.5897/AJB11.2633

Taye Bekele, Yesuf Assen, Sahlemedhin Sertsu, Amanuel Gorfu, Mohammed Hassena, D.G. Tanner, Tesfaye Tesemma, and Takele Gebre. (2002). Optimizing fertilizer use in Ethiopia: Correlation of soil analysis with fertilizer response in Hetosa Wereda, Arsi Zone. Addis Ababa. *Sasakawa-Global, 2000*.

Tekalign Tadese. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. *Working Document* (No. (No. 13).). Addis Ababa, Ethiopia.

Vavilov. (1951). The Origin, Variation, Immunity and Breeding of Cultivated Plants. *Chronica Botanical*, *13*, 1–364.

Response of tef to nitrogen and phosphorous rates in Wag-Lasta areas of the Amhara Regional State, Ethiopia

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Abstract

Teff is one of the nutritious cereal crops grown in most agro-climatic zones in wag-last areas. The experiment was conducted to determine the optimum rates of nitrogen and phosphorous fertilizer for tef production in Sekota (Woleh) and Lasta-Lalibela (Medagie and Kechin-abeba) during 2019 and 2020 cropping seasons. A factorial experiment with four level of nitrogen (N) 0,46,69,92 kg ha-1 and three level of phosphorous (P2O5) 0, 23, 46 kg ha-1 arranged in randomized complete block design (RCBD) with three replications was used. Sources of N and P2O5 were Urea and triple super phosphate (TSP) respectively. The maximum grain yields of 1900.91 and 1755.36 kg ha-1 were obtained from 92 kg N ha-1 at Sekota and Lasta-Lalibela respectively while the minimum grain yield was recorded from the unfertilized plots. Applications of N fertilizer increased the grain yield from 786.56 kg ha-1 to 1900.91 kg ha-1 in Lasta-Lalibela and from 925.86 to 1755.36 kg ha-1 in Sekota. This showed that N fertilizer increase the grain yield by 141.66% in Lasta-Lalibela and by 89.59 % in Sekota districts. The cost benefit analysis also showed that combined application of 92 N and 23 P2O5 kg ha-1 is economically optimum rate for tef production in Sekota and Lasta-Lalibela.

Key words: Biomass, Grain yield, Nitrogen fertilizer, Phosphorous fertilizer Sekota, and Lalibela

Introduction

Tef *(Eragrostis tef)* is an important cereal crop grown in Ethiopia (Abeba., 2009). It is estimated to be grown by 6.3 million farmers every year in Ethiopia (Alemu *et al.*, 2016). 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 (CSA, 2013).

It has the highest share in Ethiopia for area of production. Out of the total grain crop area, 81.27% (10,219,443.46 hectare) was under cereals and the share of tef is about 24.11% (3,101,177.38 hectares). Cereals contributed 87.42% (about 25,384,723.96 ton) of the grain production of which tef contributes 17.11% (5,735,710.14 ton), the national average yield of tef is 1.85 t/ha. In Amhara National Regional State 1,156131.09 ha of land was covered by tef with the average productivity of 1.89 t/ha and its coverage in Waghimra and N/wollo zones was 27,603.46 ha and 71,227.59 ha respectively with average productivity of 1.01 t/ha at Waghimra 1.69t/ha N/Wollo (CSA, 2021).

Tef is grown under diverse agro-climatic zones. It grows from sea level to 2800 masl with rainfall of 750-850 mm and temperatures between 10 and 27^{o}C (Seyfu 1993). Moderately fertile clay and clay loam soils are ideal for tef. Interestingly, it can also withstand both water logged and drought conditions (Alemu *et al.*, 2016).

On nutritional value, the grain is basically utilized for preparing injera (favorite national dish of Ethiopians), and it is a staple food crop for millions of people. Nutritionally tef is comparable to other major cereals (wheat, rice, oats, maize, and sorghum) and it provides more of the daily dietary protein intake for most Ethiopians (Kebebew *et al.*, 2019). Unlike other cereals, the seeds of tef can be easily stored under local storage conditions without losing viability since the grains are resistant to attack by storage pests (Seyfu 1997). Its straw is used as fodder for cattle besides other household activities.

Regardless of its wider adaptation, nutritional value and economical use, productivity of tef is low in the country with the national average grain yield of 1.85 tons ha^{-1} (CSA,2021).This is mainly because of low soil fertility (Alemu *et al.*, 2016) and severe organic matter depletion (Getachew *et al*,. 2010) aggravated by low rate of chemical fertilizer application. The rate of chemical fertilizer application is low in the country due to unaffordable price for resource-poor smallholder farmers (Endale, 2016). Many scholars suggested that application of chemical fertilizer increase grain yield and related parameters. Many studies in Amhara Agriculture Research Institute revealed that most of the yield limiting nutrients were N and P. Amare *et al.*, (2021) stated that the yield limiting nutrient of maize was N followed by P. Addis et al (2018) also showed that the application of additional nutrients like S, K, Zn, and B do not have any yield advantage over the recommended NP fertilizer on grain yield of barley. Abebe et al., (2018) also stated that the application of blended fertilizer did not have any yield advantage over the recommended NP fertilizer. Similarly, Gizaw Desta et al., (2022) stated that grain yield of sorghum is increased on N and P fertilizer. Grain yield of tef was highly significantly affected by the main effect of NP fertilizer and the interaction of NP fertilizer and compost (Alemu *et al.*, 2016). According to Fissehaye et al., (2009), the highest grain yield of tef was recorded from plots that received the maximum NP nutrients. Getahun et al., (2018) also reported the maximum grain yield from the application of NP while the smallest grain yield was from the unfertilized plots.

Effective use of chemical fertilizer is one of the main solutions to ensure food security in short run. The current fertilizer application rate in Ethiopia is too low to improve production and ensure food security. Applications of 100 kg DAP and 50 kg urea ha^{-1} all over the Wag-Lasta irrespective of soil, crop types, and agro-ecological zones has resulted in wide gap between the potential and the actual crop yields. Hence, this research was conducted to determine the economically optimum rates of nitrogen and phosphorous for tef production in Wag–Lasta.

Materials and methods

Description of the study area

The study was conducted in Lasta-Lalibela (Medagie and Kechin abeba) and Sekota (Woleh) districts for two consecutive years of 2019 and 2020 rainy season. The site is situated at about 2061 at Woleh, 2208 at Medagie and 2204 at Kechin-Abeba m.a.s.l. respectively. These areas are usually referred as by undulated topography, uneven distribution and erratic rain fall, very shallow soil depth, high soil erosion, sloppy farming practice and scattered forest coverage. Soil erosion by water and low productivity are a serious problem in the study areas (Girmay et al., 2021). The major crops: - sorghum, tef, wheat, barley, maize, fababean, and check pea are grown in these districts. Sorghum is the leading crop (45.1% of area of cultivated cereals) followed by tef (20.6%), barley (19.1%), wheat (12.01%) and maize (2.18%) in Waghimra zone. Whereas

Tef is the leading crop (31.8% of area of cultivated cereals) followed by sorghum (25.3%), wheat (23.0%), barley (15.5%), and maize (3.4%) in north Wollo (CSA 2021). Intercropping and rotation of cereals with legumes are commonly practiced in those districts to improve soil fertility. The annual rainfall of Sekota districts is about 589.2 mm, with mean minimum and maximum temperatures of 12.7 and 26.7 °C, respectively whereas the annual rainfall of Lasta Lalibella districts is about 799.3 mm, with mean minimum and maximum temperatures of 11.8 and 27.4 °C, respectively (Kombolcha metrological station).

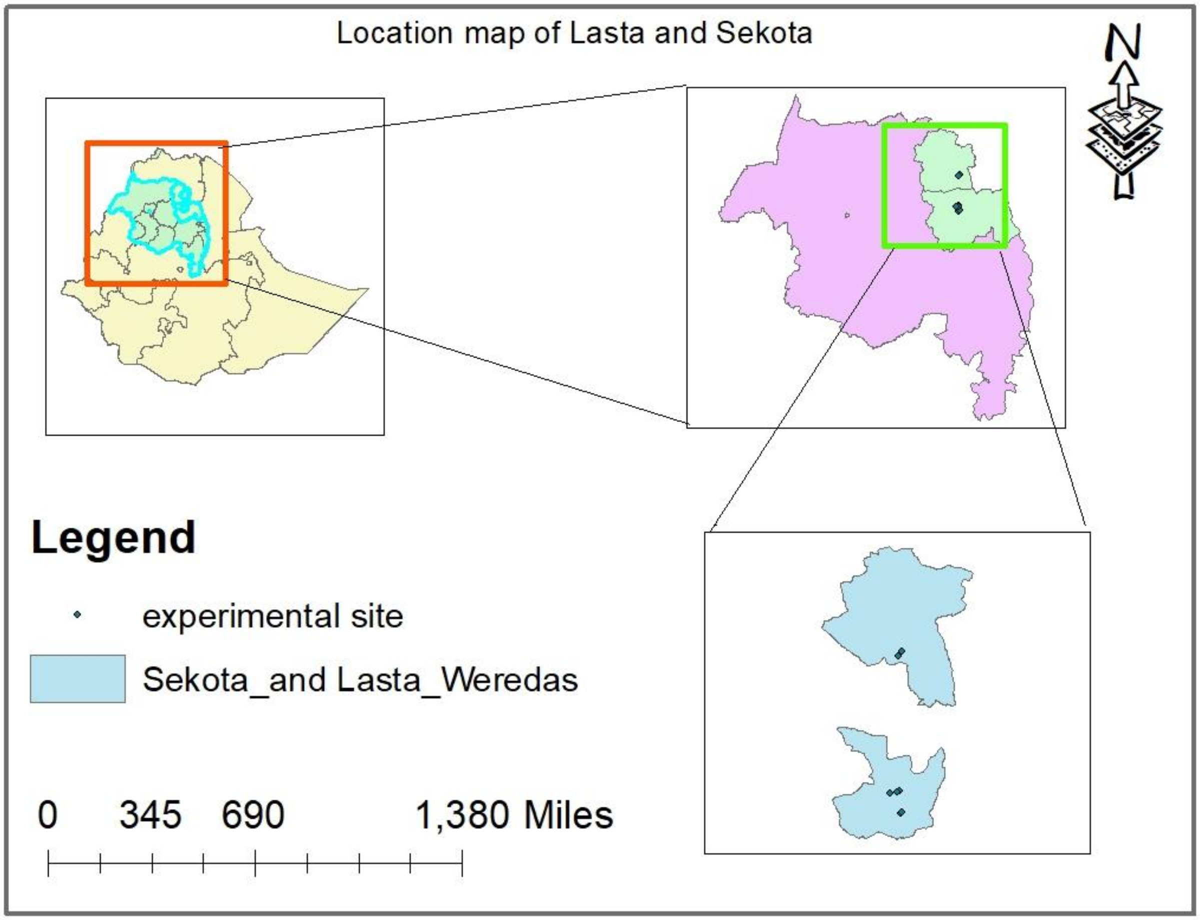

Figure 1. Location map of the study sites

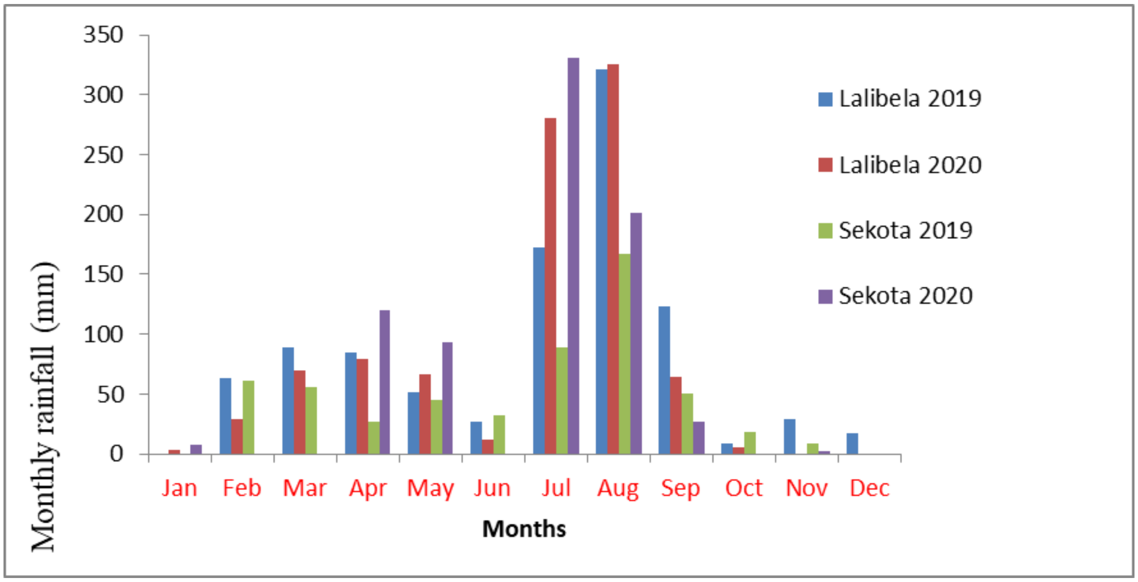

Figure 2. Monthly rain fall distribution at Sekota and Lalibela in 2019-2020

Treatments and experimental design

The experiment is conducted in eight farmers' land of which six farm from Lasta-Lalibela and two farms from Sekota. Four farm are in 2019 and the remaining four farms conducted in 2020.The treatments consisted of factorial combinations of four levels of N (0, 46, 69 and 92 kg N ha^{-1}) and three levels of P_2O_5 (0, 23 and 46 ha^{-1}) with total of 12 treatments. The experiment was laid out in a randomized complete block design (RCBD) with three replications on a plot size of 3m x 3m with the net plot size of 7.8m^2. The Source of N and P fertilizers were Urea and triple super phosphate (TSP) respectively. Application of urea was in two splits half at planting and half at vegetative, while the full rate of phosphorus was applied at sowing. Quncho variety was used as a test crop which is adapted to the agro-ecology with high yielding in the study area. The spacing between block, plot and row were 1m, 0.5m and 0.2m respectively.

Soil sampling, preprocessing and analysis

The representative composite soil samples were collected before planting to 0-20cm and subjected to analysis of texture, pH, organic carbon, total nitrogen, available P, and electrical conductivity (EC) following the standard procedure. The determination of particle-size distribution was done by using the hydrometer procedure (Sahlemedhin and Taye, 2000). Organic carbon was determined following the wet digestion method (Walkley and Black, 1934). Total nitrogen was analyzed by the Micro-Kjeldahl method (Horneck *et al*., 2011). The pH of the soil was determined using a 1:2.5 soil sample to water ratio using a digital pH meter (FAO, 2009), and available phosphorous was determined by Olsen's method (Olsen *et al*., 1954). The soil was analyzed at Sekota Dryland Agriculture Research Center soil laboratory.

Data collection

The biological data were collected from five representative plants per plot. That includes plant height (cm), panicle length (cm), while biomass (kg ha^{-1}) and grain yield (kg ha^{-1}) were collected from the net harvestable plots.

Partial Budget Analysis

The actual biomass and grain yield were adjusted down by 10%. The costs that vary among all the treatments were fertilizer cost. The partial budget analysis was done based on the procedure developed by CIMMYT (1988).

Data Analysis

Analysis of variance was carried out using R studio 1.4.1106. Whenever treatment effects were significant, the mean differences were separated using LSD test at a 5% level of significance.

Results and Discussion

Soil properties of experimental sites

The results of the laboratory analysis for some chemical properties of the experimental soil indicated that the soil pH (H2O) was range between 6.2 to 7.25 which were slightly acidic to neutral Tekalign (1991) and good for plant growth (FAO, 2000); the organic carbon content of the soil was in between 0.04% to 0.68% indicating that the SOC was very low to low range (Tekalign,1991) ; the total N amount vary between 0.01% to 0.03% classified as very low (Tekalign, 1991), the available P content of the experimental soil was also ranged from 14 to 45.6 ppm classified as high. The available p was just sufficient for plant growth (Olsen et al., 1954). The high available P might have occurred due to the continuous P fertilizer application. The electrical conductivity of soil at all experimental sites was also ranges from 0.03 to 0.16 ms/m grouped under normal, free from salt.

Table 1. Soil properties of experimental site at planting time

	Year 1				Year 2			
Soil parameter	Farm1	Farm2	Farm3	Farm4	Farm1	Farm2	Farm3	Farm4
pH	6.9	6.8	7.25	6.7	6.2	6.2	6.6	6.6
SOC%	0.35	0.37	0.04		0.62	0.66	0.59	0.68
TN (%)	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0.03
P(ppm)	27.02	45.6	22	14	38.03	43.94	22.05	21
EC(ms/m)	0.03	0.03	0.03	0.16	0.13	0.12	0.13	0.11

Effect of NP fertilizers on growth parameters

Plant height

Based on the analysis of variance the plant height was significantly affected ($p \leq 0.05$) by the main effect of N and P fertilizer application but not by their interactions. As the NP fertilizers increased the plant height was also increase in Lasta-Lalibela and Sekota districts' except P that did not show any significant effects on plant height in Sekota districts. The tallest plant (106.1cm and 98.8cm) were obtained from combine application of 69 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} respectively, while the lowest (77.5 cm and 95.9 cm) were from the control treatment in Lasta-Lalibela district (Table 4). But (69, 92) kg ha^{-1} N and (23, 46) kg ha^{-1} P_2O_5 did not bring significant difference. Similarly, in Sekota district the highest plant height was 108.5 cm at rate of 92 kg ha^{-1}, while 85.8 cm from unfertilized treatment. In this area application of P_2O_5 did not show any significant difference in plant height, but numerically103.3cm obtained from 46 kg ha^{-1} P_2O_5. Dereje *et al.*, (2018), Haftom et al. (2009) and Yared et al.,(2019) also reported that every increase in NP increase tef plant height.

Panicle length

Panicle length of tef was significantly ($P<0.05$) affected by the application of NP fertilizer. Every increase in NP fertilizer boosts the panicle length in both areas. In Lasta- Lalibela the highest panicle length was 43.7 recorded from the highest NP fertilizer, while the lowest (35.2 and 40.55cm) was from the control plots. Likewise, in sekota district the highest panicle length (43.7cm and 41.46cm) was recorded at the highest rate of N (92 N) and 46 P_2O_5 respectively the lowest panicle length was recorded from the control plots, (Table 4). This research was par with Giday, **(**2014**),** reported that an increase the nitrogen fertilizer from zero to 46 and 69 increase the panicle length significantly. In the same way Yared et al., (2019) and Alemu et al., (2016) reported that increased the panicle length with increased NP fertilizers.

Biomass yield

Based on the result biomass was also significantly ($P \leq 0.001$) affected by the main effect of nitrogen and phosphorous fertilizer but not by their interactions. Generally, application of N and P resulted in increased straw yields (Table 4). The highest biomass yield 6003.9 kg ha^{-1} and 4728.28 kg ha^{-1} was recorded from the application of 92 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} respectively at Lasta-Lalibela. In Sekota districts, application of 92 kg N ha^{-1} resulted in the highest biomass yield, but application of P did not show any yield advantage over the control. Application of N fertilizer leads to gain yield increment about 137% compared to the control in Lasta district. In Sekota district use of 92 kg ha^{-1} contributed 103.5% yield advantage over the control. The lowest (2530.64 and 2913.5kg ha^{-1}) biomass yield was recorded from the control treatment in Lasta-Lalibela and Sekota districts separately. This showed that NP fertilizers contributed in increasing biomass yield. The increased biomass 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 and the low to very level of nitrogen nutrient in soil (Table 1). It is in agreement with this finding,Temesgen (2012), Haftamu *et al*. (2009) and Mitiku (2008) who 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.

Effect of NP fertilizer on grain yield

The analysis of variance showed that grain yield of tef was significantly ($P \leq 0.05$) influenced by the main effect of N and P fertilizer rate in Lasta-Lalibela and the main effects of N in Sekota districts but without interaction effects. The maximum grain yields (1900.91 and 1755.36 kg ha-1) were obtained from application of 92 kg N ha^{-1} for Lasta-Lalibela and Sekota respectively. The minimum grain yield of tef was recorded from the unfertilized plots in both locations (Table 4&6). Applications of N fertilizer increase the grain yield from 786.56 kg ha^{-1} to 1900.91 kg ha^{-1} in Lasta-Lalibela and applications of N fertilizer increased the grain yield from 925.86 to 1755.36 kg ha^{-1} in Sekota. This showed that N fertilizer increase the grain yield by 141.66% in Lasta-Lalibela and by 89.59 % in Sekota districts. Application of nitrogen had more significant effect on grain yield of crop in both location this may be in case of the soil nitrogen content was too low to complete the full growth and get optimum grain yield. The increase in crop yields may be due to N fertilizer associated with increase in panicles length, Improvement in grain or seed weight. This research also par with Jabesa, and Abraham, (2016) an increase NP fertilizer also increased the grain yield of tef. Similarly, Alemu *et al*., (2016) indicated that NP fertilizer and compost rate increased the grain yield. In this experiment an increased N fertilizer from zero to 92 kg ha^{-1} increased the grain yield of tef, the increase of P_2O_5 from 23 to 46 showed a non-significant but decreasing trend. This activity was in lined with Dereje, (2018) application of P from 10 to 20 and 30 kg ha^{-1} decreased the grain yield of tef significantly. In contrary Abay *et al.*, (2011), reported increased N rate, decreased the grain yield and increased in P increased the grain yield. The P rate didn't have significant effect on in teff grain yield at Sekota. This might be attributed to the high content of the soil. This finding is supported by Abay *et al*., (2011) who reported application of any type of fertilizer did not show a yield advantage over unfertilized plot in Awassa.

Table 2. The main effects of N and P rates on plant height, panicle length, biomass and grain yield of tef in Lasta-Lalibela district at 2019.

Nitrogen	Farm 1				Farm 2				Farm 3			
rate (kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha-1)	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})
0	77.23^{c}	34.73^{c}	82.43^{b}	35.42^{b}	4183.00^{c}	1418.68^{c}	2035.30^{d}	698.61^{d}	70.53^{b}	35.98^{b}	2473.00^{d}	758.81^{d}
46	98.80^{b}	40.54^{b}	83.88^{ab}	37.66^{a}	5833.00^{b}	1996.39^{a}	4658.30^{c}	1423.32^{c}	102.96^{a}	42.09^{a}	5493.90^{c}	1901.85^{c}
69	104.82^{a}	43.25^{a}	83.03^{ab}	35.89^{ab}	6084.40^{b}	1946.47^{a}	5441.60^{b}	1576.50^{b}	103.54^{a}	42.90^{a}	6620.10^{b}	2198.49^{b}
92	106.85^{a}	43.90^{a}	86.26^{a}	36.99^{a}	6960.40^{a}	1781.72^{b}	6011.60^{a}	1725.08^{a}	103.43^{a}	43.13^{a}	7265.80^{a}	2403.09^{a}
LSD (5%)	2.71	1.36	3.61	1.94	291.39	94.54	318.52	92.25	2.27	1.89	366.96	109.11
P2O5 rates (kg ha^{-1})												
0	96.91^{ab}	40.05^{b}	83.76^{a}	36.13^{ab}	5827.80	1633.03^{b}	4551.30^{a}	1365.37^{ab}	92.31^{c}	40.21^{b}	5099.00^{b}	1678.37^{c}
23	95.49^{b}	40.16^{b}	83.03^{a}	35.81^{b}	5620.10	1823.41^{a}	4434.00^{a}	1311.01^{b}	95.31^{b}	40.98^{ab}	5787.70^{a}	1936.69^{a}
46	98.38^{a}	41.6^{a}	84.90^{a}	37.53^{a}	5847.80	1901.00^{a}	4624.80^{a}	1391.25^{a}	97.73^{a}	41.92^{a}	5502.80^{a}	1831.62^{b}
LSD (%)	2.35	1.18	Ns	1.67	Ns	81.88	275.84	79.89	1.97	1.64	317.8	94.49
CV (%)	2.88	3.43	4.45	5.45	5.45	5.19	7.21	6.99	2.45	4.74	6.90	6.17

*Means in a column with same letter are not significantly different at 5% probability level. Ns=not significant

Table 3. The effects of N and P rates on plant height, panicle length, biomass and grain yield of tef in Lasta-Lalibela district at 2020.

Nitrogen rate	Farm 1				Farm 2				Farm 3			
(kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})
0	87.10^{c}	39.07^{b}	2754.40^{d}	841.40^{d}	73.20^{c}	31.43^{b}	1705.20^{d}	608.80^{d}	70.40^{c}	31.47^{c}	2202.70^{c}	584.93^{c}
46	106.30^{b}	44.22^{a}	3689.20^{c}	1278.37^{c}	99.92^{b}	40.10^{a}	2930.00^{c}	920.24^{c}	97.72^{b}	39.52^{b}	4021.50^{b}	1181.28^{b}
69	114.30^{a}	44.80^{a}	5017.70^{b}	1823.40^{b}	104.73^{ab}	41.93^{a}	3452.40^{b}	1239.78^{b}	106.06^{a}	42.97^{a}	4912.80^{a}	1513.35^{a}
92	116.33^{a}	46.30^{a}	6111.10^{a}	2123.90^{a}	105.33^{a}	41.76^{a}	4987.70^{a}	1941.98^{a}	98.65^{b}	42.04^{a}	4865.90^{a}	1474.02^{a}
LSD (5%)	5.6	2.37	225.58	86.86	5.18	2.95	376.18	85.25	2.58	1.49	319	146.17
P2O5 rates (kg ha^{-1})												
0	105.07	43.90	4423.65	1394.83^{c}	92.44^{b}	37.85	3025.8^{b}	998.78^{b}	92.75	38.70	3932.30	1190.37
23	106.95	43.88	4382.29	1655.19^{a}	99.08^{a}	39.50	3658.1^{a}	1263.14^{a}	93.01	38.70	4153.90	1238.98
46	105.98	43.00	4373.38	1500.29^{b}	95.87^{ab}	39.07	3122.5^{b}	1271.18^{a}	93.86	39.60	3916	1135.84
LSD (%)	Ns	Ns	Ns	75.22	4.4	Ns	325.78	73.83	Ns	Ns	Ns	Ns
CV (%)	5.43	5.59	5.28	5.88	5.56	7.8	11.83	7.44	2.84	3.93	8.19	12.64

*Means in a column with same letter are not significantly different at 5% probability level. Ns=not significant

Table 4. The over year combined main effects of N and P fertilizer rates on plant height, panicle length, biomass and grain yield of tef in Lasta-Lalibela.

Nitrogen rate (kg ha^{-1})	PH (cm)	PL (cm)	BM (kg ha^{-1})	GY (kg ha^{-1})
0	77.5^{c}	35.2^{c}	2530.64^{d}	786.56^{d}
46	101.2^{b}	41.6^{b}	4552.85^{c}	1421.58^{c}
69	106.1^{a}	43.3^{a}	5352.20^{b}	1714.27^{b}
92	105.7^{a}	43.7^{a}	6003.90^{a}	1900.91^{a}
LSD (5%)	1.75	0.84	193.64	129.22
P$_2$O$_5$ rate (kg ha^{-1})				
0	95.9^{b}	40.55^{b}	4447.65^{b}	1367.85^{b}
23	98.1^{a}	40.80^{ab}	4728.28^{a}	1528.15^{a}
46	98.8^{a}	41.46^{a}	4653.24^{a}	1471.50^{ab}
LSD (5%)	1.52	0.73	167.70	111.90
CV (%)	4.73	5.40	11.05	23.58

*Means in a column with same letter are not significantly different at 5% probability level.

Table 5. The main effects of N and P fertilizer rates on plant height, panicle length, biomass and grain yield of tef in Sekota district at 2019 and 2020

Nitrogen rate (kg ha^{-1})	2019				2020			
	Farm 1				Farm 1			
	PH	PL	BM	GY	PH	PL	BM	GY
0	81.98^{c}	31.53^{c}	363.5^{c}	1162.94^{c}	89.82^{b}	38.44^{c}	2193.60^{d}	688.78^{c}
46	98.21^{b}	39.18^{ab}	5611.9^{b}	1786.05^{b}	115.51^{a}	45.13^{a}	4600.30^{c}	1279.56^{b}
69	97.03^{b}	38.58^{b}	5683.8^{b}	1862.84^{b}	114.70^{a}	45.53^{a}	5218.40^{b}	1265.59^{b}
92	101.37^{a}	40.53^{a}	6064.5^{a}	2022.15^{a}	116.13^{a}	46.42^{a}	5793.70^{a}	1488.59^{a}
LSD (5%)	2.91	1.68	368.38	92.53	3.21	1.90	316.61	59.43
P$_2$O$_5$ rates (kg ha^{-1})								
0	97.62^{a}	46.00^{a}	5727.70^{a}	1673.39^{b}	105.67^{c}	43.00^{b}	4012.90^{c}	1108.14^{b}
23	91.87^{c}	36.38^{b}	4965.80^{b}	1696.51^{ab}	109.05^{b}	43.75^{ab}	4507.40^{b}	1228.07^{a}
46	94.46^{b}	36.23^{b}	5051.70^{b}	1755.09^{a}	112.41^{a}	44.80^{a}	4834.10^{a}	1205.68^{a}
LSD (5%)	2.52	1.46	319.03	80.14	2.78	1.65	274.19	51.47
CV (%)	3.16	4.62	7.21	5.67	3.03	4.45	7.31	5.57

*Means in a column with same letter are not significantly different at 5% probability level.

Table 6. The over year combined main effects of N and P fertilizer rates on plant height, panicle length, biomass and grain yield of tef in Sekota district.

Nitrogen rate (kg ha^{-1})	PH	PL	BM	GY
0	85.90^{c}	34.99^{c}	2913.5^{c}	925.86^{b}
46	106.86^{ab}	42.15^{b}	5106.1^{b}	1532.81^{a}
69	105.86^{b}	42.02^{b}	5451.1^{b}	1564.21^{a}
92	108.75^{a}	43.47^{a}	5929.1^{a}	1755.37^{a}
LSD (5%)	2.55	1.27	366.58	218.91
P2O5 rate (kg ha^{-1})				
0	101.64^{ab}	39.73^{b}	4870.3	1390.76
23	100.45^{b}	39.98^{b}	4736.6	1462.29
46	103.43^{a}	42.25^{a}	4942.9	1480.63
LSD (5%)	2.12	1.13	Ns	Ns
CV (%)	3.75	4.7	11.31	21.92

*Means in a column with same letter are not significantly different at 5% probability level. Ns=not significant

Correlation analysis of agronomic parameters

Correlations among parameters are presented in Table 7. Grain yield of tef was significant and positively correlated with plant height (r=0.74**), panicle length (r=0.71**) and biomass yield (r=0.9**) in Lasta-Lalibela while only biomass was correlated (0.79**) at Sekota. This indicated that grain yield significantly increased with the increased in plant height, panicle length, and biomass yield. This was in line with the report of Bekalu and Arega (2016) who reported that grain and straw yields of tef were significantly and positively correlated with plant height and panicle length. Dereje (2018) also showed that grain yield significantly increased with the increased in plant height panicle length and biomass yield.

Table 7. Correlation analysis {Bibliography}between Tef agronomic parameters at lasta-Lalibela and sekota districts

	Lasta lalibela			
	Ph	pl	Bm	Gy
Ph	1			
Pl	0.86**	1		
Bm	0.68**	0.69**	1	
Gy	0.74**	0.71**	0.9**	1
	Sekota			
Ph	1			
Pl	0.89**	1		
Bm	0.53**	0.35*	1	
Gy	0.14ns	0.07ns	0.79**	1

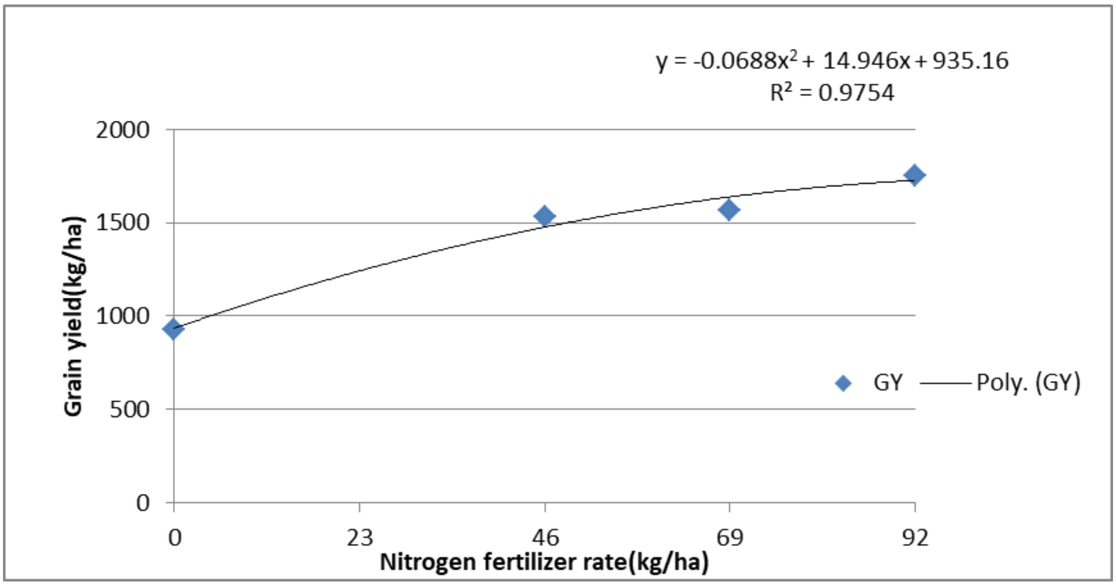

Fig 3. Regression and response curve of tef on N in Sekota districts

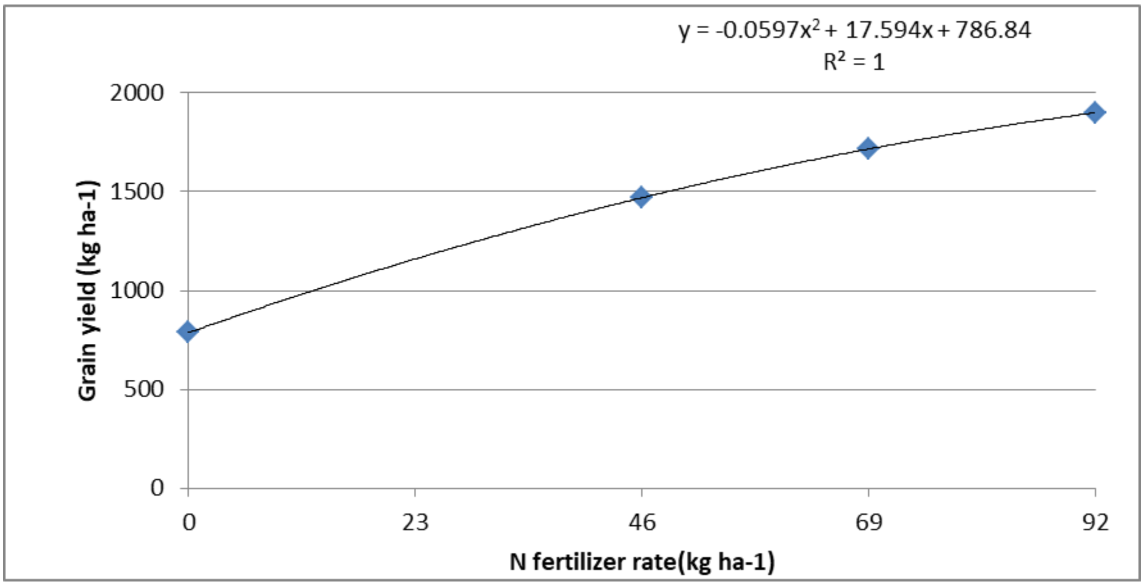

Fig 3. Regression and response curve of tef on N in Lasta -Lalibela districts

The response curve showed that the grain yield of tef to nitrogen fertilizer is still in increasing from 0 to 92 kg ha^{-1} in both Sekota and Lasta-Lalibela. The result showed that the increase of N fertilizer rate from lower to each fertilizer rates were increased the grain yield of tef.

Partial Budget Analysis

The partial budget analysis of the research showed that 92 kg ha^{-1} N earned the maximum net benefit in both locations. The highest net benefits were 73321.79 and 67796.53 ETB ha^{-1} with corresponding MRR of 919.88 and 883.75% in Lasta-Lalibela and Sekota districts respectively (Table 8&9).

Table 8. Partial budget analysis of N for tef production in Lasta-Lalibela

	Adjusted yield		Benefit					
Urea	SY	GY	SB	GB	TB	TVC	NB(ETB)	MRR (%)
0	1569.67	707.90	1883.60	29732.06	31615.67	0	31615.67	
46	2818.14	1279.42	3381.77	53735.87	57117.65	1482	55635.65	1620.78
69	3274.1	1542.84	3928.96	64799.46	68728.43	2223	66505.43	1466.90
92	3692.68	1710.82	4431.22	71854.57	76285.79	2964	73321.79	919.88

NB: SY, straw yield, GY,grain yield, SB straw benefit,GB,grain benefit, TB,total benefit, TVC ,total variable cost,NB, net benefit, MRR%, marginal rate of return

Table 9, Partial budget analysis of NP for tef production at Sekota district

	Adjusted yield		Benefit					
Urea	SY	GY	SB	GB	TB	TVC(ETB)	NB(ETB)	MRR (%)
0	1788.87	833.28	2146.65	34997.59	37144.24	0	37144.24	-
100	3215.96	1379.53	3859.16	57940.15	61799.3	1532.00	60267.30	1509.34
150	3498.36	1407.79	4197.84	59127.19	63325.03	2298.00	61027.03	99.18
200	3756.36	1579.83	4507.63	66352.90	70860.53	3064.00	67796.53	883.75

SY, straw yield (kg ha^{-1}) , GY,grain yield(kg ha^{-1}), SB straw benefit(kg ha^{-1}),GB,grain benefit(kg ha^{-1}), TB,total benefit (kg ha^{-1}), TVC ,total variable cost,NB, net benefit, MRR%, marginal rate of return

Conclusion and recommendation

Soil fertility problem is one of the yield limiting factors of crops. Optimum levels of fertilizer applications and sustaining soil fertility improvement can enhance higher crop productivity. The results showed that most of the agronomic parameters considered were significantly affected by NP fertilizers. The yield and yield components were significantly enhanced when N fertilizer rate increased from 0 to 92 kg ha^{-1} in both Lasta-Lalibela and Sekota. Whereas the lower yield and yield-related parameters were recorded from control (unfertilized) plot. Generally, from this work, it could be concluded that using 92 kg ha^{-1} N rate resulted in higher grain yield of tef in both locations. Based on the partial budget analysis, the first recommendation fertilizer rate at Lasta-Lalibela, and Sekota is 92 kg ha^{-1}N, and while the second recommendation is 69 kg ha^{-1} N in for both locations. Even if P did not show any significant effect on yield, it should be applied at the rate of 23 kg ha^{-1} as maintenance.

Reference

Abebe Tadesse & Gebreselassie (2009). Material Transfer Agreements on Teff and Vernonia-Ethiopian Plant Genetic Resources, (Note 6), 77-89.

Abebe Getu, Samuel Adissie, Tadesse Hailu, Seid Belay, Habtemariam Teshome and Abreham Teshager (2018). Evaluation of blended fertilizers and validation of soil fertility map-based fertilizer recommendations in Jamma and Werreillu Districts of South Wollo Zone, Amhara Region. Proceedings of the 11th Annual Regional Conference on Completed Research Activities of Soil and Water Management Research.

Abay Ayalew, Kelsa Kena and Tesfaye Dejene (2011) Application of NP Fertilizers for Better Production of Teff (Eragrostis tef (zucc.) trotter) on Different Types of Soils in Southern Ethiopia. Journal of Natural Sciences Research www.iiste.org ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online) Vol.1, No.1, 2011.

Alemu Assefa, Tamado Tana. and Jemal Abdulahi (2016). Effects of Compost and Inorganic NP Rates on Growth, Yield and Yield Components of Teff (Eragrotis teff (Zucc.) Trotter) in Girar Jarso District, Central Highland of Ethiopia. J Fertil Pestic 7: 174. doi:10.4172/2471-2728.1000174

Ayalew Addis, Baye Ayalew, Meron Lakew, Tamrat Worku and Melkamu Adane (2018). Comparative evaluation and validation of soil fertility map based fertilizer recommendation for bread wheat and food barley. 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

Bekalu Abebe and Arega Abebe. 2016. Effect of Seed Rate on Yield and Yield Components of Tef [(Eragrostic tef) Trotter] at Shebedino, Southern Ethiopia.Journal of Natural Sciences Research. www.iiste.org. Vol.6, No.21.

Berihun Sime, 2020. Response of Tef [Eragrostis tef (Zucc.) Trotter] Varieties to Different Rates of Nitrogen Fertilizer in East Gojjam, North West Ethiopia. North West Ethiopia (March 24, 2020).

Bodena Kumela Jabesa and Abraham Thomas (2016). Performance of yield attributes, yield and economics of teff (Eragrostis tef) influenced by various row spacing, nitrogen and phosphorus fertilizers. African Journal of Plant Science, 10(10), pp.234-237.

Chanyalew, Solomon, Setotaw Ferede, Tebkew Damte, Tsion Fikre, Yazachew Genet, Worku Kebede, Kidist Tolossa, Zerihun Tadele, and Kebebew Assefa. (2019). "Significance and prospects of an orphan crop tef." *Planta* **250**, 753–767 (2019). https://doi.org/10.1007/s00425-019-03209-z

CIMMYT Economics Program, International Maize and Wheat Improvement Center. (1988). From agronomic data to farmer recommendations: an economics training manual (No. 27). CIMMYT.

CSA. (2021). The federal democratic republic of Ethiopia central statistical agency report on area and production of major crops, i.

Getahun Dereje, Dereje Alemu,Tigist Adisu, and Bekele Anbessa. (2018). Response of yield and yield components of Tef [Eragrostis tef (Zucc.) Trotter] to optimum rates of nitrogen and phosphorus fertilizer rate application in Assosa Zone, Benishangul Gumuz Region. *Ethiopian Journal of Agricultural Sciences*, *28*(1), pp.81-94.

FAO. (2000). Fertilizers and Their Use. International Fertilizer Industry Association. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fissehaye Mirutse, Mitiku Haile, Fassil Kebede, Alemteshay Tsegay and Charles Yamoah. (2009). Response of Teff [(*Eragrostis teff*) Trotter] to Phosphorus and Nitrogen on Vertisols at North Ethiopia, 2(1), 8–14.

Getachew Agegnehu, Dejene Abera, Gete Zelleke and Shahid R. (2010). Fertilizer and Soil Fertility Potential in Ethiopia: Constraints and opportunities Fertilizer and Soil Fertility Potential in Ethiopia Constraints and opportunities for enhancing the system Private consultant to the International Food Policy Research Institute Ethiopian Institute of Agricultural Research Ethiopian Institute of Agricultural Research, (July).

Gizaw Desta, Tilahun Amede, Tadesse Gashaw, Gizachew Legesse, Getachew Agegnehu , Kindu Mekonnen and Anthony Whitbread. (2022). Sorghum yield response to NPKS and NPZn nutrients along sorghum-growing landscapes. Experimental Agriculture (2022), 1–16 doi:10.1017/S0014479722000072.

Haftamu Gebretsadik, Mitiku Haile, and Yamoah, C.F. (2009. Tillage frequency, soil compaction and N-fertilizer rate effects on yield of teff (Eragrostis tef (Zucc) Trotter) in central zone of Tigray, Northern Ethiopia. Momona Ethiopian journal of science, 1(1).

Kefyalew Endale. (2016). Fertilizer Consumption and Agricultural Productivity in Ethiopia February 2011 Fertilizer Consumption and Agricultural Productivity in Ethiopia Kefyalew Endale Ethiopian Development Research Institute, (February). http://doi.org/10.13140/RG.2.1.3450.6009.

Okubay Giday, Heluf Gibrekidan, and Tareke Berhe. (2014). Response of teff (Eragrostis tef) to different rates of slow release and conventional urea fertilizers in vertisols of southern tigray, Ethiopia. Advances in Plants & Agriculture Research, 1(5), pp.1-8.

Tadele Amare, Erkihun Alem, Zerfu Bazie, Asmare Woubet, Selamyihun Kidanu, Beamlaku Alemayehu, Abrham Awoke, Assefa Derebe, Tesfaye Feyisa, Lulseged Tamene, Bitewlgn Kerebh, Sefinew Wale and Aweke Mulualem. (2021). Yield-limiting plant nutrients for maize production in northwest Ethiopia. Experimental Agriculture (2022), 1–10 doi:10.1017/S0014479721000302

Temesgen Kebede. (2012). Response of tef [Eragrostis Tef (Zucc.) Trotter] cultivars to nitrogen and phosphorus fertilizer rates at Menzkeya District, North Shewa, Ethiopia (Doctoral dissertation, Haramaya University).

Yared Tesfaye, Girma Teshome and Kabna Asefa. (2019). Effects of Nitrogen and Phosphorus Fertilizers Rate on Yield and Yield Components of Tef at Adola District, Guji Zone, in Southern Ethiopia. American Journal of Agricultural Research, 2019, 4:57.

Response of of hot pepper (C*apsicum annum* L.) to urea and NPS fertilizers under irrigation at Abergelle, Waghimra, eastern Amhara

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Abstract

Hot pepper is one of the most important spice crops widely cultivated around the world. Due to nutrient deficiency and disease the productivity of hot pepper is very low as compared to the other country. Therefore, the experiment was conducted to investigate the response of green pod yield and yield component of hot pepper for urea and NPS fertilizers under irrigated condition. It was conducted during 2019 and 2020 irrigation season at Abergelle district of Wag-himra eastern Amhara Ethiopia consisting of four rates of urea (0, 100, 150 and 200 kg/ha urea) and three rates of NPS (0, 100, and 150kg/ha NPS) levels were used and laid out in randomized complete block design with three replications. Result of current study revealed that N and P_2O_5 *fertilizer had significant effect on plant height, number of pod number, pod weight and green pod yield of hot pepper. Highest green pod yield (13.86 t* ha^{-1}*) was obtained from combined application of 97.5* $kgha^{-1}$ *N and 57* $kgha^{-1}$ P_2O_5 *followed by (*12.98 *t* ha^{-1}) *was gained from 74.5* $kgha^{-1}$ *N and 57* $kgha^{-1}$ P_2O_5*. The cost benefit analysis also showed that application of 97.5 N and 57* P_2O_5 *is the first and followed by 74.5* $kgha^{-1}$ *N and 57* $kgha^{-1}$ P_2O_5 *second appropriate rates for optimum green pod pepper yield in Abergelle district of saka irrigation command area under irrigation season.*

Keywords: hot pepper, green pod, urea, NPS

Introduction

Hot pepper (capsicum annuumL.) belongs to genus Capsicum and family Solanaceae. It is one of the most important spice crops widely cultivated around the world for its pungent flavor and aroma (Ikeh *et al.,* 2012). Fine spicy powder of the hot pepper ('berbere') is an indispensable flavoring and coloring ingredient in the daily preparation of different types of Ethiopian sauces(wot), the green pod also consumed as a vegetable with other food items (MARC, 2004). In Ethiopia, the total production share of green pod pepper was estimated to be 7449.59 ha total production of 45853.7 ton with the average productivity of 6.2 ton ha^{-1}. In Amhara National Regional State, it covers 1331.46 ha with a total production of 8521.1 ton and the average productivity of 6.4 ton ha^{-1} and in Waghimra zone , the total area under hot pepper for the green pod (Karia) was 27.65 ha with a total production of 68.2 ton in the average productivity of 2.5 ton ha^{-1} (CSA, 2016). This shows that the productivity of pepper in Waghimra is much lower than both from the national and regional production.

The productivity of hot pepper is constrained by lack of proper nursery and field agronomic management practices; these are lack of adequate and balanced nutrient supply, diseases, poor aeration, and absence of high yielding cultivars. Amongst these, nutrient deficiency is the most yield-limiting factor in vegetable crop production in Ethiopia (Alemu and Ermias, 2000)**.** Many scholars reported that chemical fertilizers are the major nutrient sources to improve crop productivity (Tamene *et al.,* 2017).

Soil fertility decline (nutrient deficiency) is one of the most limiting factor for vegetable production including hot pepper in different agro-ecology of Ethiopia. The main limiting nutrients are N, P and other macro and micronutrients such as K, S, B and Zn scarcities (Alemu and Ermias, 2000). The key problem in achieving the first growth and transformation plan (GTP) of doubling up agricultural production by the end of the five years plan period was lack of soil fertility map and absence of site and crop-specific fertilizer recommendation (IFDC, 2015). Plant nutrients have a vital role in improving crop production and productivity on a sustainable basis; fertilizers are an effective source of plant nutrients. Accordingly, (Akram *et al.,* 2007, Gezahegn *et al*., 2020) the application of NP fertilizer can boost the production of hot pepper in their work the higher yield and yield related traits were high in higher rates of NP fertilizers. Knowing crop and site-specific recommendations of fertilizer are ideal for the production of hot pepper. Hence, this study was aimed to determine optimum and economical feasible urea and NPS fertilizer rates for sustainable production of hot pepper in Abergelle district of the Waghimra zone in eastern Amhara.

Materials and methods

Description of the study area

The study was conducted for two years during 2019 and 2020 in Saka, Abergelle district, Waghimra Administrative Zone of the Amhara Region, by irrigation. The area is characterized by undulated topography, very shallow soil depth, high soil erosion, and scattered forest coverage. The major crops on the main season were sorghum, sesame, pearlmilet and lowland pulses and in irrigation Onion, tomato, and hot pepper are the main dominance horticulture crops are grown in the district. Sorghum is the leading crop in the district. The trial sites of the two consecutive years are located with 1426417 N latitude 494322.5 E longitude with the altitude of 1313 m.a.s.l and 1426352.36 N latitude, 494288.57 E and 1316 m.a.s.l (fig. 1).The climate of the area is categorized by unimodal rainfall characteristics, and the rainfall pattern has a high amount of rainfall occurring during the main rainy season of July and August the study area indicates that the mean annual rainfall is 622.37 mm with erratic and uneven distribution over seasons and years. The mean minimum and maximum annual air temperatures of the area are 19.19°C and 36.08°C, respectively, with a mean annual air temperature of 24.54°C. The geology of the area also is characterized by a Precambrian basement unconformable overlain by a Paleozoic–Mesozoic sedimentary succession capped by Tertiary volcanics (Sembroni et al. 2017)

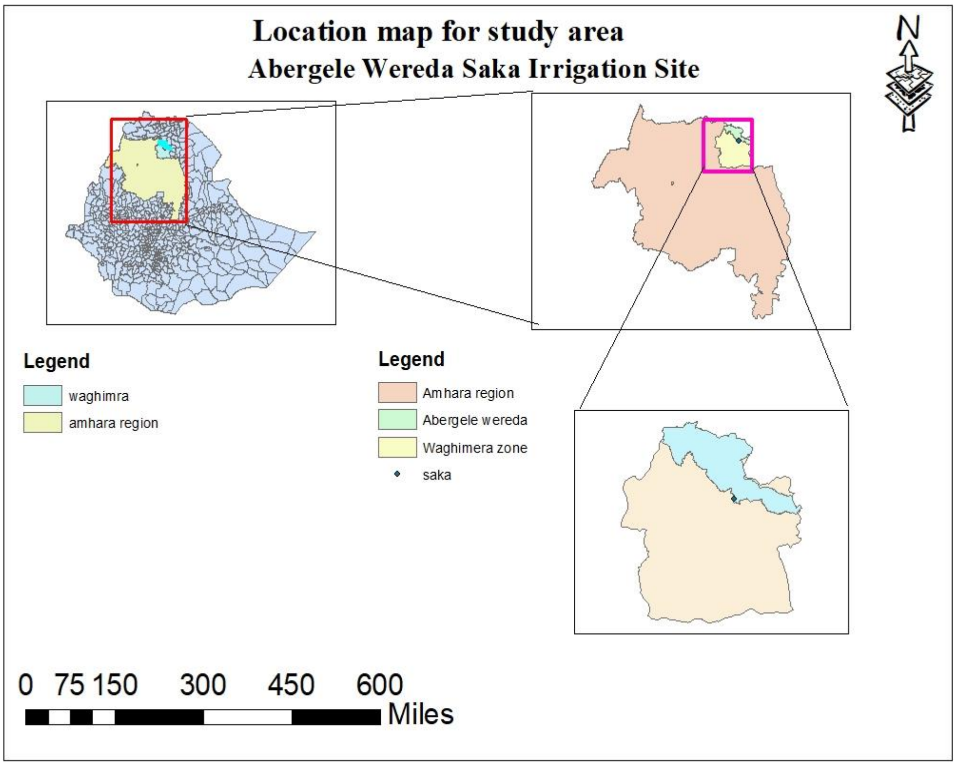

Figure 1. Location map of Abergele wereda and Saka irrigation scheme

Soil sampling, pre-processing and analysis

The representative composite soil samples were collected before planting from a depth of 0-20cm. It was sun dried under shadow, grinded and sieved for the analysis of texture, pH, organic matter, total nitrogen, and available P following with the standard procedure. The determination of particle-size distribution was done using the hydrometer procedure (Sahlemedhin and Taye, 2000). Organic carbon was determined by wet digestion method (Walkley and Black, 1934). Total nitrogen contents were analyzed by the Micro-Kjeldahl method (Horneck et al., 2011). The pH of the soil was determined using a 1:2.5 soil sample to water ratio using a digital pH meter (FAO, 2009), and Available phosphorous was determined by Olsen's method (Olsen et al., 1954).

Table 1**.** Properties of the soil at the experimental field

Soil properties	Values	Rating
pH (by 1:2.5 soil water ratio)	7.05	Neutral. (Murphy, 1968, and Tekalgn, 1991)
Total nitrogen (%)	0.01	Very low (Murphy, 1968 Tekalign, 1991 and Berhanu, 1980)
Available phosphorus(ppm)	0.84	Low. (Olsen *et al.* 1954)
Organic carbon (%)	1.05	Low (Murphy 1968, Tekalgn, 1991 and Berhanu 1980
Electrical conductivity(ms/cm	0.42	Low

Seedling management and transplanting

The seedlings were raised on a seedbed with 5 m length and 1 m width by hand drilling the seeds at the inter-row spacing of 15 cm and mulched with grass. After planting 3-4 leaf stages, healthy and vigorous seedlings were transplanted to the well managed and prepared farmland.

Design of the experiment and treatments

The experiment was organized in a randomized complete block design (RCBD) with three replications. The fertilizer levels were, four levels of urea (0,100,150.200), and three levels of NPS (0, 100,150) kg ha^{-1} arranged a factorial and have a total of 12 treatments (Table 2). Mareko Fana hot pepper variety was used as a test crop which is adapted to the agro-ecology and high yielder in the study area. The plot size of the experiment was 17.64 m^2 (4.2m wide and 4.2 m long), with the spacing of 0.5m and 1m between plots and blocks respectively and the spacing between plant and row was 0.3m and 0.7m respectively, which were six rows per plot and 14 plants per row with a total of 84 plants per plot. Data was collected from net harvestable 4 rows.

Table 2. Fertilizer amount in kg ha^{-1} applied to each treatment was

Treatment NO.	Treatment	N:P_2O_5:S
1	Urea 0+NPS 0	0:0:0
2	Urea 0+ NPS100	19 : 38:7
3	Urea 0+NPS150	28.5:57:10.5
4	Urea 100+NPS0	46:0:0
5	Urea 100+NPS100	65:38:7
6	Urea 100+NPS150	74.5:57:10.5
7	Urea 150+NPS0	69:0:0
8	Urea 150+NPS100	88:38:7
9	Urea 150+NPS150	97.5:57:10.5
10	Urea 200+NPS0	92:0:0
11	Urea 200+NPS100	111:38:7
12	Urea 200+NPS150	120.5:57:10.5

Data Collection

The agronomic data were collected from the representative samples. The collected parameters were growth parameters (plant height) and yield and yield component parameters (number of pods per plant, average pod weight (gm.), green pod yield (t ha^{-1}).

Partial Budget Analysis

To consolidate the analysis of variance (ANOVA) of the agronomic data, an economic analysis was used for every treatment. For economic valuation, cost and return, and benefit to cost ratio was calculated according to the procedure given by CIMMYT (1988). The actual green pod yield was adjusted down by 10% .The costs that vary among all the treatments was fertilizer cost. The economic analysis was done based on the formula developed by CIMMYT (1988). Treatments (dominance analysis) were carried out first by listing the treatments in order of increasing cost variation to identify the economically preferable treatment.

Data Analysis

Analysis of variance was carried out for the growth, yield, and yield components using R-software version 4.0.5. Whenever treatment effects were significant, the mean separation was done by Duncan multiple range tests (DMRT) at 5% level of significance.

Results and discussion

Table 3. Response of green pod yield, plant height. number of pod per plant, and pod weight of hot pepper to urea and NPS fertilizers in 2019 and 2020.

NPS rate	Urea rate (Kg/ha)			
	Green pod yield (kg ha^{-1})			
	Urea 0	Urea100	Urea150	Urea200
NPS 0 (0 P_2O_5)	6407^{e}	8867^{cde}	10274^{ab}	7960^{cde}
NPS 100 (38 P_2O_5)	7025^{e}	10978^{abc}	7813de	9143^{cde}
150 (57 P_2O_5)	7542de	12980^{ab}	13841^{a}	12176^{ab}
P level (0.05)	**			
CV (%)	24.28			
	Plant height(cm)			
NPS 0 (0 P_2O_5)	44.75^{f}	54.57^{e}	61.02^{bc}	57.97^{cd}
NPS 100 (38 P_2O_5)	50.23^{c}	63.27^{ab}	56.46^{cd}	63.87^{ab}
150 (57 P_2O_5)	58.4^{d}	63.9^{ab}	63.97^{ab}	65.98^{a}
P level (0.05)	**			
CV (%)	4.64			
	Number of pod per plant			
NPS 0 (0 P_2O_5)	15.48^{f}	20.57^{e}	19.47^{ef}	22.42^{de}
NPS 100 (38 P_2O_5)	21.69^{e}	29.47^{bc}	27.37^{bc}	31.20^{b}
150 (57 P_2O_5)	26.3^{cd}	35.97^{a}	29.47^{bc}	26.06^{cd}
P level (0.05)	**			
CV (%)	14			
	Average pod weight (g)			
NPS 0 (0 P_2O_5)	5.9^{e}	6.18^{e}	6.07^{e}	6.44^{e}
NPS 100 (38 P_2O_5)	7.29^{d}	8.14^{b}	6.41^{e}	7.26^{d}
150 (57 P_2O_5)	7.4^{cd}	8.4^{ab}	8.5^{a}	7.94^{bc}
P level (0.05)	**			
CV (%)	6.8			

*Means within a column sharing common letter(s) are not significantly different. NPS are Fertilizer that contains nitrogen, phosphorous and sulfur, Ns non significance, ** highly significant level (P= 0.05), CV (%) = Coefficient of variation in percent.

Response of Green pod yield to urea and NPS fertilizers

The current investigation revealed that the green pod yield was highly significantly ($P < 0.001$) affected by rates of nitrogen, phosphorus (Table 3). Based on the analysis, the highest total green pod yield (13.84 t ha^{-1}) was attained by the rate of (Urea 150 plus NPS 150) kg ha^{-1} followed by 12.98 t ha^{-1} (Urea100 with NPS 150) kg ha^{-1}. Whereas the lowest (6.41t ha^{-1}) was recorded form 0 kg ha^{-1}of urea and NPS. There is no significantly different from the rate of (100kg with 150 kg, 200kg with 150 kg, 150kg with 0kg, and 100 with 100) kg ha^{-1} urea and NPS respectively. The difference in green pod yield might be due to varying levels of fertilizer treatment and the nutrient status of the cultivated area. The application of 150 kg ha^{-1} urea and 150 kg ha^{-1} NPS increases the green pod yield by 7.45 t ha^{-1} or increased by 116% the over the control treatment. Research conducted in many parts of Ethiopia shows those applications N and P_2O_5 increase the dry pod of hot pepper (Tesfaw & Sadik, 2013, Gezaheg *et. al.,* 2020, Hintsa et.al. 2019, Wakuma et al., 2021).

In the contrary extra increases in applied fertilizers from 150 Urea and 150 NPS to 200 urea and 150 NPS kg ha^{-1} reduced green pod yield. This work is supported by Mebratu *et al*., (2014) further increases in applied nitrogen from 100 to 150 kg N ha^{-1} reduced marketable yield by about 42%. Similarly, Nimona *et.al.* (2018) stated that the more increases in applied fertilizers from 150 to 200 NPSBZn kg ha^{-1} reduced marketable pod yield. Likewise, Hintsa *et.al.* (2019) they reported that more increase NPS fertilizer decreases the marketable yield of hot pepper.

Response plant height for urea and NPS fertilizer

The application of urea and NPS fertilizer were highly significantly ($p < 0.001$) increase the plant height of the hot pepper as compared with unfertilized one (Table 3). The highest plant height was recorded at the rate of Urea 200+NPS 150 kg ha^{-1} about 65.98cm but not significantly different from (150+ 150, 100+ 150 , 200+ 100 , 100+ 100) kg ha^{-1} urea and NPS respectively, whereas 44.75 cm was the lowest plant height recorded from control plot. This implies the application of urea and NPS fertilizer can increase the plant height to 21.23 cm. This might be shows that the soil nutrient status of the experimental area is deficiency or low fertility levels. The nutrient NP used for cell division and elongation. Many scholars stated that application of N and P fertilizer increase the plant height of hot pepper (Ayodele, 2017). Kassa *et.al.* (2018) reported that the tallest and shortest plants were observed in plots that received high amount of NP fertilizer plus FYM and unfertilized plot, respectively.

Similarly, Fufa *et al*., (2018a) says that application of high rate of blended fertilizer increase the plant height of the hot pepper compared with the unfertilized plots. Gezahegn *et.al*. (2020) also reported that the highest plant height recorded from the plots they received maximum amounts of NP fertilizers.

Response of number of pod per plant and average pod weight on urea and NPS fertilizer

Application of urea and NPS fertilizer had highly significant (*P*=0.001) effect on the number of pod per plant and on average pod weight of hot pepper (Table 3). The highest number of pods was recorded as 35.97 at a rate of (Urea100 plus NPS 150) kg ha^{-1}, but not statically difference at a rate 200 with 100 kg ha^{-1} Urea and NPS correspondingly and the lowest pod number also recorded from unfertilized plot which were 15.48. This showed that urea and NPS fertilizer used for pod production. It was increased the pod number by 20.49 in number and 132.4%. Similarly, Mebratu et al., (2014) reported that Plants that received nitrogen at the rates of 50, 100, and 150 kg N ha^{-1} produced a higher number of pods and about 60, 133, and 152%, yield improvement over the unfertilized treatments respectively. Gezahegn Assefa *et al., (*2020), showed that the maximum number of pod recorded from the maximum NP treatment. The highest pod weight also observed from Urea 150 combined with NPS 150 about 8.5g, but non-significant with 100 with 150 kg ha^{-1} urea and NPS whereas the smallest pod weights recorded from control or unfertilized plot which was 5.9g.

Correlation of agronomic parameters

Green pod of hot pepper was significant and positively correlated with plant height (r=0.0.65**), NPPP (r=0.0.6**) and APW (r=0.58**) (Table 4). This indicates that every increases green pod yield with the increase in PH, NPPP, GP and APW of hot pepper. This work par with Gezahegn A *et.al.* (2020), and Munda & Shumbulo (2020), stated that an increase in dry fruit weight due to increase the fruit number per plant fruit weight and plant height of hot pepper.

Table 4; Correlation of PH, NPPP, GP and APW of hot pepper

Parameters	GP	PH	NPPP	APW
GP	1			
PH	0.65**	1		
NPPP	0.6**	.51**	1	
APW	0.58**	.59	0.47**	1

*PH implies plant height, NPPP, no of pod per plant, GP: green pod yield, APW: average pod weight, and *** very highly significance

Partial Budget Analysis

The partial budget analysis of the research showed that 150 with 150 kg ha^{-1} Urea and NPS earned the maximum net benefit of 493809 ETB ha^{-1} with MRR of 4083% and followed by 100 with 150 and 100 with 100 kg ha^{-1} Urea and NPS with a net benefit of 463554 and 392230 ETB respectively and MRR of 3240% and 3256.82% (Table 5).

Table5. Cost benefit analysis for the application of urea and NPS fertilizers rates on hot pepper production at Abergelle, Waghimra Eastern Amhara.

Urea	NPS	GPY	TVC	APY	GB	NB	MRR%
0	0	6407	0	5766.3	230652	230652	
100	0	8867	1482	7980.3	319212	317730	5875.71
0	100	7025	1496	6322.5	252900	251404	D
150	0	10274	2223	9246.6	369864	367641	6735.63
0	150	7542	2244	6787.8	271512	269268	D
200	0	7960	2964	7164	286560	283596	D
100	100	10978	2978	9880.2	395208	392230	3256.82
150	100	7813	3719	7031.7	281268	277549	D
100	150	12980	3726	11682	467280	463554	9535.29
200	100	9143	4460	8228.7	329148	324688	D
150	150	13841	4467	12456.9	498276	493809	4082.99
200	150	12176	5208	10958.4	438336	433128	D

*GPY =green pod yield, AGPY=adjusted green pod, GB gross benefit, TVC=total variable cost NB= net benefit MRR=marginal rate of return

Conclusion and Recommendation

Soil fertility problem is one of the yield limiting factors of crops, including hot pepper in Ethiopia. Optimum levels of fertilizer applications and sustaining soil fertility improvement can enhance for higher crop yields.

The results with our research showed that most of the agronomic parameters considered were highly significant affected by both N and P nutrients. Most of the yield and yield components were significantly enhanced when N and P_2O_5 fertilizer rate of 97.5 and 57 kg ha^{-1} respectively. Whereas the lower yield and yield-related parameters was recorded at control (unfertilized) plot. Generally, from this work, it could be concluded that using 97.5 and 57 kg ha^{-1} N and P_2O_5 fertilizer rate was the most appropriate rate on hot pepper green pod yields. Based on net benefit 493809 Eth birr followed by 463554 Eth birr could be achieved by the application of (150:150 and 100:150) kg ha^{-1} urea and NPS fertilizer level and their respective MRR% of this rate was 4083% and 9535.294% (Table 5). Therefore, the first appropriate fertilizer rate for hot pepper at Abergelle, Waghimra and similar agro-ecology to be 97.5 and 57 kg ha^{-1} N and P_2O_5, and the second most appropriate was also 74.5 and 57 kg ha^{-1} N and P_2O_5 fertilizer respectively. Additional research should be also conducted on yield limiting nutrient and times of nitrogen fertilizer application at different vegetative stages to enhance the productivity of hot pepper.

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References

Alemu, H. and Ermias, A., 2000. Horticultural crops production and associated constraints in Northwest Ethiopia. Working paper. Agricultural Economics Research Division. Agricultural Research Center, Adet. 18p.

Ayodele, O.J., Alabi, E.O. and Aluko, M., 2015. Nitrogen fertilizer effects on growth, yield and chemical composition of hot pepper (Rodo). *International Journal of Agriculture and Crop Sciences*, *8*(5), p.666.

Central Statisitics Agency (CSA), 2016. The federal democratic republic of ethiopia central statistical agency report on area and production of major, *Italy, Rome*.

CIMMYT Economics Program, International Maize and Wheat Improvement Center, 1988. From agronomic data to farmer recommendations: an economics training manual (No. 27). CIMMYT.

Fufa, N., Abera, G. and Etissa, E., 2019. Agronomic and economic performance of hot pepper (Capsicum annuum L.) in response to blended fertilizer supply at Asossa, Western Ethiopia. *International Journal of Plant & Soil Science*, pp.1-11.

Gezahegn Assefa, Sintayehu Girma, Dereje Deresa, 2020. Response of Hot Pepper (Capsicum annuum L.) as Affected by NP Fertilizer and Planting Method on Yield and Yield Related Traits in West Hararghe Zone, Eastern Ethiopia. American Journal of Bioscience. Vol. 8, No. 4, 2020, pp. 113-122. doi: 10.11648/j.ajbio.20200804.13

Hintsa Meresa, Fantay Belay, Atsbaha Gebreslase, and Kassa Melese (2019) Evaluation of NPS Fertilizer on Yield and Economic Performance of New Variety of Hot Pepper (Capsicaim Annum) in Tanqua Abergelle, Central Tigray, Ethiopia, Int. J. of. Life Science, Volume 7(2): 181-186.

International Fertilizer Development Center (IFDC) (2015). Assessment of Fertilizer consumption and use by Crop in Ethiopia. Available at: .Ethiopia-Final-Report-2016.pdf. http://www.africafertilizer.org/wp-content/uploads/2017/05/FUBC

Ikeh AO Ndaeyo NU Uduak IG Iwo GA Ugbe LA Udoh EI, Effiong GS (2012). Growth and yield responses of pepper (Capsicum Frutescens L.) To vary poultry manure rates in Uyo, Southeastern Nigeria. ARPN J. Agric. Biol. Sci. 7(9).

Sembroni, A., Molin, P., Dramis, F., & Abebe, B. (2017.). Geology of the Tekeze river basin (Northern Ethiopia). Journal of Maps, 13, 621–631. https://doi.org/10.108 0/17445647.2017.1351907

Obidiebube EA, Eruotor PG, Akparobi SO, Emosaariue SO, Achebe UA, Kator PE (2012). Response of four cultivars of pepper (Capsicum frutescens L.) to different levels of N, P and K fertilizer in rainforest Agro-ecological zone. Int. J. Agric. Sci. 2(12):1143-1150.

Nimona Fufa, Girma Abera and Edossa Etissa, 2018. Agronomic and Economic Performance of Hot Pepper (Capsicum annuum L.) in Response to Blended Fertilizer Supply at Asossa, Western Ethiopia. International Journal of Plant & Soil Science 26(2): 1-11. Article no.IJPSS.46132 ISSN: 2320-7035.

Munda Daniel & Shumbulo Abrham 2020 .Growth, Pod Yield and Quality of Hot Pepper (C ap sicum Annuum L.) as Affected by Variety and Rates of Nitrogen Fertilizer in Wolaita, Southern Ethiopia. Global Journal of Science Frontier Research: D Agriculture and Veterinary Volume 20 Issue 1 Version 1.0 .Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4626 & Print ISSN: 0975-5896.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean, 1954.Estimation of available phosphorus in soils by extraction with sodium carbonate. USDA Circular 939: 1-19.

Tamene, L., Amede, T., Kihara, J., Tibebe, D. and Schulz, S., 2017. A review of soil fertility management and crop response to fertilizer application in Ethiopia: Towards development of site-and context-specific fertilizer recommendation.

Tibebu Simon1 and Bizuayehu Tesfaye., 2014. Growth and productivity of hot pepper (Capsicum annuum l.) as affected by variety, nitrogen and phosphorous at Jinka, Southern Ethiopia.Research Journal of Agriculture and Environmental Management. Vol. 3(9), pp. 427-433. Available online at http://www.apexjournal.org ISSN 2315 - 8719© 2014 Apex Journal International.

Wakuma Biratu, Derbew Belew and Edossa Ettissa., 2021, Evaluation of hot pepper (Capsicum annuum L.) cultivars for growth and dry pod yields against different blended fertilizer and nitrogen rates in raya Azebo, Southern Tigray, International Journal of Research in Agronomy 2021; 4(2): 15-22

Response of bread wheat to different rates of nitrogen at Lasta and Sekota districts of Ethiopia

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Abstract

Depletion of soil nutrient is among the major factor that affects crop production and productivity in Ethiopia. From the nutrients, nitrogen is the most yield-limiting which governs bread wheat production. Therefore, the study was conducted to examine the effect of nitrogen on yield and yield components of bread wheat. The experiment was implemented in the 2019 and 2020 cropping seasons at Sekota and Lasta districts on the farmer's field. The treatments consist of a factorial combination of four levels of nitrogen 0, 46, 69, and 92 kg ha-1 and two varieties of wheat (Sekota-1 and Hibst) which were replicated three times in a randomized complete block design. The amount of phosphorous was 23 kg ha-1 P2O5 for all treatments. The results of the study indicated that grain and yield-related traits were significantly affected by nitrogen fertilizer. The increasing rate of nitrogen up to 92 and 69 kg ha-1 increases the grain and biomass yield of wheat at Sekota and Lasta districts respectively. The highest grain yield (2562.1 and 2980.25 kg ha-1) was obtained from the application of 92 and 69 kg ha-1 N at Sekota and Lasta respectively. Therefore, the application of 92 and 69 kg ha-1 N is the appropriate rate and recommended for Sekota and Lasta districts respectively.

Keywords: Nitrogen, Variety, Grain yield, Biomass yield

Introduction

Wheat (Triticum aestivum L.) is one of the major global cereal crops; ranking second after paddy rice both in area and production, and provides more nourishment than any other food crop (Curtis, 2002). Ethiopia is one of the largest wheat producers in sub-Saharan Africa (FAOSTAT, 2014) with an estimated area of 1 million hectares (ha) (CSA, 2000). Despite this large area coverage, the productivity of this crop is very low because of the high depletion of soil fertility, low levels of chemical fertilizer usage, limited knowledge on time and rate of fertilizer application, and the unavailability of other modern crop management inputs (Asnakew et al., 1991; Amsal et al., 1997). Especially nitrogen is often the most limiting nutrient for crop yield in many regions of the world. The increase in agricultural food production worldwide over the past four decades has been associated with a 7-fold increase in the use of N fertilizers (Hirel et al., 2007). Nitrogen is the most limiting nutrient for wheat production that affects rapid plant growth and improves grain yield. Many researches showed that nitrogen application increased grain yield and other parameters of wheat (Subedi et al., 2007; Asif et al. 2012; Bereket et al. 2014; Bekalu and Arega 2016; Abrham et al., 2020). Abedi et al. (2011) reported that higher grain yield (8230 kg ha^{-1}) was produced in a treatment receiving 240 kg N ha^{-1} than in control (3930 kg ha-1), 120 kg N ha^{-1} (4400 kg ha^{-1}), and 360 kg N ha^{-1} (6530 kg ha^{-1}). Research conducted in Tigray (Northern Ethiopia, by Belaynesh et al., (2017) indicated that increasing the rate of nitrogen increases the grain and biomass yield. Tilahun and Temado (2019) also reported that increasing the N level from 23 to 92 kg ha^{-1} significantly increased the grain yield of bread wheat. Similarly, Alemu et al (2019), reported that increasing N up to 96 kg ha^{-1} increased the grain and biomass yield of wheat. The above mention findings showed that the application of nitrogen fertilizer had a positive impact on the yield and yield component of Wheat. Despite, the positive response of nitrogen fertilizer on bread wheat production there are no research recommendations on nutrient management to enhance the productivity and profitability of wheat production in the study areas. Therefore, the objective of this experiment was to investigate the effect of N rates on yield and yield components of bread wheat and find economically appropriate rates of N fertilizer rates for the study area.

Materials and Methods

Description of the study area

The experiment was conducted for two consecutive years 2019 and 2020 in Sekota and Lasta districts of eastern Amhara Region, Ethiopia (Fig 1). The districts are located in Wag-himra and north Wollo zones of the Amhara regional State. These areas are usually referred as by undulated topography, uneven distribution and erratic rainfall, very shallow soil depth, high soil erosion, scattered forest coverage, and sloppy farming is commonly practicing. The major crops: - sorghum, tef, wheat, barley, maize, fababean, and check pea are grown in these districts. Sorghum is the leading crop (45.1% of the area of cultivated cereals) followed by tef (20.6%), barley (19.1%), wheat (12.01%), and maize (2.18%) in Wag-himra zone. Whereas Tef is the leading crop (31.8% of area of cultivated cereals) followed by sorghum (25.3%), wheat (23.0%), barley (15.5%), and maize (3.4%) in north Wollo (CSA 2021). Intercropping and rotation of cereals with legumes are commonly practiced in those districts to improve soil fertility.

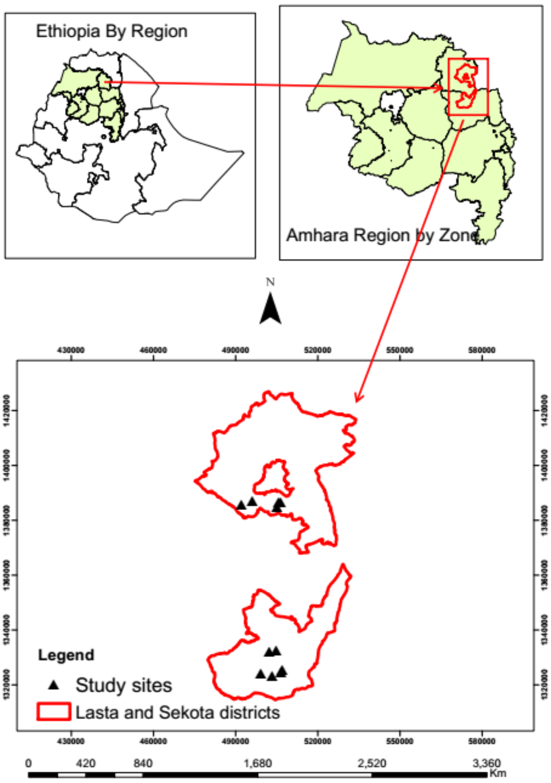
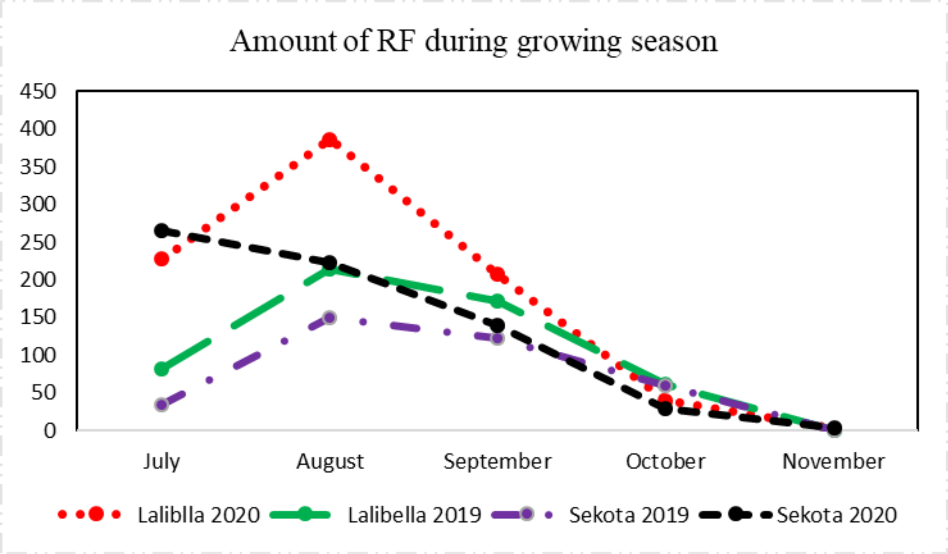
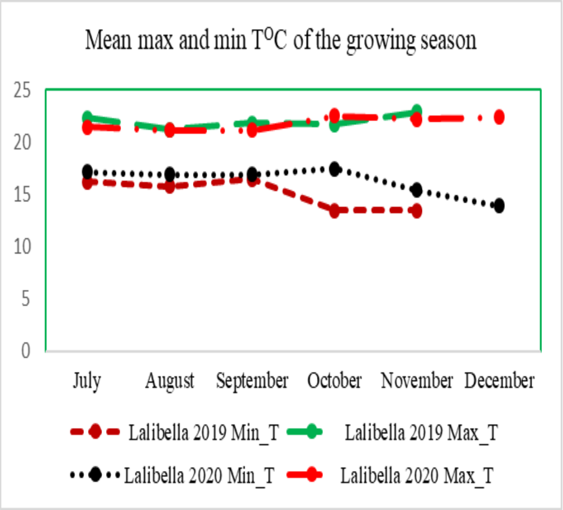


Fig 1: Map of study area

The maximum amount of rainfall during the growing season was 386.84 mm and 265.37 mm in August 2020 at Lalibela and July 2020 at Sekota districts respectively (Fig 2). Relatively the highest rainfall was recorded at Lasta district as compared with Sekota district (Fig 2). Whereas the mean minimum and maximum temperatures of the growing season were 16.01 and 26.51°C, respectively (NASA 2019 and 2020).





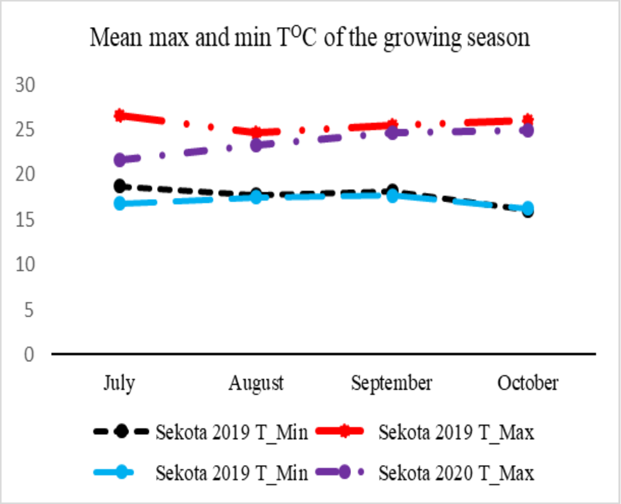


Fig 2: amount of rainfall, max and min temperature of during the growing season at Lasta and Sekota district

Treatment setup

The treatments were four levels of nitrogen 0, 46, 69, and 92 kg ha^{-1} and two varieties of bread wheat (Sekota-1 and Hibst) combined in factorial arrangement with randomized complete block design (RCBD). The amount of phosphorous used for all treatments was 23 kg ha^{-1} P2O5. The plot size was 3X3, and the distance between the plots and blocks (replications) was kept at 0.5 m and 1 m apart, respectively. Fertilizer sources used for the study were N in the form of urea [CO (NH2)2] (46% N) and phosphorus in the form of triple superphosphate (46% P2O5). Row planting with a spacing of 20cm between rows and a 125 kg ha-1 seed rate was used. Land preparation such as ploughing and weeding was carried out as per the recommendation for wheat crop production.

Data Collection

At crop maturity, five plants were randomly selected from the middle rows of each treatment for measuring the plant height, spike length, and seeds per spike. Grain and biomass yield were measured from the central thirteen rows of each experiment.

Prior to planting composite soil samples were collected from surface soil (0 - 20 cm) from the experimental sites for soil physicochemical analysis. 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 (1962). Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Carter and Gregorich 2008). The 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). The result of the soil analysis with their respective rating is presented in Table 1.

Table 1: soil analysis result

	Soil parameter								
Experimental sites	pH (1:2.5)	EC/ms	SOC %	Total N%	AvP ppm	Textural class %			
						Sand	Silt	clay	Class
Site 1	6.6	0.14	0.88	0.017	17.6	43	31	26	loam
Site 2	6.7	0.21	0.8	0.031	32.45	53	25	22	Sandy clay loam
Site 3	6.7	0.16	0.68	0.021	14.65	33	35	32	Clay loam
Site 4	7.8	0.049	0.3	0.0042	25.4	52	13	35	Sandy clay
Site 5	6.9	0.022	0.31	0.0014	34.69	77	13	10	Sandy loam
Site 6	8.2	0.033	0.38	0.0013	21.3	72	17	11	Sandy loam
Site 7	7.3	0.035	0.42	0.0014	17.45	60	23.2	16.8	Sandy loam
Rating	Sl acidic to mo alkaline	Non-saline	Low to very low	very low	High				
Source	Tekalign (1991)	Hazelton & Murphy (2007)	Tekalign (1991)	Tekalign (1991)	Olsen 1954	USDA			

Sl=slightly, mo= moderately, SOC soil organic carbon, Avai P=available phosphorous

Partial budget Analysis

The cost of fertilizer (15.56 and 14.6 ETB kg^{-1}) and wheat grain price of 30 ETB kg^{-1} was used for the partial budget analysis for Lasta and Sekota districts. The marginal rate of return was calculated as a change of benefit divided by a change in total cost that varies as described by CIMMYT (1988). The grain yield was adjusted downwards by 10 % of the actual yield to reflect the difference between the experimental yield and the yield of farmers.

Data analysis

Analyses of variances for recorded data were done using SAS software to determine the relationship between yield and yield components due to application of N fertilizer rates and variety. Least significant difference (LSD) test at 5% probability was used for mean separation when the analysis of variance indicated the presence of significant differences.

Results and discussion

Anova for Lasta and Sekota areas

The results of combined analysis over years on the effects of N application, variety and their interactions are presented in (table 2). Nitrogen levels were significantly ($p < 0.01$) affected plant height, spike length, seed per spike, biomass yield, grain yield and thousand seed weight of bread wheat at all location. Furthermore, seed per spike and grain yield were affected by variety at Lasta and Sekota whereas biomass yield and thousand seed weight were significantly affected by varieties at Sekota district only.

Table 2: the mean square values main and interaction effects of nitrogen and variety on yield and yield component of bread wheat

		Mean Square					
Source of Variation	DF	Lasta district					
		PH cm	SL cm	SP	BY kg ha^{-1}	GY kg ha^{-1}	TSW
N	3	1054.99^{**}	30.95^{**}	1344.63^{**}	66916201.7^{**}	17113197.15^{**}	20.51^{ns}
V	1	7.91^{ns}	0.04^{ns}	595.01^{**}	2857802.6^{ns}	1059404.79^{**}	11.15^{ns}
Rep	2	10.88^{ns}	1.52^{ns}	45.82^{ns}	703538.3^{ns}	24635.45^{ns}	0.56^{ns}
N*V	3	110.81^{*}	2.38^{*}	74.61^{ns}	5164855.6^{ns}	483261.23^{**}	3.47^{ns}
Error	71	30.65	0.72	80.50	2166306.8	39601.51	10.95
		Sekota district					
N	3	301.59^{**}	3.71^{**}	90.82^{*}	25573503.72^{**}	3613358.56^{**}	0.13^{ns}
V	1	49.66^{ns}	0.23^{ns}	640.56^{**}	17572739.46^{**}	1690073.89^{**}	19.88^{*}
Rep	2	5.39^{ns}	1.43^{ns}	20.83^{ns}	20481.82^{ns}	6148.41^{ns}	1.17^{ns}
N*V	3	39.10^{ns}	1.91^{ns}	8.92^{ns}	4450875.33^{*}	405407.65^{*}	3.49^{ns}
Error	71	16.29	0.70	25.58	1310771.5	139733.03	4.53

PH= plant height, SL=spike length, SP= seed per spike, BY=biomass yield, GY= grain yield, TSW=thousand seed weight

Effects of nitrogen on yield components of bread wheat

Application of nitrogen was significantly affected the growth parameters of bread wheat at Lasta and Sekota districts. The increasing rate of nitrogen up to 92 kg ha^{-1} increases the plant height, spike length and seed per spike of wheat but, statistically similar with the plant height, spike length and seed per spike obtained at N rate of 69 kg N ha^{-1}. The highest plant height (76.6 and 75.12 cm) was obtained from application 92 kg ha^{-1} N and the lowest plant heights (62.41 and 67.30 cm) were recorded from control treatment from Lasta and Sekota districts respectively (Table 3). By applying nitrogen, the plant height was increased by 22.74 and

11.62% as compared with control. This increment with application of nitrogen might be due to the fact that N is the essential constituent of proteins; it is involved in all the major processes of plant development and yield formation. A good supply of nitrogen for the plant is also important for the uptake of the other nutrients (Bell, 2016). The current result is similar with finding of Bereket *et al.* (2014) who reported that by applying nitrogen up 92 kg ha^{-1} the plant height was increased by 17.44%.

The highest spike length (7.98 and 7.79 cm) and maximum seed per spike (42 and 46) were recorded from application of 92 and 69 kg ha^{-1} N at Lasta and Sekota districts respectively, which were statistically at par with application of both fertilizer rate (69 and 92 N kg ha^{-1}). Spike length and seed per spike were significantly increased with increasing nitrogen rate. Study conducted by Bekalu and Arega (2016) in southern Ethiopia showed that by applying N at rate of 69 kg ha^{-1} gave the highest spike length. Similar results were also reported by Hameed *et al.,* (2002) who said that increasing rate of nitrogen increases the spike length of bread wheat. Seed per spike was significantly affected by variety at Sekota and Lasta district. High number of seed per spike was recorded from Hibst variety and the lowest was recorded from Sekota 1.

Effects of nitrogen on grain and biomass yield of bread wheat

The result showed that application of nitrogen had a significant effect on the grain and biomass yield of bread wheat in the tested districts. The increasing rate of nitrogen increased the grain yield of bread wheat in the two districts ((Table 3&4)). The highest grain yield (2980.25 and 2562.1 kg ha^{-1}) were obtained from the application of 69 and 92 N kg ha^{-1} which was statistically similar with the grain yield obtained at N rates of 92 and 69 kg N ha^{-1} at Lasta and Sekota respectively, whereas the lowest was obtained from the control treatment. By applying 69-92 kg ha^{-1} nitrogen the grain yield was increased by 150.29 and 54.05% as compared to the control at Lasta and Sekota districts respectively.

Table 3: effects of nitrogen and variety on growth and yield of wheat at Lasta district

Treatment N kg ha^{-1}	PH cm	SL cm	Seed/spike	BY kg ha^{-1}	GY kg ha^{-1}	TSW g
0	62.41^{c}	5.44^{c}	25.85^{b}	3751.7^{c}	1190.71^{c}	37.61^{b}
46	72.99^{b}	7.29^{b}	40.38^{a}	5548.9^{b}	2210.22^{b}	39.38^{ab}
69	76.21^{a}	7.65^{ab}	41.55^{a}	7349.3^{a}	2980.25^{a}	39.59^{a}
92	76.60^{a}	7.98^{a}	40.40^{a}	7138.8^{a}	2965.75^{a}	39.39^{ab}
LSD	3.18^{**}	0.48^{**}	5.16^{**}	847.19^{**}	114.55^{**}	1.90^{*}
Variety						
Sekota-1	71.76	7.11	34.55^{b}	6119.7	2441.78^{a}	39.34
Hibst	72.34	7.07	39.53^{a}	5774.7	2231.68^{b}	38.65
LSD (5%)	ns	ns	3.65^{*}	ns	80.99^{**}	ns
CV (%)	7.68	11.99	24.21	24.21	8.51	8.48

PH= plant height, SL=spike length, BY=biomass yield, GY= grain yield, TSW=thousand seed weight

Table 4: effects of nitrogen and variety on growth and yield of wheat at Sekota district

Treatment N kg ha $^{-1}$	PH cm	SL cm	Seed/spike	BY kgha^{-1}	GY kgha^{-1}	TSW g
0	67.30^{b}	6.91^{b}	41.49^{b}	4166.1^{c}	1663.2^{c}	34.07
46	73.28^{a}	7.36^{ab}	43.88^{ab}	5537.3^{b}	2297.6^{b}	34.11
69	74.28^{a}	7.68^{a}	46.19^{a}	5745.5^{b}	2356.4^{ab}	34.24
92	75.12^{a}	7.79^{a}	44.45^{a}	6665.7^{a}	2562.1^{a}	34.19
LSD (5%)	2.32^{**}	0.48^{*}	2.91^{*}	659^{**}	215.17^{*}	ns
Variety						
Sekota-1	71.77	7.38	41.42^{b}	5956.5^{a}	2352.51^{a}	33.70^{b}
Hibst	73.21	7.48	46.59^{a}	5100.8^{b}	2087.14^{b}	34.61^{a}
LSD (5%)	ns	ns	2.05*	465.98^{**}	152.14^{*}	0.86^{*}
CV (%)	5.56	11.26	11.49	20.70	16.83	6.23

PH= plant height, SL=spike length, BY=biomass yield, GY= grain yield, TSW=thousand seed weight

The increase in grain yield of the wheat with increasing N rates might be due to the role of N in increasing the leaf area and promoting photosynthesis efficiency. This again promoted dry matter production and increase yield; which showed N is crucial as a constituent of all proteins and is essential for the growth of plants (Johnston et al., 1994). A study conducted by Belaynesh *et al.*, (2017) in northern Ethiopia (Enderta areas) showed that increasing the rate of nitrogen application up to 69 kg ha^{-1} N significantly increased the grain yields of the wheat by 159 %. Belete *et al.*, (2018) reported that increasing the rate of nitrogen up to 120 kg ha^{-1} increases the yield by 220.53%. Similarly, Bekalu and Arega (2016) reported that the application of nitrogen at a rate of 69 kg ha^{-1} had increased the grain yield of wheat by 64.80%. Concomitant with the results of this study, higher grain yields in response to increased application of nitrogen fertilizer were also reported by (Haile et al 2012, Bereket *et al.,* 2014, Belete *et al.,2018,* Tilahun and Temado 2019).

The rate of N fertilizer application was significantly affected the biomass yield of bread wheat in both districts (Table 3&4). The highest total biomass (7349.3 and 6662.1 kg ha^{-1}) was obtained from application 69 and 92 kg ha^{-1} N at Lasta and Sekota districts whereas the lowest (3751.7 and 4166.1 kg ha^{-1}) was found from the control treatment. By application of nitrogen, the total biomass yield was increased to 95.89 and 59.91%. Similar results were reported by Bekalu and Arega (2016) by applying N at a rate of 69 kg ha^{-1}. These authors reported that the biomass yield was increased by 33.6 %. Belaynesh *et al.,* (2017) also reported that increasing the rate of nitrogen up to 69 kg ha^{-1} increased the biomass yield of wheat by 341.84%. The current study is in line with the findings of Hameed *et al.,* (2002), Abebe (2012), Bereket *et al*., (2014).

Sekota-1 bread wheat variety gave a higher yield than Hibst in both districts. Nitrogen fertilizer significantly affected the grain yield of Sekota 1 wheat variety than Hibst which indicated Sekota 1 bread wheat variety was more responsive to nitrogen fertilizer than Hibst. Thus, the grain yield of this variety Sekota 1 exceeded that of Hibst by 9.41 and 12.71% at Lasta and Sekota districts respectively.

Partial budget analysis

Table 5 partial budget analysis for Lasta and Sekota districts

(N levels)	Unadjusted yield	Adjusted yield	Gross benefit	Costs that vary	Net Benefit	MMR
			Lasta district			
0	1190.71	1071.639	32149.17	0	32149.17	0
46	2210.22	1989.198	59675.94	1556	58119.94	1669
69	2980.25	2682.225	80466.75	2334	78132.75	2572
92	2965.75	2669.175	80075.25	3112	76963.25	D
			Sekota district			
0	1663.2	1496.88	41912.64	0	41912.64	0
46	2297.6	2067.84	57899.52	1460	56439.52	994.99
69	2356.4	2120.76	59381.28	2190	57191.28	102.98
92	2562.1	2305.89	64564.92	2920	61644.92	610.08

For a treatment to be considered as advisable to farmers, between 50 and 100% marginal rate of return (MRR) is the minimum acceptable rate of return (CIMMYT 1988). The partial budget analysis showed that the highest net benefit of 78132.75 Birr ha^{-1} and 61644.92 Birr ha^{-1} with the highest MRR was obtained from the treatment that received 69 and 92 kg N ha^{-1} (Table 5) at Lasta and Sekota districts respectively. The next higher net benefit 57191.28 with MRR % 102.98 was recorded for the treatment with 69 kg N ha^{-1} at Sekota district. Therefore, the application of 69 and 92 N ha^{-1} is profitable and recommended for farmers in Lasta and Sekota areas as the first option respectively and 69 kg N ha^{-1} is the second option at Sekota and other areas with similar agro-ecological conditions.

Conclusion and recommendation

For sustainable crop production, appropriate fertilization application based on actual limiting nutrients is a very important task for farmers to boost the production and productivity of bread wheat. This study shows that the application of nitrogen can improve the yield and yield components of bread wheat in the study areas. Among the rates of nitrogen, 92 and 69 kg ha^{-1} were identified to be the most economical optimum rates of nitrogen fertilizer for bread wheat production at Sekota and Lasta districts. Therefore, 92 and 69 kg ha^{-1} is the appropriate rate for maximum yield of wheat at Sekota and Lasta districts and are recommended for these and similar areas and soil types respectively.

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References

Abebe Getu. 2012. Soil characterization and evaluation of slow release urea fertilizer rates on yield components and grain yields of wheat and tef on Vertisols of Jamma district of south Wollo zone, Amhara region. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

A.E. Johnston, The role of nitrogen in crop production and losses of nitrate by leaching from agricultural soil, Marine Pollution Bulletin, Volume 29, Issues 6–12, 1994, Pages 414-419, ISSN 0025-326X, https://doi.org/10.1016/0025-326X(94)90664-5.

Abedi, T., A. Alemzadeh, and S.A. Kazemeini. 2011. Wheat yield and grain protein response to nitrogen amount and timing. Australian Journal of Crop Science 5:330-336.

Alemu D,. Belete K, Shimbir T (2019). Response of Wheat (Triticum aestivum L.) to different

rates of nitrogen and phosphorus at Fiche-Salale, highlands of Ethiopia. International Journal of Plant Breeding and Crop Science 6(1): 474-480.

Amsal Tarekegn, D.G. Tanner, Amanuel Gorfu, Tilahun Geleta and Zedu Yilma. 1997. The effects of several crop management factors on bread wheat yields in the Ethiopian Highlands. Africa Crop Sci. J. 5: 161-174.

Asif, M., A. Ali, M.E. Safdar, M. Maqsood, S. Hussain, and M. Arif. 2009. Growth and yield of wheat as influenced by different levels of irrigation and nitrogen. International Journal of Agriculture and Applied Sciences 1:25-28.

Asnakew W., Tarekegn M., Mengesha B., Tefera A., Soil fertility management studies and wheat in Ethiopia. In: Hailu Gebre-Mariam, D.G. Tanner and Mengistu Hulluka (Eds.), Wheat Research in Ethiopia. A Historical Perspective, IAR, CIMMYT, Addis Ababa, Ethiopia, 1991, 112-144Bell, C. 2016. The importance of nitrogen for plant health and productivity. Growcentia: Mammoth.

Belete F., Dechassa N., Molla A., 2018. Effects of split application of different nitrogen rates on productivity and nitrogen use efficiency of bread wheat. Agric and food secur 7, 92

Bekalu A,. and Abebe, A., 2016. Effect of the time and rate of N-fertilizer application on growth and yield of wheat (triticum aestivum l.) at Gamo-Gofa Zone, Southern Ethiopia. *Journal of Natural Sciences Research*, *6*(11), pp.111-122.

Bereket H., Dawit H., Haileselassie M., Gebremeskel G., Effect of Mineral Nitrogen and Phosphorus Fertilizers on Yield and Nutrient Utilization of Bread Wheat on the Sandy Soils of Hawzen District, Northern Ethiopia, Agriculture, Forestry and Fisheries, 2014, 3(3), 189-198

Bremner JM, Mulvaney C (1982) Nitrogen total methods of soil analysis. Part 2. Chemical and microbiological properties. Soil Science Society of America, Madison, pp 595–624

Belayenesh Z., Nigussie D., Fetien A., Yield and Nutrient Use Efficiency of Bread Wheat (*Triticum Aestivum* L.) as Influenced by Time and Rate of Nitrogen Application in Enderta, Tigray, Northern Ethiopia Open Agriculture. 2017; 2: 611–624

Bouyoucos GJ (1962) Hydrometer method improvement for making particle size analysis of soils. Agron J 54:179–186

Carter MR, Gregorich EG (2008) Soil Sampling and Methods of Analysis. Taylor & Francis Group, LLC, Boca Raton, Canadian Society of Soil Science

CIMMYT (International Maize and Wheat Improvement center) (1988) An Economic Training Manual: from agronomic data recordation. CYMMT. Mexico.pp. 79.

CSA (Central Statistics Agency). Report on area and production of major crops. Volume.5, Statistical Bulletin, Addis Ababa, 2021

Curtis, B.C. (2002) Wheat in the World. In: Curtis, B.C., Rajaram, S. and Macpherson, H.G., Eds., *Bread wheat improvement and production, plant production and protection Series* 30, FAO, Roma, 1-18.

FAOSTAT (FAO Statistical Databases) 2014. Agricultural production statistics. http://www.fao.org/faostat.

Haile D, Nigussie-Dechassa R, Abdo W and F Girma, 2012. Seeding rate and genotype effects on agronomic performance and grain protein content of durum wheat (*triticum turgidum* l. var. *durum*) in south eastern Ethiopia. African Journals of food, Agriculture, nutrition and development. Vol.12, No.3, 6080- 6094 (2012).

Hameed E.,Wajid A,. Shad F. and Jahan B., Yield and yield components of wheat as affected by different planting dates, seed rate and N levels Asian journal of plant science Vol1 no5 pp 502-506

Hazelton P., Murphy B., Interpreting soil test results: what do all the numbers mean? Csiro Publishing, Collingwood VIC, 2007

Hirel B, J Le Gouis, B Ney, and A Gallais. 2007. The challenge of improving nitrogen use efficiency in crop plants: toward a more central role for genetic variability and quantitative genetics within integrated approaches. *Journal of Experimental Botany* 58(9): 2369-2387.

POWER Data Access Viewer 2019 and 2020 solar and meteorological **data** sets https://power.larc.nasa.gov/data-access-viewer/ Accessed 26 Dec 2022

Olsen.S.R., Cole. C.V., Watanabe.F. S. and Dean,L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939: 1- 19.

Subedi, K.D., B.L. Ma, and A.G. Xue. 2007. Planting date and nitrogen effects on grain yield and protein content of spring wheat. Crop Science 47:36-44.

Tekalign T (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Tilahun. A. and Tana, T., 2019. Growth, yield component and yield response of durum wheat (Triticum turgidum L. Var. Durum) to blended NPS fertilizer supplemented with N rates at Arsi Negelle, Central Ethiopia. *African Journal of Plant Science*, *13*(1), pp.9-20.

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38

Quantifying optimum lime requirements to increase the productivity of potato (*Solanum tubersum* L.) in West Amhara, Ethiopia

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Abstract

*A field study was conducted to determine the optimum rate of lime for potato production at Banja and Machakel. The experiment comprising twelve levels of lime rates (0%, 11.1%,12.5%,14.3%,16.7%,20%,25%,33.3%,50%,75%,100%,125%) with common 138N and 69*P_2O_5 *laid out in randomized complete block design (*RCBD) *with three replications. The study showed that the application of different rates of lime was not significantly affected the yield of Potato. But the Application of 14.3% lime rate at Banja gives 6.41 and 4.51tha*$^{-1}$ *tuber yield advantage over the control at year one site one and year two and site two(Y1S1&Y2S2) respectively. Similarly, the application of 20% lime at Machakel provides 4.04, 1.13, and 0.94 tuber yields than the control treatment at Y1S1, Y2S1&Y2S2 respectively. On the contrary, soil properties changed by the application of lime. This might be due to the reclamation activity of lime through the substitution of aluminum (Al+3) and (H+1) with (CaCO3) on soil exchangeable site that makes the formation of aluminum hydroxide and water than free hydrogen and aluminum. Based on this finding the application of minimum lime rate 14.3% at Banja and 20% at Machakel is important for acid reclamation with recommended fertilizer (138N, 69P2O5) for potato production. But for concrete recommendation we suggest further research on lime residual effect and time of application with the different lime requirement calculation methods.*

Key Words: Potato, lime, soil Physico-chemical properties

Introduction

Potato was one of the major strategic crops to the United Nation's Millennium Development Goals of achieving food security and eradicating poverty. Moreover, 2008 was recognized as the year of potato by the United Nations. Its contribution to food security with a stable price might be continued as price of potato mainly depends on local demand and supply than global trade. It is a short cycle and early maturing additional advantages of double cropping and crop intensification than other crops that take longer days for maturity. Ethiopia has a vast potential to increase the production and productivity of potato, especially in the highlands (Gebremehdin *et al.,* 2012; Haverkot *et al.,* 2012). About 70% of the cultivated land in Ethiopia is suitable for potato production (FAO, 2008) but only 2% of the potential has been used (Adane *et al.*, 2015). About 40% of potato producers in the country are in the South Gonder, North Gonder, East Gojam, West Gojam, and Agew Awi zones of the Amhara region (Adane *et al*., 2015) where the Adet Agricultural Research center is mandated for this potential. Potato is the fourth crop globally in terms of production and area coverage. It also ranks first among root and tuber crops in Ethiopia (CSA, 2016). Potato is cheap and nutritive food security crop, because of its high production per unit area and time with good nutritive values than other major cereal crops. However, the productivity of potato in Ethiopia is below 10 tons per hectare (Adane *et al*., 2015; Asresie *et al*., 2015; Haverkort *et al*, 2012).

On the contrary, Gebremehdin *et al.*, 2012 indicated that released potato varieties have high yielding potentials of up to 54 tons/ha in Ethiopia under farm conditions. Furthermore, Haverkot *et al*., (2012) reported up to 64 tons/ha around Shashemene area. We also recently assured that the achievable potentials of potato with nutrient management (Gudene variety) are above 40tons/ha (unpublished data). Soil fertility is one of the factors that limit agricultural productivity in Ethiopia including potato (Adane *et al*., 2012; Degefu and Mengistu, 2017; Tadele *et al*., 2018). Then can further improve the productivity of potato through acid soil management? Soil acidity is one of the challenges of crop production in the high rainfall areas of the country where potato is the staple crop (Getachew *et al.*,2021). About 30% of the world's total land area consists of acid soils (< pH 5.5), and as much as 50% of the world's potentially arable lands are acidic (Kochian *et al*., 2004). Due to Transportation costs and labor intensiveness, farmers are not interested to apply fully calculated lime rate at once on their farmland. However, Birhanu *et al*., (2016), reported that 25% of the lime calculated based on the exchangeable acidity applied in row at planting gave an equivalent bread wheat yield with a full dose. Hence, based on this finding, wider demonstration activities were conducted on the row application of lime by Adet Agricultural

Research Center and was successful with the production of wheat in areas where it has been out of production (Asmamaw *et al*., 2020). This result has been scaled up to end users (farmers) that are getting a high rate of acceptance. This method significantly reduces the amount of lime which has a problem for the adoption of the lime technology by the farmers. Due to the large area coverage of acid soils in Ethiopia, it is also difficult for the government to supply the total lime required. That is why using only 25% by row application at planting is the best approach to increase the rate of adoption and productivity of crops. Accordingly, the question of other crops to develop the rate of lime with row application at planting has been requested by the stakeholders including the bureau of agriculture. The recommendation given for wheat may not be equally work for other crops. One of the targets of the growth and transformation of the program of the soil and water research directorates is also to improve the productivity of crops in the highland through soil fertility management including acid soil management. Therefore, the research was initiated to improve the productivity of potato through the application of optimum lime rate both economically and biologically.

Objective

- To determine the economical and biological optimum micro dozing level of lime for potato production in highly acidic areas of North West Amhara region

Materials and methods

Description of the study area

The experiment was conducted at Banja and Machakel woredas on a farmer’s field in North West Amhara region Ethiopia. The site is located to southwest 175 and 230 km away from Bahir-Dar respectively. Geographically the sites at Banja lies at (10^{0}55'00" latitude and 37^{0}05'00'longitude) and Gozamen (10˚19'75" latitude and 37^{0}16'46"longitude). The study areas receive a mean annual rainfall of 2348 and 1700 mm with an altitude of 2312 and 2200m above sea level respectively. Major Crops grown in the areas include Potato, Barley, Wheat, Oat, Teff, Faba-Bean, and Triticale.

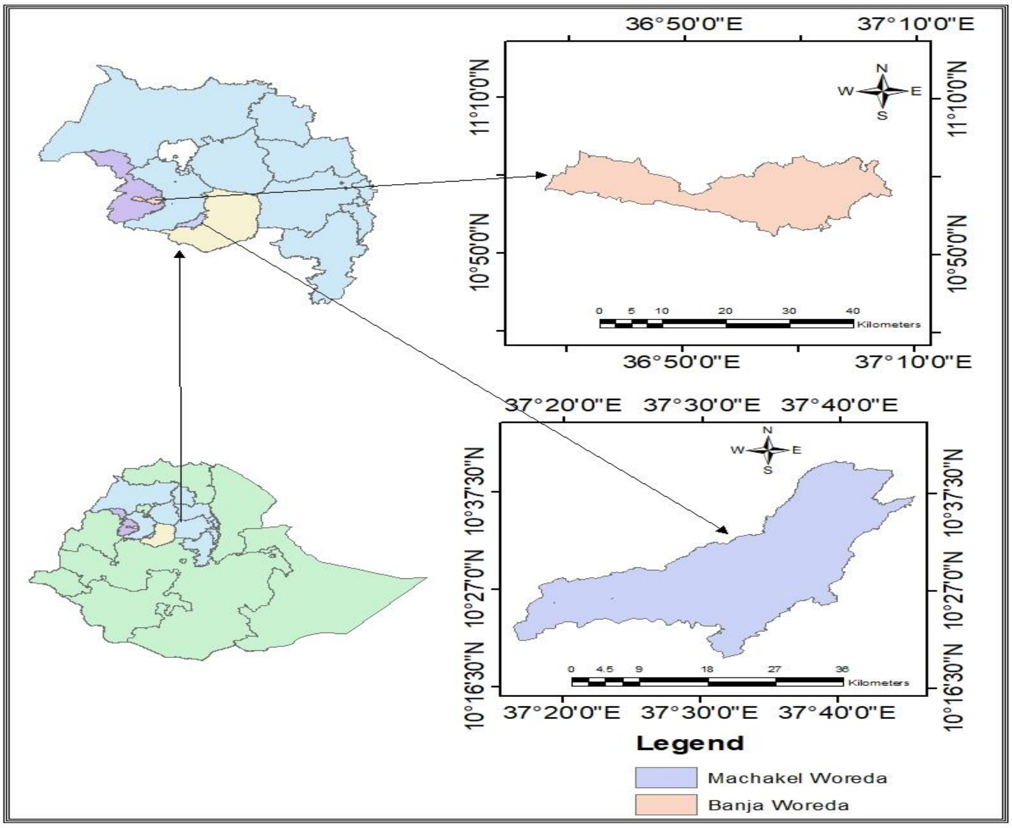

Figure1.Geographical location of the study Area

Soil sampling and experimental procedure

Before and after planting, representative soil samples were collected from 0-20 cm depth in a random sampling method from 10 spots in the field by using auger. All samples were mixed together and one composite sample was formed. The composite sample was grounded using a mortar and pistil as well as passed through 2mm sieve for analysis of soil texture, exchangeable acidity, CEC, pH, and available P whereas 0.5 mm sieve was used for determining the soil organic carbon (OC) and total N. Bulk density was determined by core sampling method. Major chemical properties of soil such as exchangeable acidity, OC, pH, CEC, total N and available P were analyzed following the compiled laboratory manual of Sahlemedhin and Taye (2000). Soil pH was measured in water at the ratio of 1:2.5 using glass electrode pH meter. The soil OC content was determined following the wet digestion method as outlined by Walkley and Black which involves digestion of the OC in the soil samples with potassium dichromate ($K2Cr2O7$) in sulphuric acid solution. AvP was determined by Olsen extracting method. Total N content in the soil sample was determined following the Kjeldahl method. CEC was determined by extracting the soil samples by ammonium acetate (1N $NH4OAc$) followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution. Percolating the NH4+saturated soil with sodium chloride would displace the ammonium ions adsorbed in the soil and the ammonium liberated from the distillation was titrated using 0.1N NaOH. Simultaneously the core samples per site were collected for the determination of the bulk density which is important for the calculation of the amount of lime as shown below. The soil samples were air-dried, ground, and sieved according to standard procedures. Then exchangeable acidity (sum of exchangeable Al^{+3} and exchangeable H^{+}) of the collected soil samples were determined at Adet Agricultural Research Center Laboratory. Following the determination of the exchangeable acidity of the samples, the lime requirement was calculated with the following formula and applied in rows at planting.

$$\mathbf{Lime(CaCO3)kgh}^{-1} = \frac{\mathbf{Exacidity(cmolkgha-1)*0.2m*10000m2*BD(Mgm-3\ )*1000}}{\mathbf{2000}}\mathbf{*1.5}$$

Accordingly, the optimum rate of lime for the production of potato was examined based on the following treatments. Fertilizers with a rate of 138N and 69 P_2O_5 were uniformly applied. Nitrogen was applied by three splitting: one third at planting, one third at about 30 days after planting and the remaining was at the beginning of flowering. The total phosphorus was applied at planting with the following treatments:

1) Full amount of Equation 1+25% (125%)
2) Full amount of Equation-1 (100%
3) Three-fourth of Equation-1 (75%)
4) Half of Equation-1 (50%)
5) One–third of Equation-1 (33.3%)
6) One-fourth of Equation-1 (25%)
7) One-fifth of Equation-1(20%)
8) One-sixth of Equation-1(16.7%)
9) One-seventh of Equation-1(14.3%)
10) One-eighth of Equation-1(12.5%)
11) One-tenth of Equation-1(11.1%
12) Control (without lime) (0%)

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications carried out under rain fed condition while potato variety *Gudene* was used as a test crop. The total area of each plot was 3 m x 4.5 m (13.5m^2) having 1m space between plots and blocks. The spacing between plants was 0.3m and each plot consisted of six rows at 0.75m interval. Data were collected from the middle four rows.

Data collection

Collected agronomic data

Number of tubers per plant was measured at harvesting by counting tubers from randomly selected five plants and averaged for a single reading while Total tuber yield was measured by harvesting both fresh marketable and non-marketable tubers from the net middle plot area of 3m x 3m to avoid border effects

Statistical Analysis

All data were subjected to analysis of variance by using SAS software program version 9.4(SAS Institute, 2002). List significant test (LSD) at 0.05 probability level was employed to separate treatments means where significant differences exist (Gomez and Gomez, 1984).

Results and discussion

Soil Chemical Properties before and after planting at Banja and Machakel

Results of soil chemical analysis before and after harvest from each experimental site was presented in Table 1,2&3. The soil analysis result of before planting revealed that the soil was acidic with a exchangeable acidity 2.78, 1.52 and 3.55cmolkg^{-1} and pH 5.03,5.30&5.13 at Banja, on first year site one and second year site one and two respectively. Similarly, the laboratory analysis result for the composite soil sample from Machakel district also indicated that the soil was highly acidic with the exchangeable acidity of 6.09, 6.44 & 5.12 cmolkg^{-1} and pH values 4.8,4.76 & 4.73 for site one (first year) and for site 1 and 2 (second year) respectively; which is out of the critical range of optimum soil exchangeable acidity and low pH for crop production (Tekalign 1991).

On the other hand, after harvest soil pH and exchangeable acidity was affected by the application of different lime rates in table 3&4 at Banja and Machakel districts respectively. These might be due to the chemical reaction of the applied calcium carbonate ($CaCO_3$) on aluminum (Al^{+3}) and hydrogen (H^{+1}) in the soil exchangeable site. And make them unavailable in soil solution through a substitution reaction of Aluminum and Hydrogen by Ca^{+2} that makes decreasing the exchangeable acidity by increasing soil pH. The result was in line with the finding of Athanase (2013) who reported that the application of different lime sources and rate affected on exchangeable acidity and soil pH. And the same author concluded that the application of 4.2tha^{-1} Rusizi lime decreased exchangeable Acidity by a unit of 2.67 cmolkg^{-1} as compare to control treatment.

Table1. Soil physical and chemical properties across locations for Year 1 and 2 before planting

Campsite sample	pH	Ex H^{+1}	Ex Al $^{+3}$	Ex A (cmol kg^{-1})	BD (gcm^{-3})	TN%	OC%	Av P (mg kg-1)	CEC (cmol kg-1)	LR(tha^{-1})
Banja										
Y1S1	5.03	1.14	1.64	2.78	1.2	0.28	3.55	15.64	27.70	5.1
Y2S1	5.30	0.34	1.18	1.52	1.27	0.19	2.67	17.43	30.92	2.9
Y2S2	5.13	1.25	2.3	3.55	1.30	0.12	1.57	10.15	29.04	6.9
Machakel										
Y1S1	4.80	1.27	4.82	6.09	1.23	0.12	1.71	15.04	28.56	10.3
Y2S1	4.76	1.11	5.33	6.44	1.16	0.17	2.47	9.36	24.80	11.2
Y2S2	4.73	0.32	4.79	5.12	1.27	0.18	1.91	4.94	20.72	9.7

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two LR= calculated lime requirement each site and Ex A=exchangeable acidity
Calculated lime per site

Table2. Soil chemical properties at Banja sites after haresting for year 1 and 2

	Y1S1				Y2S1				Y2S2			
Treatment	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})
125%lime	6.05	0.0	0.12	0.12	5.40	0.33	0.0	0.33	6.53	0.18	0.0	0.18
100%lime	6.80	0.0	0.59	0.59	5.15	0.53	0.0	0.53	6.20	0.26	0.0	0.26
75%lime	6.89	0.0	0.20	0.20	4.80	0.55	0.54	1.09	6.97	0.11	0.0	0.11
50%lime	6.56	0.0	0.09	0.09	4.83	0.77	0.0	0.77	6.51	0.15	0.0	0.15
33.3%lime	5.93	0.15	0.58	0.73	5.26	0.34	0.46	0.80	5.87	0.26	0.0	0.26
25%lime	6.48	0	0.15	0.15	4.98	0.52	1.01	1.53	6.02	0.16	0.0	0.16
20%lime	4.78	3.6	0.05	3.6	4.89	0.49	1.18	1.67	5.67	0.19	0.0	0.19
16.7%lime	6.08	0.27	0.31	0.58	4.94	0.60	1.25	1.85	5.88	0.22	0.0	0.22
14.3%lime	5.72	0.75	0.15	0.90	4.74	0.69	1.52	2.21	5.78	0.31	0.0	0.31
12.5%lime	4.96	2.27	0.33	2.61	4.85	0.42	1.20	1.62	6.72	0.16	0.0	0.16
11.1%lime	5.13	2.15	0.08	2.23	4.76	0.56	1.65	2.21	5.90	0.21	0.0	0.21
0%lime	4.76	5.15	0.04	5.19	4.82	0.43	1.47	1.90	5.46	0.74	0.0	0.74

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two and ExA=exchangeable acidity

Table3. Soil chemical properties at Machakel sites after haresting for year 1 and 2

	Y1S1				Y2S1				Y2S2			
Treatment	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{-1})
125%lime	5.53	0.81	1.96	2.77	5.47	0.05	1.60	1.65	7.03	0.39	0.0	0.39
100%lime	5.12	0.27	3.63	3.90	5.40	1.03	4.16	5.19	6.83	0.21	0.0	0.21
75%lime	5.17	0.71	3.57	4.29	4.88	0.27	4.46	4.73	6.78	0.12	0.0	0.12
50%lime	5.20	0.88	3.52	4.40	4.86	0.46	3.47	3.93	6.15	0.19	0.0	0.19
33.3%lime	5.07	0.40	4.01	4.41	4.84	1.11	3.86	4.97	6.09	0.18	0.0	0.18
25%lime	4.74	0.50	4.64	5.14	4.82	0.37	3.69	4.06	6.27	0.20	0.0	0.20
20%lime	4.89	0.33	4.55	4.88	4.47	0.82	4.42	5.24	6.42	0.12	0.0	0.12
16.7%lime	4.76	0.68	4.46	5.14	4.76	0.92	3.50	4.42	5.76	0.23	0.0	0.23
14.3%lime	4.79	0.25	4.65	4.90	4.93	0.42	4.27	4.69	5.14	0.29	1.27	1.56
12.5%lime	4.76	0.53	4.61	5.14	4.69	0.55	4.10	4.65	4.80	0.62	2.25	2.87
11.1%lime	4.70	0.53	4.60	5.13	4.77	0.87	4.07	4.94	4.99	0.43	1.89	2.32
0%lime	4.78	0.54	4.61	5.15	4.87	0.43	4.78	5.21	4.76	0.56	4.42	4.98

*Y*1S1=year one site one, Y2S1=year two site one, Y2S2=year two site two and ExA=exchangeable acidity

Effect of different lime rates on Potato total tuber yield at Banja and Machakel

The analysis of variance revealed that the tuber yield of potato is not significantly different at ($P < 0.05$) due to lime application rate across different testing sites (Tables 4 and 5). Even if the application lime rate reaches 125% tha^{-1} it doesn't give a significant tuber yield as compared to other lower rate treatments including control. Although the result is statistically not significant some treatments have a yield advantage as compared to the control that gives the lowest fresh total tuber yield in both areas of Banja and Machakel (Tables 4&5). For instance, in Banja, the application of 14.3% of recommended lime gives 4.57 and 6.41 tha^{-1} tuber yield advantage as compared to control on Y1S1 and Y2S2 respectively. Similarly, in Machakel, the application of 20% full recommended lime gives 4.04, 1.13 &0.94 $tha^{-1}$of total tuber yield advantage over control treatment @Y1S1, Y2S1andY2S2 respectively. This might be due to the neutralization activity of lime that helps to plant get nutrients in the plant root system, especially phosphorus deliver into the soil solution beyond its sorption by Aluminum and Iron in acidic soil conditions. In addition, non-significant results in all lime-applied treatments as compared to the control and even with each other might be from the biological acid tolerance capacity of potato as compared to other crops like Barley, Faba-bean, wheat, and Maize. The finding in line with the study of Natalia *et al*., (2019) who revealed that the Supplement of dolomitic limestone did not increase plant growth and tuber yield of potato even when soil correction was performed with calcitic limestone to elevate the base saturation to 60%. Another study conducted by Hajduk *et al.*, (2016) indicated that Liming had no statistically significant impact on potato tuber yields even if the mean value of potato yield from non-limed and limed fields varied depending on mineral NPK nutrition; the yield from the non-limed field ranged from 19.3 to 29.7 tha^{-1}. While the limed field was 20.6-32.5 t ha^{-1}

Table 4. Effect of lime rates on Potato tuber yield and yield components of at Banja

Treatment	Y1S1			Y2S1			Y2S2		
	MY (tha^{-1})	UMY (tha^{-1})	TY (tha^{-1})	MY (tha^{-1})	UMY (tha^{-1})	TY (tha^{-1})	MY (tha^{-1})	UMY (tha^{-1})	TY (tha^{-1})
125%lime	12.82	0.63	13.44	20.52	2.22	22.74	13.37	0.3	13.67
100%lime	11.7	0.24	11.94	21.78	4.15	25.93	13.5	0.29	13.79
75%lime	11.89	0.57	12.46	19.89	2.78	22.67	13.44	0.2	13.64
50%lime	12.3	0.4	12.70	17.15	1.85	19.00	18.14	0.28	18.42
33.3%lime	10.74	0.19	10.93	16.59	2.41	19.00	17.72	0.33	18.05
25%lime	11.56	0.38	11.94	18.41	2.37	20.78	10	0.31	10.31
20%lime	10.52	0.35	10.87	16.93	1.7	18.63	14.89	0.3	15.19
16.7%lime	11.78	0.22	12.00	19.37	2.07	21.44	14.39	0.76	15.15
14.3%lime	13.93	0.62	14.55	18.74	2.07	20.81	16.78	0.24	17.02
12.5%lime	11.7	0.23	11.93	18.96	3.04	22	17.78	0.25	18.03
11.1%lime	10.74	0.72	11.46	19.56	2.74	22.3	14.59	0.16	14.75
0%lime	9.63	0.35	9.98	14.44	2.33	16.77	10.17	0.44	10.61
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	22.3	80.6	22.1	25.2	90,0	23.1	30.2	45.6	29.8

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two, MY=marketable tuber yield, UMY=unmarketable tuber yield and TY =total tuber yield

Table 5. Effect of lime rates on Potato tuber yield at Machakel

Treatment	Y1S1			Y2S1			Y2S2		
	MY (tha-1)	UMY (tha-1)	TY (tha^{-1})	MY (tha^{-1})	UMY (tha-1)	TY (tha-1)	MY (tha-1)	UMY (tha-1)	TY (tha-1)
125%lime	10.1	0.67	10.78	6.2	0.88	7.1	7.19	0.42	7.61
100%lime	8.96	0.22	9.19	8.1	0.71	8.82	5.59	0.66	6.27
75%lime	10.1	0.96	11.04	7	0.7	7.74	5.41	0.26	5.67
50%lime	9.41	0.26	9.67	8.8	0.92	9.73	6.59	0.3	6.89
33.3%lime	8.89	1.7	10.59	8.7	0.86	9.57	6.3	0.61	6.91
25%lime	9.44	0.52	9.96	7.3	0.74	8.0	6.37	0.42	6.79
20%lime	10	0.85	10.89	9.7	0.58	10.3	6.56	0.45	7.01
16.7%lime	9.67	0.93	10.59	6.6	0.78	7.33	5.93	0.56	6.49
14.3%lime	7.96	0.89	8.85	8.4	0.64	9.01	5.41	0.78	6.19
12.5%lime	7.15	1.93	9.07	8.8	0.43	9.21	6.52	0.16	6.68
11.1%lime	8.52	0.52	9.04	9.4	0.89	10.3	6	0.83	6.83
0%lime	5.67	1.19	6.85	7	0.36	7.36	5.78	0.29	6.07
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	20.2	79.5	18.6	22.3	37.3	21.2	27.1	69.4	28.1

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two, MY=marketable tuber yield, UMY=unmarketable tuber yield and TY =total tuber yield

Conclusion and recommendation

It is concluded that the application of lime rates on acidic soils of Banja and Machakel did not significantly improve the tuber yield of Irish potato as compared with control treatment on experimental fields of each district. However; the application of 14.3% lime at Banja gives 6.41 and 4.51tha^{-1} tuber yield advantage over the control at Y1S1&Y2S2 respectively. Similarly, the application of 20% lime at Machakel provides 4.04, 1.13, and 0.94 tha^{-1}tuber yields than the control treatment at Y1S1, Y2S1&Y2S2 respectively. The soil was affected due to the application of different lime rates on selected soil properties such as decreasing exchangeable acidity (exchangeable aluminum and hydrogen concentration). This might be due to the reclamation (neutralization) activity of lime through the substitution chemical reaction of ($CaCO_3$) with aluminum (Al^{+3}) and (H^{+1}) on soil exchangeable site that makes the formation of aluminum hydroxide and water than free hydrogen and aluminum. So in the study areas further cost to lime for potato production is not necessary or by using recommended fertilizer it is enabled to produce potato but in order to fulfill the principle of reclamation acidic soil for production of subsequent crops, it is important to use the minimum rate of lime. Based on this application of 14.3% of the lime rate at Banja and 20% of the lime rate at Machakel with recommended fertilizer (138N,69P2O5) would be important for potato production. But for concurrent suggestion and recommendation is vital to do further research findings on lime like its long-term residual effect and time of application with the different lime requirements calculation methods by including potential verities. In addition, it is also important to do integrated nutrient management in permanent plots in order to back up the depletion of soil organic matter

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References

Adane Hirpa, Meuwissen, M. P.M, Van der Lans, I.A., Lommen, W. J.M. , Oude Lansink, A. G.J.M., Admasu Tsegaye and Struik, P. C. 2012. Farmers' opinion on seed potato management attributes in Ethiopia: A conjoint analysis. Agronomy Journal, 104:1413–1424.

Asmamaw Demil, Tadele Amare, Yihenew Awoke, Assefa Derebe and Tilahun Adera. 2020. Bridging the yield gaps of bread wheat at a scalethrough an innovative method of lime application in the acidic soils of Northwestern Ethiopia.Jouranal of Cogent Food & Agriculture 6: 1803578.

Asresie Hassen, Alemu Worku, Molla Tafere, Mekonen Tolla, Abel Ahmed, Seferew Dagnew, Yihenew G. Selassie, Desallegn Molla and Tesfaye Abebe . 2015. Best Fit Practice Manual for Potato Production and Utilization, BDU-CASCAPE working paper 8 .

Athanase Nduwumuremyi. 2017. Effects of Different Limes on Soil Properties and Yield of Irish Potato (Solanum tuberosum. L). MSc. Thesis, Presented to School of Plant and Horticultural science of Hawassa University. 22p.

Birhanu, A., Anteneh, A., Dereje, A., Kenzemed, K., Genet, T.,& Gebreyes, G. 2016. Effect of lime and phosphorus on wheat (Triticum aestivum) wheat, Tef Eragrostisteff), and Barley (Hordium Vulgars L.) yields in the Amhara highlands; Proceeding of the 7th and 8thannual regional conference on completed research activities of soil and water management research, (vol.25-31, pp. 29–42), January, 2013 and 13-20, February,2014 (ARARI-2016), Bahir Dar: Ethiopia:

Bremner, J. M., & Mulvaney, C. S. 1982. Nitrogen total. In A. L. Page, R. H. Miller, D. R. Keeney (Eds.), Methods of soil Analysis, vol. 2, American Society of Agronomy, Madison, Wis. (1982), 95-624.

CSA (Central Statistics Agency). 2016. Agricultural Sample Survey Report on Area and Production of Crops. Addis Ababa. 14pp.

Degefu Kebede and Mengistu Ketema .2017. Why do Smallholder Farmers Apply Inorganic Fertilizers below the Recommended Rates? Empirical Evidence from Potato Production in Eastern Ethiopia. Adv Crop Sci Tech 5 (2): 265.

Food and Agriculture Organization of the United Nations. International Year of the Potato, 2008. www.potato2008.org.

Gebremedhin Woldegiorgis, Schulz, S., Baye Berihun .2013. Seed potato production and dissemination, experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination, 12-14 March 2012, Bahir Dar, Ethiopia.

Getachew Agegnehu, Tilahun Amede, Teklu Erkossa, Chilot Yirga, Carol Henry, Robert Tyler, MatthewG. Nosworthy, Sheleme Beyene and Gudeta W. Sileshi.2021. Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. Journal of soil and plant science 71(9),pp 852-869.

Hajduk E., Gąsior J., Właśniewski S., Nazarkiewicz M., Kaniuczak J. 2017.Influence of liming and mineral fertilization on the yield and boron contentof potato tubers (Solanum tuberosum L.) and green mass of fodder sunflower (Helianthus annuus L.) cultivated in loess soil. J. Elem., 22(2): 411-426.

Haverkot, A., van koesveld, F., Schepers, H., Wijnands, J., Wustman, R., and Zhang, X. 2012. Potato prospects for Ethiopia: On the road to value addition. Applied plant research Publication number 528. Wageningen University and Research Center, The Netherlands.

Natália S. Assunção, Nathalia P. Ribeiro, Rudieli M. da Silva, Rogério P. Soratto & Adalton M. Fernandes.2019. Tuber yield and allocation of nutrients and carbohydrates in potato plants as affected by limestone type and magnesium supply.Journal of plant nutrition.1532-4087.

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet, Birhanu Agumas, Mengistu Muche, Tesfaye Feyisa and Desalew Fentie. 2018. Crops Response to Balanced Nutrient Application in Northwestern Ethiopia. Blue Nile Journal of Agricultural Research: 1 (1), pp 1-14.

Tekalign Tadese. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Identifying limiting nutrient(s) for better bread wheat and teff productivity in acidic soils, West Amhara, Ethiopia

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Abstract

Food crop productivity is still low due to the decline of soil fertility in Ethiopia in general and western Amhara in particular. This is mainly associated with deficiencies of macronutrients N, P, K, and S as well as micronutrients. Satisfying nutrient deficiencies with the addition of synthetic fertilizer is one of the major options to boost crop productivity. However, the responses to fertilizer application are varied across geographical locations and environments. As a result, fertilizer use efficiencies and economic profitability are different across different environments. Thus, fine-tuning the use of nutrients through the right fertilizer source is needed to solve soil fertility problems. Therefore, this study was initiated to investigate the need for applying selected nutrients on teff and wheat in acidic soils of North West Amhara. This study was conducted in 74 farmers' fields in Gozamen and Machakel districts. The experiment employed an omission trial design. The omitted nutrients were sulfur (S), Zinc (Zn), and boron (B). Potassium (K) was added rather than omitted that consisting of N, P, S, Zn, B, and K (All). Nitrogen and Phosphorus (NP) treatment was included as a positive control. Additional two treatments: 50% and 150% of the ALL+K were also included. High-yielding bread wheat (Ogalcho) and teff variety (Quncho) were used for the study. The outcome of the experiment shows that the application of different nutrient types with different rates has a significant role in grain and biomass yield of teff and bread wheat across landscape positions with and without lime application in acidic soils of the East Gojjam zone. Teff yield was not obtained without fertilizer application in the study area whereas the lowest yield of bread wheat was also obtained without fertilizer application (no input) treatment. The application of all nutrient types (NPKSZnB) has no significant yield advantage compared to NP fertilizer alone. This implies that N and P are the most yield-limiting nutrients in producing teff and bread wheat whereas KSZnB nutrients are not yield-limiting. However, this should be supported with grain quality analysis. Therefore, refining the rate of NP in acidic soils is important for the economical use of inorganic inputs. Finally, the use of blended fertilizer without empirical evidence for test crops is not recommended to smallholder farmers in the study area.

Keywords: Acidity, Deficiency, Fertilizer, Landscape, Omission.

Introduction

Achieving food security through increased productivity of food crops is the main problem in Ethiopia. Crop productivity is not improved due to the decline of soil fertility (Hirpa et al., 2012; Kebede, 2017; Tadele et al., 2018). To enhance crop yield, adding synthetic fertilizer is one of the major components. Thus, the national annual fertilizer use raised by about 30 % from 1994 to 2005, and 63 % from 2005 to 2010 (Birhan et al., 2017; Tefera et al., 2012). Recently the use of synthetic fertilizers for crop production was increased drastically even though the expected crop yield is not achieved.

Many studies in the last decades indicate that crop production constraints are mainly deficiencies of macronutrients N, and P, to some extent K and S (Ayalew, 2011; Aleminew and Legas 2015; Argaw, and Tsigie 2015; Tamene et al., 2017). The addition of sulfur is also recommended in lowland parts of the country (Habtegebrial, and Singh 2009; Habtegebrial, 2013). Contrary to these reports, other studies show that the deficiency of K is not a major problem for most agricultural soils in Ethiopia (Tadele et al., 2018; 2019). Recently, limitations of secondary nutrients and deficiencies of micronutrients are also obtaining attention (EthioSIS, 2016).

The responses to fertilizer application are varied across geographical locations (Tamene et al., 2017; Tadele et al., 2018) and environments. Site-specific fertilizer applications should consider landscape position in farms with undulating topographic features (Amede et al., 2020). The response of fertilizers is ranged from low too high for any nutrient combination. Moreover, the responses can be happened due to management factors and biophysical attributes. As a result, fertilizer use efficiencies and economic profitability are different. Thus, optimizing the use of nutrients through the right fertilizer source, rate placement, and time of application during crop growing season is critical to solve soil fertility problems (Ferguson, 2006; Ahmad et al., 2018; Barłóg et al., 2022) and economic use of fertilizers.

Fertilizer rates are better recommended based on the available nutrient in the soil and the crops' requirement for that nutrient (Scherer, 2001). The demand for the plant should be addressed through the supply of required plant nutrients in adequate amounts. However, this is not done in previous soil management efforts to halt soil fertility declines in Ethiopia. This is due to a lack of site-specific fertilizer use and the right fertilizer combination. On the other hand, there is a yield gap between teff and wheat production in Ethiopia due to sub sufficient fertilizer use (Tadesse *et al.*, 2000; Zeleke *et al.*, 2010; Mann, and Warner 2015; Birhan *et al.*, 2017). The yield gaps in these crops suggest that there is potential for increasing production through the lime application, selection of acid-tolerant crop varieties, increased use of fertilizers amount, and identification of the right nutrient types for each location and crop type, particularly in acidic areas.

In designing site-specific fertilizer recommendations, an understanding of the effects of each nutrient/fertilizer application on crop yield is required. Moreover, increasing crop production with the use of synthetic fertilizer must be profitable to smallholder farmers to promote sustainably (Tamene *et al.*, 2017). Inefficient use of chemical fertilizer might cost the farmer and pollute the environment (Vanlauwe *et al.*, 2011). In addition, the high variability between and within farms calls for site-specific recommendations that will reduce wastage and reap maximum benefits from fertilizer use. Therefore, fine-tuning fertilizer recommendations is required via selecting the right nutrient types in acidic soils for wheat and teff crops. Hence, the objective of this study was to identify the major yield-limiting nutrients for wheat and teff production in acidic-prone areas of North West Amhara, Ethiopia.

Materials and Methods

Location and description of the area

On-farm plant nutrient omission experiments were conducted in acid-prone areas of the Northern highlands of Ethiopia (Gozamen and Machakel districts), within the geographical coordinates of 10°00’N - 10°40’N latitudes and 37°20’E - 37°50’E longitude (Figure 1). Gozamen district is found at a distance of about 305 and 251 km from Addis Ababa (the capital city of Ethiopia) and Bahir Dar (the capital city of Amhara regional state), respectively. Whereas Machakel district is located 330 km on the road from Addis Ababa to East Gojjam, and 235 km east of Bahir Dar. The elevation of the Gozamen and Mackakel districts ranges from 1200 to 3510 and 1200 to 3200 m.a.s.l., respectively.

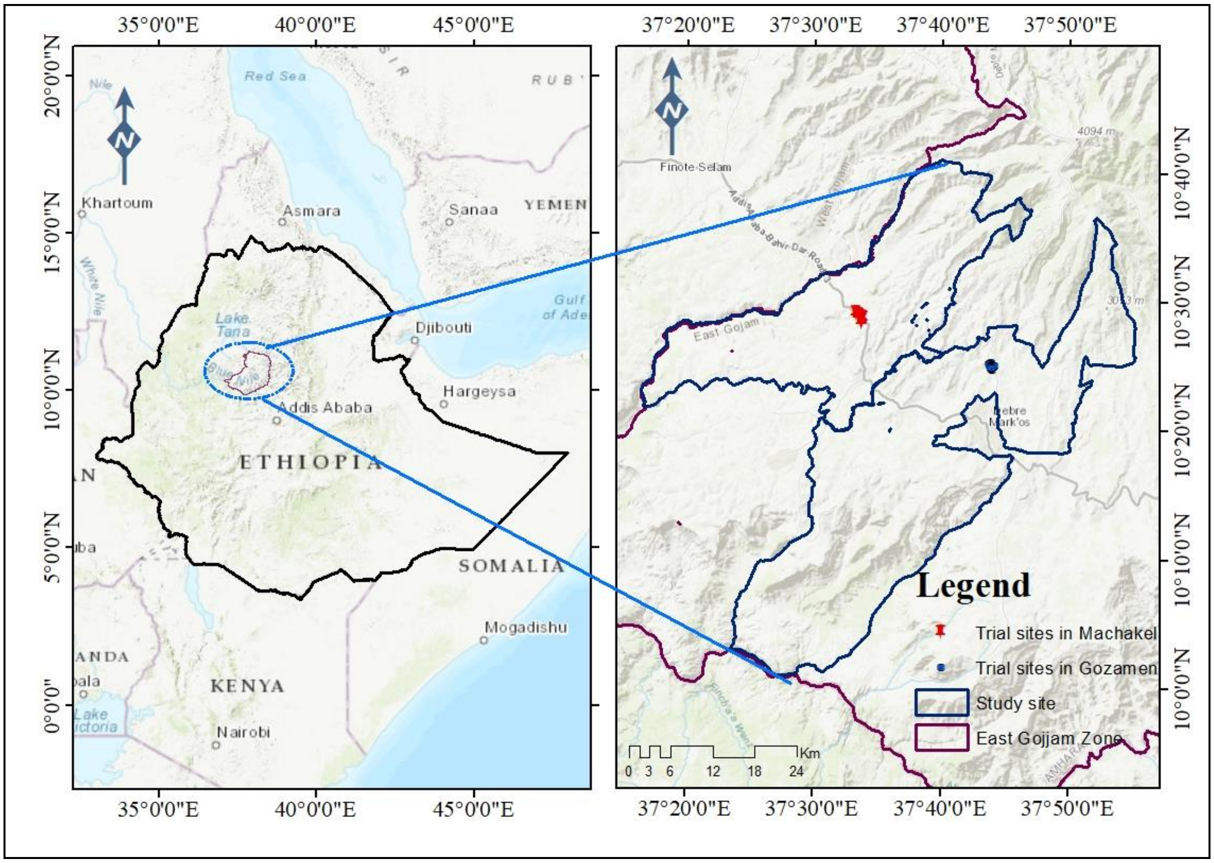

Figure 3. Location map trial sites in Gozamen and Mackale districts

In Both districts, the average annual rainfall ranges between 1300 mm and 1900 (EMA, 2020), with the highest amount of rainfall received in July and August. The maximum and the minimum annual average temperatures are 27 °C and 8 °C, respectively. Wheat (Triticum vulgare), tef, (Eragrostic tef), maize (Zea mays), barley (Hordeum vulgare), white lupine (Lupines albus), and food oat are the dominant cereal crops that are grown in both districts. Nitisols followed by vertisols are the most dominant agricultural soils in study districts.

This experiment was superimposed in previously lime-amended farmer fields in both districts. The lime was applied based on the blanket recommendation of 100 kg ha^{-1} by farmers with the help of development agents. For this experiment, lime-amended and not amended farmers' fields were selected and implemented side by side at all landscape positions for both test crops.

A total of 74 trial sites were used for this study. Out of these, 44 trial sites have been carried in Gozamen and 30 trial sites in Machakel districts that represent the acid soils of North West Amhara, Ethiopia (Table 1). About 38 sites were amended by lime whereas the remaining 36 sites were not amended by lime before experimentation. A total of 37 sites were used as common experimental sites for both teff and bread wheat in the study areas.

Table 19. Details of the number of sites in study districts

District	Landscape position	Test crop	Soil acidity management		Total number of sites [N]
			Lime amended	Not lime amended	
Gozamen	_	2	22	22	44
	Hill	Tef and Wheat	6	6	12
	Mid	Tef and Wheat	12	12	24
	Foot	Tef and Wheat	4	4	8
Machakel	_	2	16	14	30
	Hill	Tef and Wheat	6	4	10
	Mid	Tef and Wheat	6	6	12
	Foot	Tef and Wheat	4	4	8
Total [N]		2	38	36	74

Trial design

The core set of treatments was harmonized with the All-Ethiopian Coordinated Fertilizer Research (AECFR) Project. Recommended N and P rates for each location to teff and wheat were used as a positive control. The core treatment set was employed as an omission trial design (Table 2). The omitted nutrients were S, Zn, and B. “ALL” treatment consists of N, P, S, Zn, and B. K is an addition rather than omission treatment consisting of N, P, S, Zn, B, and K. In addition to the omission treatment and the K adding treatment, NP-only treatment is included such that the cumulative effect of S, Zn, and B omission were evaluated; this treatment then is effectively ALL- (S Zn B). Additional two treatments: 50% and 150% of the ALL+K were included. These treatments permit an evaluation of the fertilizer rate response according to landscape position and soil type. A non-fertilized control treatment was included in the core harmonized treatment set. Treatments were arranged in completely randomized designs by considering farmers as replicas in three landscape positions (foot, mid, and hill).

Table 20. Treatments were applied in the nutrient omission trials conducted in acidic soils of Gozamen and Machakel districts.

Treatments	Fertilizer rate (kg ha^{-1})											
	Bread wheat						Teff					
	N	P_2O_5	S	K_2O	Zn	B	N	P_2O_5	S	K_2O	Zn	B
NPSZnB	120	76	7		1	0.3	80	57	7		1	0.3
NPZnB	120	76			1	0.3	80	57			1	0.3
NPSB	120	76	7			0.3	80	57	7			0.3
NPSZn	120	76	7		1		80	57	7		1	
NPKSZnB	120	76	7	30	1	0.3	80	57	7	30	1	0.3
NP	120	76					80	57				
50%NPKSZnB	60	38	3.5	15	0.5	0.15	40	28.5	3.5	15	0.5	0.15
150%NPKSZnB	180	114	10.5	45	1.5	0.45	120	85.5	10.5	45	1.5	0.45

Fertilizer sources and test crop

Urea, triple super phosphate, potassium chloride, and borax are used as a source of fertilizer for nitrogen, phosphorus, potassium, and borax, respectively. Whereas zinc sulfate was used as a source for both S and Zn. The test crops used for this study were bread wheat (Ogalcho variety) and teff (Kuncho) at a seed rate of 150 and 10 kg ha^{-1}.

Experimental management

All trials were on farmers' fields, and soil and crop management practices were done following research recommendations. After preparing the trial sites, all the sites were planted by drill method at 20 cm spacing from 21 July 2020 to 31 July 2020. All fertilizers were applied by band application at plating except split urea for top dressing. The first split of nitrogen was applied one month after emergence. Weed management was started just after 2 weeks of seed emergence of the trials mainly for bread wheat (July 2020). Each site has been weeded twice. All experimental sites were harvested from 15 December 2020 to 06 January 2020. Then, the threshing is done after drying of harvested test crop.

Data collection

Soil sampling

Before planting, one composite soil sample at 0-20 cm of depth was collected from each trial site to see the status of selected soil chemical properties. The composite samples were collected from

11 sites on lime-amended farmers and 12 not lime amended sites in Gozamen whereas 8 sites from each lime-amended and not amended farmer in Machakel district. Major soil parameters such as soil pH-H_2O, organic carbon (OC), available phosphorus (AP), exchangeable acidity, and total nitrogen (TN) analysis were conducted in Adet Agricultural Research Center's soil laboratory.

Biological data

Measurements such as plant height, spike/panicle length, number of kernels per spike for wheat, total aboveground biomass, and grain yield were done for each test crop and undertaken at the appropriate times. Plant height was measured from the soil surface to the tip of a spike (awns excluded) from 5 randomly selected plants from the net plot area at physiological maturity. Spike length/panicle length was measured at physiological maturity at the same time as plant height using 5 randomly selected plants for measuring plant heights. Spike/panicle length was measured from 5 plants starting at the base of the spike to the tip of the spike (excluding the awns) and averaged. The number of kernels per spike for wheat was determined from the five randomly sampled spikes mentioned above. Harvesting will be done from the middle rows of 3.2 m by 3 m area (9.6 m^2 net plot area), leaving the outside rows as a buffer to avoid border effects. Then, total biomass was determined from plants harvested from the net plot area after sun drying to a constant weight and converted to kg per hectare for statistical analysis. Grain yield was also determined after threshing the total biomass harvested from the net plot area and converted to kg ha^{-1} for statistical analysis. The grain yield was adjusted to 12.5% moisture content.

Soil analysis

All collected soil samples were air-dried and crushed to pass a 2-mm sieve. Analyses were performed on surface samples (0-20 cm) including pH, organic carbon (OC), total nitrogen (N), available phosphorus (P), sulfur (S), zinc (Zn), boron (B), and exchangeable aluminum (Al) following standard soil laboratory procedures.

Soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios (Lean, 1982). Available phosphorus was also done following the Olsen method (Olsen, and Sommers, 1982) while total nitrogen was done using the Kjeldahl method (Bremner, and Mulvaney, 1982). The wet oxidation method was used to determine soil organic carbon (Walkley and Black, 1934). Cation exchange capacity was also determined by ammonium acetate extraction procedures (Houba *et al.*, 1986).

Data Analysis

For all the sites, yield and yield-related data were arranged in excel and subjected to analysis of variance using R software. Analyses of variance were performed for yield data for each landscape and all sites combined. A test of significance for the treatment by-site interaction of the combined analysis was performed as outlined by Cochran and Cox, (1992) for situations with heterogeneous variance among sites. Mean separation was carried out by DMRT at a 5% level of significance when ANOVA is significant.

Results and Discussion

Soil physical and chemical properties of the study sites

In Machakel district, the soil pH (H_2O) of the experimental sites (without lime amendment) ranged between 5.4 and 5.8 across three landscape positions (Table 1) and rated strongly to moderately acidic soils (Tadesse et al., 1991), whereas experimental sites that are previously lime amended were found between 5.3 and 6.0 (Table 2) with a similar range of soil acidity. The variation of soil organic carbon between limed and un-limed soils was low in all experimental sites except at site 3 in both conditions (Table 3).

Table 21. Soil characteristics of experimental sites at planting time in Gozamen and Machakel district

District	Lime status of trial sites	Landscape position	Statistical description	Soil parameters				
				Soil pH	Ex. Acidity [meq /100g soil]	P (Olsen) [mg kg^{-1}]	SOC [%]	CEC [cmol_c kg^{-1}]
Gozamen	without lime amendment	Foot [2]	Range	4.8-5.4	0.4-3.4	4.5-14.5	1.5-1.7	25.0-29.0
			Mean	5.1	2.2	8.8	1.6	27.3
		Hill [3]	Range	4.9-6.4	0.2-0.8	4.4-20.0	1.4-2.1	27.0-38.0
			Mean	5.4	2.0	11.4	1.8	31.7
		Mid [6]	Range	5.0-5.4	0.2-2.4	8.8-17	1.0-1.9	28.0-35.0
			Mean	5.2	0.8	12.7	1.6	32.0
	Previously lime amended	Foot [2]	Range	5.1-5.5	0.2-1.38	7.7-10.7	1.5-1.9	28.9-37.6
			Mean	5.3	0.9	9.2	1.6	35.3
		Hill [3]	Range	5.1-6.0	0.1-3.5	5.1-20.8	1.1-1.8	28.8-31.7
			Mean	5.5	1.8	12.9	1.5	30.3
		Mid [6]	Range	5.0-6.1	0.1-2.6	10.8-19.3	1.4-2.2	25.6-35.5
			Mean	5.4	1.1	14.3	1.7	33.0
Machakel	without lime amendment	Foot [2]	Range	5.5-5.8	0.2-0.8	10.8-13.2	1.2-1.3	30.0-32.0
			Mean	5.7	0.5	12.0	1.2	30.8
		Hill [2]	Range	5.4-5.5	0.7-1.2	7.3-9.0	1.1-2.3	34.2-34.7
			Mean	5.4	0.9	8.1	1.4	34.5
		Mid [3]	Range	5.4-5.6	0.4-1.5	5.8-7.4	1.2-1.31	22.7-29.8
			Mean	5.5	1.0	6.6	1.3	26.3
	Previously lime amended	Foot [2]	Range	5.3-5.4	0.6-1.3	7.2-10.7	1.1-1.3	29.3-31.2
			Mean	5.3	0.9	7.5	1.2	30.3
		Hill [3]	Range	5.1-5.6	0.3-2.1	3.2-6.1	1.3-2.7	26.3-27.9
			Mean	5.3	1.2	4.4	2.2	27.0
		Mid [3]	Range	5.3-6.0	0.1-1.6	4.7-24.1	1.4-1.7	22.3-31.1
			Mean	5.7	0.7	11.9	1.5	27.5

CEC: cation exchange capacity, P: available phosphorus, SOC: soil organic carbon, Numbers in parenthesis indicates the number of observations in each landscape.

The highest soil organic carbon content of 2.7 and 2.3 % was recorded from hill landscapes in lime-amended and non-amended sites, respectively (Table 1), while the lowest soil organic carbon content of 1.1 was obtained from foot landscapes in lime-amended soils. This result is in agreement with many previous studies that reported that cropland had low soil organic carbon due to frequent tillage and removal of residue (Nega and Heluf, 2009; Tamene et al., 2017). The soil pH (H_2O) of the experimental sites (without lime amendment) was found between 4.8 (foot) and 6.4 (hill) in Gozamen district (Table 3) and ranked very strongly to slightly acidic (Tadesse et al., 1991). Whereas experimental sites that are previously lime amended were found between

5.0 and 6.0 (Table 3) with a strong to slightly acidic range of soil acidity. Some sites at hill and mid have an exchangeable acidity value of 2.1 and 1.6 (meq /100g soil), particularly in Gozamen district. These values were found higher exchangeable acidity that is above a critical level. The mean value of available phosphorus ranged between 6.6 to 12.9 mg kg^{-1} which is ranked low to medium (Tadesse et al., 1991).

Teff grain and biomass yield response to nutrients

For all the sites and landscape positions, application of all nutrient types (N, P, K, S, Zn, and B) was not resulted from significant teff yield increments ($p > 0.05$) as compared to NP nutrient alone at Machakel district (Table 4 and 5). Only increasing the rate of all nutrients by 150% gave a higher biological yield over NP alone. Nevertheless, we are not sure whether the higher yield of 150% in all nutrients comes from the increase of NP nutrients only or due to other nutrients as the experiment did not have a treatment with NP with a 150% increment. Even though the trial was designed with one no fertilizer treatment, teff yield was not recorded at all in acidic soils. This shows that without fertilizer application, it is difficult to produce teff under the current farming system in the study area. In the nutrient omission trials, teff grain yields ranged between 447.9 and 1260.4 kg ha^{-1} in Machakel district (Table 4). The trend of biomass yield was similar to grain yield to nutrient types and amounts. From this result, K, S, Zn, and B are not yield-limiting for teff in the study area.

Table 22. Teff grain and biomass yield without lime amended farm sites of three landscapes in Machakel district

	Landscape					
	Foot [2]		Mid [3]		Hill [2]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
NPSZnB	692.7	3020.8	508.3 ^{bc}	4437.5 ^{bc}	781.3 ^{c}	3052.1 ^{bc}
NPZnB	666.7	2656.3	556.3 ^{bc}	4608.3 ^{bc}	760.4 ^{c}	2555.6 ^{cd}
NPSB	447.9	2265.6	636.3 ^{b}	3875.0 ^{bc}	847.2 ^{bc}	2979.2 ^{bc}
NPSZn	661.5	2838.5	595.8 ^{b}	3316.7 ^{c}	687.5 ^{c}	2336.8 ^{de}
NPKSZnB	666.7	3046.9	704.2 ^{ab}	4941.7 ^{ab}	989.6 ^{b}	3402.8 ^{b}
NP	682.3	2500.0	641.7 ^{b}	5175.0 ^{ab}	736.1 ^{c}	2725.7 ^{cd}
50%NPKSZnB	401.0	1250.0	327.1 ^{c}	3643.8 ^{bc}	642.4 ^{c}	1961.8 ^{e}
150%NPKSZnB	937.5	4302.1	895.8 ^{a}	6330.4 ^{a}	1260.4 ^{a}	4836.8 ^{a}
CV (%)	15.1	16.9	29.3	26.2	13.1	10.5
P level (0.05)	ns	ns	**	***	***	***

*CV: coefficient of variation, ***: significant at 1 %. Numbers in parentheses indicate the number of observations in each landscape.*

Table 23. Teff grain and biomass yield at previously lime-amended farm sites of three landscape positions in Machakel district

	Landscape					
	Foot [2]		Mid [3]		Hill [3]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
NPSZnB	942.7	3614.6	377.1 ^{c}	1404.2 ^{c}	491.7 ^{bc}	1633.3 ^{bc}
NPZnB	1005.2	2958.3	514.6 ^{bc}	1722.9 ^{bc}	670.8 ^{ab}	2247.9 ^{b}
NPSB	802.1	2765.6	427.1 ^{c}	1697.9 ^{bc}	504.2 ^{bc}	1702.1 ^{bc}
NPSZn	776.0	2947.9	495.8 ^{bc}	1627.1 ^{bc}	466.7 ^{bc}	1575.0 ^{bc}
NPKSZnB	963.5	3218.8	664.6 ^{ab}	2227.1 ^{b}	633.3 ^{ab}	2079.2 ^{b}
NP	859.4	2880.2	489.6 ^{bc}	1795.8 ^{bc}	485.4 ^{bc}	1727.1 ^{bc}
50%NPKSZnB	505.2	1520.8	308.3 ^{c}	1102.1 ^{c}	306.3 ^{c}	1045.8 ^{c}
150%NPKSZnB	1119.8	5479.2	852.1 ^{a}	3162.5 ^{a}	818.8 ^{a}	3243.8 ^{a}
CV	12.9	17.1	28.7	27.7	31	27.4
P level (0.05)	ns	ns	***	***	**	***

*CV: coefficient of variation, ***: significant at 0.1 %, **: significant at 1 %, ns: non-significant. Numbers in parentheses indicate the number of observations in each landscape.*

The productivity of tef in the acidic highlands areas was very low and it was not possible to harvest yield from those plots without fertilizer. The analysis of variance indicated that there is no significant teff grain and biomass yield difference due to nutrient types and amounts at different landscapes and liming conditions except the mid-landscape position in Gozamen district (Tables 6 and 7). For both lime-amended and not amended sites, a relatively better yield was obtained from NP and 150% NPKSZnB treatments (Tables 6 and 7).

Table 24. Teff grain and biomass yield without lime amended farm sites of three landscapes in Gozamen district

	Landscape					
	Foot [2]		Mid [5]		Hill [3]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
NPSZnB	764.3	2791.7 ^{bc}	926.3	3386.9	871.9	3482.6
NPZnB	699.2	2932.3 ^{b}	1043.9	3809.5	993.1	4388.9
NPSB	584.6	2237.0 ^{bc}	831.1	2614.6	902.8	3347.2
NPSZn	563.8	2554.7 ^{bc}	1035.7	3651.8	984.4	3510.4
NPKSZnB	658.9	3099.0 ^{b}	1157.7	3474.0	923.6	3833.3
NP	713.5	2744.8 ^{bc}	1037.2	3522.3	944.4	3506.9
50%NPKSZnB	505.2	1700.5 ^{c}	873.3	2841.1	819.4	3454.9
150%NPKSZnB	1056.0	5471.4 ^{a}	1026.8	4075.9	861.9	3295.1
CV (%)	34.2	25	33	29.1	15.2	21.9
P level (0.05)	ns	***	ns	ns	ns	ns

*CV: coefficient of variation, ns: non-significant, ***: significant at 1 %. Numbers in parentheses indicate the number of observations in each landscape.*

Table 25. Teff grain and biomass yield at previously lime-amended farm sites of three landscape positions in Gozamen district

	Landscape					
	Foot [2]		Mid [6]		Hill [3]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
NPSZnB	868.5	4420.6	910.3 ^{bc}	3094.3 ^{bc}	739.6	3289.9
NPZnB	914.1	4078.1	935.8 ^{abc}	3256.9 ^{bc}	965.3	4130.2
NPSB	1001.3	4404.9	859.4 ^{bc}	3024.3 ^{bc}	849.0	3529.5
NPSZn	885.4	4242.2	957.8 ^{ab}	3686.9 ^{bc}	788.2	3187.5
NPKSZnB	1128.9	4386.7	828.1 ^{bc}	2931.1 ^{bc}	925.3	3673.6
NP	791.7	4658.9	979.2 ^{ab}	3464.1 ^{bc}	854.2	3262.2
50%NPKSZnB	688.8	2819.4	703.7 ^{c}	2478.6 ^{c}	675.3	2342.0
150%NPKSZnB	1096.4	4153.6	1151.6 ^{a}	4861.7 ^{a}	849.0	3588.5
CV (%)	27.8	30.02	25.1	31.3	21.8	31.1
p (0.05)	ns	ns	*	**	ns	ns

*CV: coefficient of variation, ns: non-significant, *: significant at 5 %. Numbers in parentheses indicate the number of observations in each landscape.*

Response of teff to omitted nutrients

There was no significant difference across trial sites in teff yield resulting from the omission of a macronutrient from the K and S treatment and micronutrients from Zn and B treatments (Figure. 2). The omitted treatment did not show a significant yield difference in both previously lime amended and not amended trial sites. The omission of sulfur (All-S) led to a reduction in yield compared to the NPKSZnB treatment in mid and hill landscape positions in previously lime-amended sites, but this reduction was not significantly varied with All (below 100 kg ha^{-1}) in Machakel districts. The omission of K, Zn, and B nutrients did not show a statistically significant teff grain yield compared to the combined application of NPKSZNB (ALL) and recommended NP nutrients. This result was consistent with earlier research showing that adding K, S, Zn, and B did not substantially boost crop yield in the majority of Ethiopia's teff-growing regions (Tadele et al., 2018, 2019).

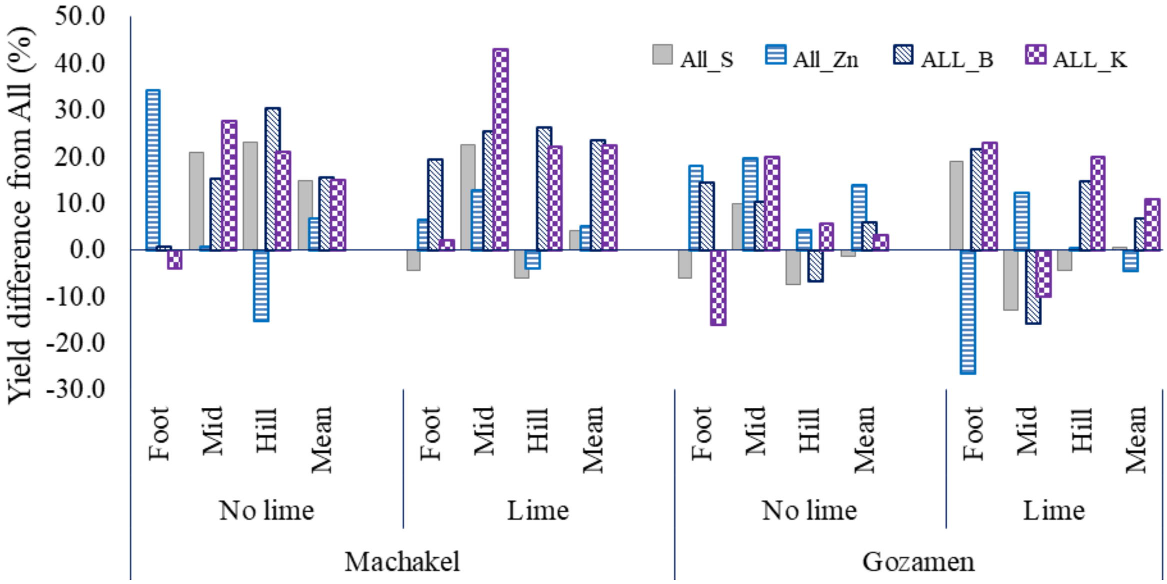

Figure 4. Effect of omission of S, K, Zn, and B on tef yield difference (5) relative to NPKSZnB in Machakel district trial sites. Error bars are confidence intervals.

Similarly, the omission of S led to a non-significant reduction in yield compared to the NPKSZnB treatment in foot and mid-landscape positions in both study districts, it was relatively low (below 200 kg ha^{-1}) in Gozamen districts (Figure 3). It had a similar trend in K omitted treatment that shows a no significant decline of yield in foot and mid landscape in previously lime amended and not amended trial sites, respectively. The omission of born had resulted from a decline of teff grain yield in mid-landscape sites in both without lime application and lime amended sites in the Gozamen district. This decrease was not statistically significant ($p < 0.05$). This result is supported by Tadele et al. (2018, 2019) who indicate that the addition of KSZnB with NP did not boost yield compared to NP alone. The finding agreed with Rawal et al. (2018) who reported that nitrogen and phosphorous are found to be the most limiting nutrient for wheat production in all sites.

Response of bread wheat to applied nutrients

The statistical analysis of bread wheat grain and biomass yield in Machakel district showed that there was a significant difference among nutrient types and rate as compared to control (no fertilizer) except biomass yield at hill landscape position (Tables 8 and 9). Higher rate and all nutrients received treatment gave maximum yield but no significant ($p>0.05$) as compared to NP fertilizer. This finding was similar to the finding of teff in the same district. Bread wheat grain yields ranged between 145.8 and 2678.6 kg ha^{-1} in Machakel district (Table 8) whereas it ranged from 300.7 to 3942.5 kg ha^{-1} in Gozamen district (Table 10).

Table 26. Bread wheat grain and biomass yield from without lime amended farm sites of three landscapes in Machakel district

	Landscape					
	Foot [2]		Mid [3]		Hill [3]	
Nutrient type	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
Control	145.8	484.4	255.8 ^{d}	1554.2 ^{d}	261.0 ^{d}	819.4
NPSZnB	2106.7	4739.6	1863.5 ^{b}	4437.5 ^{bc}	1268.6 ^{bc}	3641.7
NPZnB	2025.6	4614.6	2075.8 ^{b}	4608.3 ^{bc}	1484.4 ^{bc}	4023.4
NPSB	2187.5	4885.4	1782.3 ^{b}	3875.0 ^{bc}	1313.5 ^{bc}	3630.2
NPSZn	2123.4	4687.5	2139.9 ^{b}	3316.7 ^{c}	1301.6 ^{bc}	3893.0
NPKSZnB	2110.4	5057.3	1941.2 ^{b}	4941.7 ^{ab}	1692.9 ^{b}	4592.2
NP	2069.4	4531.3	1868.7 ^{b}	5175.0 ^{ab}	1369.9 ^{bc}	4083.3
50%NPKSZnB	1180.8	2541.7	1327.0 ^{c}	3643.8 ^{bc}	996.9 ^{c}	3653.6
150%NPKSZnB	2678.9	6500.0	2641.6 ^{a}	6330.4 ^{a}	2261.9 ^{a}	3942.7
CV (%)	13.2	17.3	15.7	26.2	24.3	35.1
P level (0.05)	*	*	***	***	***	^{ns}

*CV: coefficient of variation, ns: non-significant, *: significant at 5 %.***: significant at 0.1 %. Numbers in parentheses indicate the number of observations in each landscape.*

Table 27. Bread wheat grain and biomass yield at previously lime-amended farm sites of three landscape positions in Machakel district

	Landscape					
	Foot [2]		Mid [3]		Hill [3]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
Control	72.9	218.8	343.4 ^{d}	819.4	333.7 ^{b}	819.4
NPSZnB	1278.0	3036.5	2317.3 ^{b}	3641.7	1864.4 ^{a}	3641.7
NPZnB	1488.2	3395.8	2459.9 ^{ab}	4023.4	2025.1 ^{a}	4023.4
NPSB	1520.3	3474.0	2319.6 ^{b}	3630.2	1828.4 ^{a}	3630.2
NPSZn	1596.9	1958.3	2456.1 ^{ab}	3893.0	1810.0 ^{a}	3893.0
NPKSZnB	1750.7	3963.5	2495.5 ^{ab}	4592.2	2030.3 ^{a}	4592.2
NP	1636.6	3682.3	2394.8 ^{b}	4083.3	1964.4 ^{a}	4083.3
50%NPKSZnB	1073.2	2484.4	1696.3 ^{c}	3653.6	1377.9 ^{a}	3653.6
150%NPKSZnB	2653.6	6000.0	2955.5 ^{a}	3942.7	1942.1 ^{a}	3942.7
CV (%)	14.1	16.7	17.1	35.1	26.9	35.1
P level (0.05)	*	*	***	ns	***	ns

*CV: coefficient of variation, ns: non-significant, *: significant at 5 %. ***: significant at 0.1 %. Numbers in parentheses indicate the number of observations in each landscape.*

There were grain and biomass yield differences among the experimental sites to bread wheat. The statistical analysis result at Gozamen district showed that there was a significant difference ($p<0.01$) in grain and biomass yield when all other treatments were compared to the control treatment (Tables 10 and 11). Generally, a higher and more significant yield was recorded when 150% NPKSZnB was applied. However, the relatively equal biological yield of bread wheat was obtained from the NP compared to the NPKSZnB fertilizer type with equal rates. So, the application of NP fertilizer alone has a yield advantage for smallholder farmers in highlands areas. Phosphorus and nitrogen are critical nutrients to improve bread wheat production (Kolawole et al., 2018). The omission of potassium, sulfur, zinc, or boron did not affect the yields of bread wheat. This result is supported by Nziguheba et al. (2009) who indicate that K and B omission are not reduced cereal crop yield.

Table 28. Bread wheat grain and biomass yield without lime amended farm sites of three landscapes in Gozamen district

	Landscape					
	Foot [2]		Mid [6]		Hill [3]	
Nutrient type	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
Control	220.9 ^{c}	861.1 ^{c}	265.0 ^{e}	551.2 ^{c}	329.2 ^{c}	819.4
NPSZnB	1814.2 ^{ab}	4825.5 ^{ab}	2510.8 ^{cd}	5886.2 ^{a}	1338.0 ^{b}	3641.7
NPZnB	1937.3 ^{ab}	4656.3 ^{ab}	3441.2 ^{ab}	6773.1 ^{a}	1787.9 ^{ab}	4023.4
NPSB	1464.9 ^{b}	4875.0 ^{ab}	2825.5 ^{bc}	5720.2 ^{a}	2033.1 ^{ab}	3630.2
NPSZn	1821.0 ^{ab}	5112.0 ^{ab}	3468.4 ^{ab}	6601.3 ^{a}	1991.9 ^{ab}	3893.0
NPKSZnB	2325.0 ^{ab}	5838.5 ^{a}	3020.8 ^{abc}	6561.0 ^{a}	2223.7 ^{a}	4592.2
NP	2238.3 ^{ab}	5697.9 ^{a}	2914.8 ^{bc}	6639.9 ^{a}	1740.0 ^{ab}	4083.3
50%NPKSZnB	1630.1 ^{ab}	3697.9 ^{b}	2025.4 ^{d}	4113.1 ^{b}	1807.6 ^{ab}	3653.6
150%NPKSZnB	2535.6 ^{a}	6455.7 ^{a}	3618.4 ^{a}	7103.4 ^{a}	2067.7 ^{ab}	3942.7
CV	34.1	23.7	21.2	20.2	28.4	35.1
P level (0.05)	**	***	***	***	**	ns

*CV: coefficient of variation, ns: non-significant, ***: significant at 1 %, **: significant at 5 %. Numbers in parentheses indicate the number of observations in each landscape.*

Table 29. Bread wheat grain and biomass yield at previously lime-amended farm sites of three landscape positions in Gozamen district

	Landscape					
	Foot [2]		Mid [6]		Hill [3]	
Nutrient types	Grain yield	Biomass	Grain yield	Biomass	Grain yield	Biomass
Control	300.7 ^{b}	916.7 ^{b}	419.5 ^{d}	1218.8 ^{d}	566.6 ^{b}	1222.2 ^{b}
NPSZnB	2112.9 ^{a}	5099.0 ^{a}	3126.6 ^{b}	7283.6 ^{b}	2536.7 ^{a}	5644.1 ^{a}
NPZnB	2437.2 ^{a}	6059.9 ^{a}	3081.3 ^{b}	7030.7 ^{b}	2965.2 ^{a}	6982.6 ^{a}
NPSB	2364.8 ^{a}	5904.9 ^{a}	2924.8 ^{b}	6877.3 ^{b}	2295.9 ^{a}	5191.0 ^{a}
NPSZn	2418.4 ^{a}	5346.4 ^{a}	2945.4 ^{b}	6588.0 ^{b}	2704.5 ^{a}	5704.9 ^{a}
NPKSZnB	2066.8 ^{a}	6615.9 ^{a}	3270.2 ^{b}	7071.8 ^{b}	2570.3 ^{a}	5362.8 ^{a}
NP	2697.1 ^{a}	5113.3 ^{a}	3226.7 ^{b}	7134.3 ^{b}	2703.5 ^{a}	6053.8 ^{a}
50%NPKSZnB	1772.7 ^{a}	4147.2 ^{a}	2409.3 ^{c}	4871.5 ^{c}	2352.8 ^{a}	5215.3 ^{a}
150%NPKSZnB	2615.1 ^{a}	6163.8 ^{a}	3942.5 ^{a}	8383.1 ^{a}	2535.7 ^{a}	5474.0 ^{a}
CV(%)	26.3	28.8	17.1	15.9	18.0	19.2
P level (0.05)	***	***	***	***	***	***

*CV: coefficient of variation, ***: significant at 0.1 %. Numbers in parentheses indicate the number of observations in each landscape.*

Response of bread wheat to omitted nutrients

There was variability between sites from the omission of a macronutrient from the K and S treatment and micronutrients from Zn and B in bread wheat yield in study areas (Figure 3). The omitted treatments did not show significant yield differences in both previously lime-amended and not amended trial sites. The omissions of zinc (All-Zn) and boron (All-B) led to a non-significant reduction of yield compared to the NPKSZnB treatment in previously lime-amended sites. This result is harmonized with Tadele et al. (2018, 2019) which indicates that the addition of K is not increased crop yield significantly in most bread wheat growing areas of Ethiopia. In the Machakel district, the omission of Zn in sites of hill landscapes exhibited a negative Zn index (Figure 4). This finding, however, does contradict that of Kihara et al. (2022), who stated that micronutrients are required to increase wheat output.

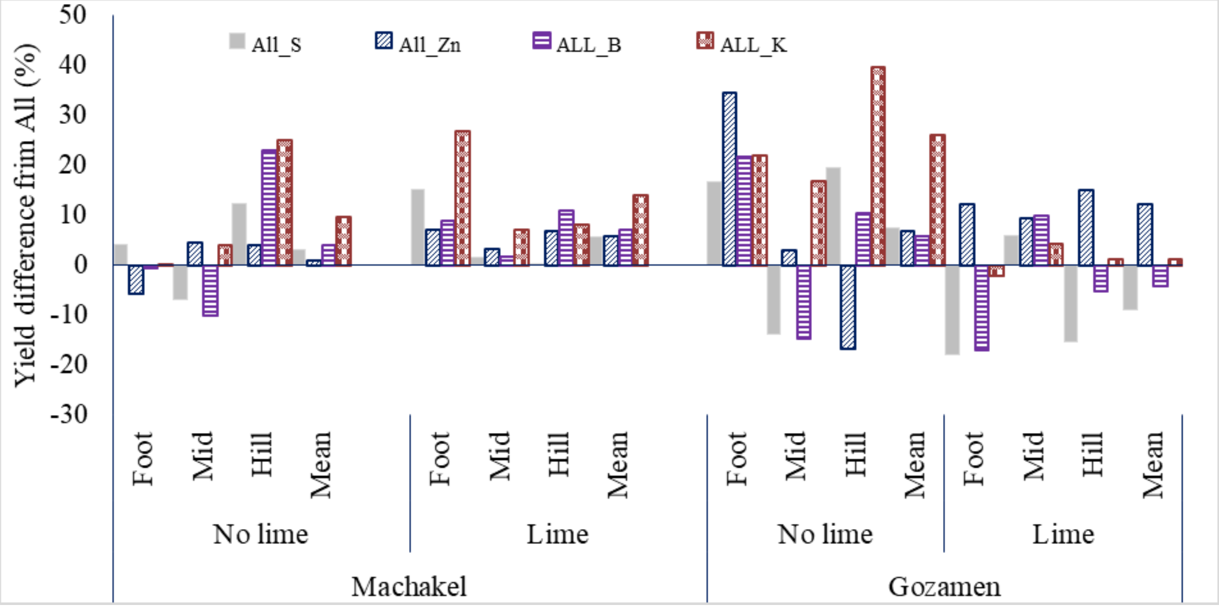

Figure 5. Effect of omission of S, K, Zn, and B on bread wheat yield (%) compared to NPKSZnB in Machekel and Gozamen districts. Error bars are confidence intervals. Note: All = NPKSZnB applied

Response of teff and bread wheat to lime amendment

The result indicated that previously lime amendment plus nutrient type and rate have a relatively higher yield of tef and bread wheat across all landscape positions except with deviation at the hill (teff) in Machakel and Gozamen districts and foot (bread wheat) in Machakel district (Figure 4 and 5). This might be associated with blanket rate lime application during 2019/20. The fertilizer application was varied across landscapes. Because when the slope is increased, there is a decrease in crop yield (Amede et al., 2020). It might be related to the decline of soil fertility. The highest mean grain yield of tef 872, and 994 kg ha^{-1} were recorded in lime amended at foot, and without lime amended at mid landscape positions (Figure 4), while the bread wheat yield 2846 and 2160 kg ha^{-1} were observed from lime amended at mid landscape position, respectively (Figure 5).

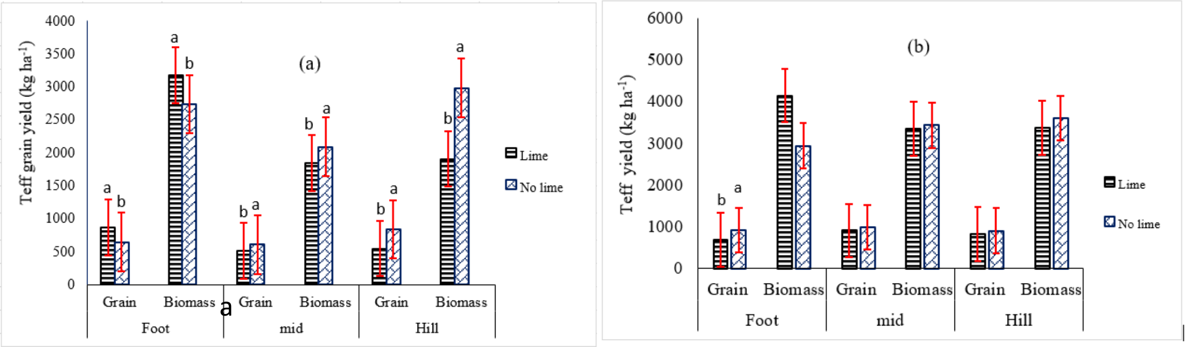

Figure 6. Effect of lime amendment and landscape on teff grain yield and biomass in Machake (a) and Gozamen (b) districts. Short lines at the top of each bar represent the standard error of lime amendment, lowercase letters indicate significant differences ($p<0.05$) among lime amendments.

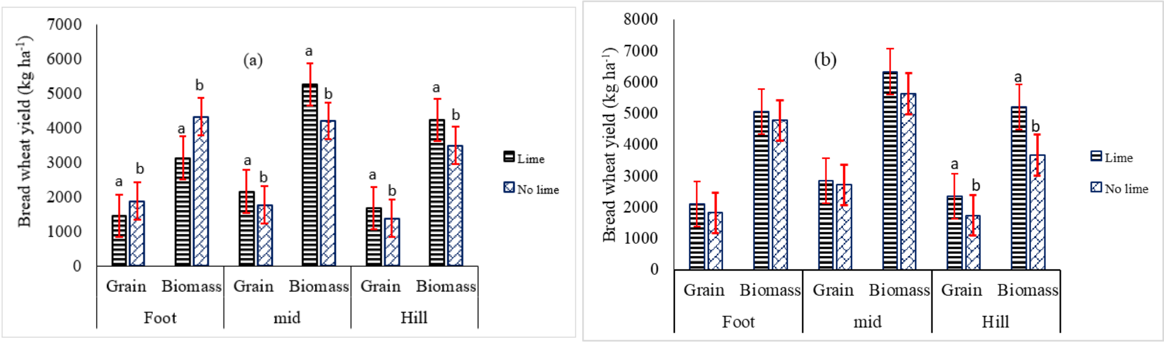

Figure 7. Effect of lime amendment and landscape on bread wheat grain yield and biomass in Machake (a) and Gozamen (b) districts. Short lines at the top of each bar represent the standard error of lime amendment, lowercase letters indicate significant differences ($p<0.05$) among lime amendments.

Teff and bread wheat response to the nutrient type and rate across three landscapes and lime amendment

The combined analysis of variance revealed that the mean tef yield was highly significantly different among nutrient types ($p < 0.001$) whereas there was no significant variation in tef yield due to the interaction effect of nutrient types, lime amendment, and landscape position in the study districts (Table 12). The grain yield of tef was significantly varied with lime amendment ($p < 0.01$) and landscape positions ($p < 0.05$) in Machakel district (Table 12).

Table 30. Analysis of variance for different factors to teff in acidic soils of East Gojjam zone districts

	Gozamen		Machakel	
Factors	Grain yield	Biomass	Grain yield	Biomass
Nutrient types	0.09^{ns}	0.003**	1.6^{-11}***	2.2^{-16}***
Landscape	0.03*	0.7^{ns}	0.0001***	5.5^{-10}***
Amendment	0.9^{ns}	0.2^{ns}	0.003**	9.2^{-5}***
Nutrient types *Landscape	1.0^{ns}	0.9^{ns}	1.0^{ns}	0.4^{ns}
Nutrient types *Amendment	1.0^{ns}	0.9^{ns}	1.0^{ns}	0.9^{ns}
Landscape * Amendment	0.02*	0.007**	1.9^{-5}***	2.2^{-5}***
Nutrient types *Landscape*Amendment	1.0^{ns}	1.0^{ns}	1.0^{ns}	0.9^{ns}

****: significant at 0.1%, **: significant at 1 %, *: significant at 5 %, ns: non-significant.*

Likewise, teff, the result for bread wheat at Gozamen and Machakel districts on acidic soils indicates that there was a highly significant ($p<0.001$) yield difference among nutrient type and the rate at three landscapes with lime amendment (Table 13). Maximum and significant biological grain and biomass yield were recorded when 150% NPKSZnB was applied in both districts. A highly significant yield of bread wheat was obtained due to the application of nutrients compared to no input at all (control). However, there was no significant difference among nutrient types (between NP and NPKSZnB) in both districts.

Table 31. Analysis of variance of bread wheat yield and biomass response across landscapes and lime amendment in acidic soils of study districts

	Gozmen		Machakel	
Factors	Grain yield	Biomass	Grain yield	Biomass
Nutrient types	2.2^{-16}***	2.2^{-16}***	2.2^{-16}***	2.2^{-16}***
Landscape	3.3^{-14}***	4.3^{-13}***	3.4^{-8}***	1.4^{-6}***
Amendment	0.002**	4.5^{-6}***	0.0003***	0.0005***
Nutrient types *Landscape	0.7^{ns}	0.8^{ns}	0.9^{ns}	1.0^{ns}
Nutrient types *Amendment	0.7^{ns}	0.04*	0.9^{ns}	0.8^{ns}
Landscape * Amendment	0.047*	1.0ns	0.0002***	0.0001***
Nutrient types *Landscape*Amendment	0.9^{ns}		0.9^{ns}	0.8^{ns}

****: significant at 0.1 %, **: significant at 1 %, *: significant at 5 %, ns: non-significant, CV: coefficient of variation, amendment: lime management*

The maximum grain (1026 and 942 kg ha-1) and biomass (4246 and 3703 kg ha^{-1}) yields were recorded from 150% NPKSZnB treatment (Table 14). In Gozamen district, there was a non-significant grain yield between NP, NPKSZnB, and 150% NPKSZnB. This is supported by

Alemayehu et al. (2022) who stated yield of tef is not maximized due to the application of KSZnB nutrients. However, the result disagreed with Gessesew et al. (2022) who described that applying higher rates of NPSZnB nutrients enhances crop yield. how

Table 32. Combined tef and biomass yield response to nutrient types and rate across landscapes and lime amendment in acidic soils of East Gojjam zone districts

	Gozamen		Machakel	
Factors	Grain yield	Biomass	Grain yield	Biomass
Nutrient types				
NPSZnB	868.1^{ab}	3357.5 ^{bc}	568.2 ^{c}	1252.4 ^{d}
NPZnB	935.2^{a}	3652.6^{ab}	651.5 ^{bc}	2129.3 ^{bc}
NPSB	838.4^{ab}	3090.6 ^{bc}	585.4 ^{c}	2178.0 ^{bc}
NPSZn	896.6 ^{ab}	3535.0 ^{ab}	578.6 ^{c}	2120.1 ^{bc}
NPKSZnB	941.8 ^{a}	3438.7 ^{b}	738.2 ^{b}	2058.2 ^{c}
NP	916.3^{ab}	3606.4 ^{ab}	608.0 ^{bc}	2557.8 ^{b}
50%NPKSZnB	736.0^{b}	2636.2 ^{c}	384.0 ^{d}	2170.0 ^{bc}
150%NPKSZnB	1026.1^{a}	4245.8 ^{a}	942.2 ^{a}	3703.1 ^{a}
Landscape				
Foot	807.5 ^{b}	3543.5	758.1 ^{a}	2954.1 ^{a}
Mid	949.5 ^{a}	3488.5	562.2 ^{c}	1967.0 ^{c}
Hill	869.3 ^{ab}	3385.6	656.3 ^{b}	2309.7 ^{b}
Amendment				
Lime	901.3	3553.5	588.3 ^{b}	2091.0 ^{b}
No lime	888.7	3326.0	684.4 ^{a}	2487.2 ^{a}
CV(%)	38.3	40.4	34.4	29.2

****: significant at 0.1%, **: significant at 1 %, ns: non-significant, CV: coefficient of variation.*

A higher yield of bread wheat was obtained from the mid-landscape position. Yield variability has occurred across landscape positions within farmers' fields with a range of 588 and 901 kg ha^{-1} (Table 15). This finding was contrary to Amede et al. (2020) who stated higher yield is recorded in foot landscapes due to relatively improved soil fertility at the lower slopes.

Table 33. Overall bread wheat yield and biomass response to nutrient types and rate across landscapes and lime amendment in acidic soils of East Gojjam zone districts

Factors	Gozmen		Machakel	
	Grain yield	Biomass	Grain yield	Biomass
Nutrient types				
Control	351.8 ^{d}	941.9 ^{c}	267.5 ^{d}	1067.5 ^{f}
NPSZnB	2399.5 ^{bc}	5740.4 ^{a}	1805.8 ^{b}	4351.6 ^{cd}
NPZnB	2753.7 ^{ab}	6148.2 ^{a}	1968.9 ^{b}	4492.9 ^{cd}
NPSB	2465.8 ^{bc}	5650.0 ^{a}	1818.1 ^{b}	4193.6 ^{cd}
NPSZn	2704.1 ^{ab}	5807.1 ^{a}	1915.8 ^{b}	3806.9 ^{de}
NPKSZnB	2733.9 ^{ab}	6059.3 ^{a}	2021.7 ^{b}	5274.3 ^{b}
NP	2758.9 ^{ab}	6316.2 ^{a}	1891.7 ^{b}	4706.2 ^{bc}
50%NPKSZnB	2167.5 ^{c}	4548.1 ^{b}	1318.2 ^{c}	3294.4 ^{e}
150%NPKSZnB	2999.5 ^{a}	6457.0 ^{a}	2486.3 ^{a}	6387.0 ^{a}
Landscape				
Foot	1958.6 ^{b}	4922.0 ^{b}	1663.3 ^{b}	3713.4 ^{b}
Mid	2789.2 ^{a}	6028.2 ^{b}	1963.0 ^{a}	4733.3 ^{a}
Hill	2010.4 ^{b}	4336.3 ^{c}	1535.4 ^{b}	3868.1 ^{b}
Amendment				
Lime	2568.7 ^{a}	5808.3 ^{a}	1844.6 ^{a}	4475.8 ^{a}
No lime	2220.0 ^{b}	4883.4 ^{b}	1626.5 ^{b}	3933.0 ^{b}
CV(%)	32.9	27.7	28.8	30.6

****: significant at 1 %, **: significant at 5 %, ns: non-significant, CV: coefficient of variation, treatment: nutrient type and rate, amendment: lime management*

Conclusions and Recommendations

The application of different nutrient types has a significant grain and biomass yield of teff and bread wheat across landscape positions with and without lime application in acidic soils of the East Gojjam zone. Teff yield cannot obtain without fertilizer application in the study area. Similarly, the lowest yield of bread wheat was obtained without fertilizer application (no input). There was yield variability among trial sites and applied nutrients in the study area. The application of all nutrient types (NPKSZnB) has no significant yield advantage compared to NP fertilizer alone. This implies that N and P are the most yield-limiting nutrients compared to other applied nutrients in the acidic soils of Machakel and Gozamen districts whereas the application of KSZnB nutrients was not yield-limiting. Therefore, refining the rate of NP in acidic soils is important for the sustainable use of inorganic fertilizer. The application of sulfur fertilizer with NP needs further study. Future research is looked-for to finetune crop response to micronutrient element's limitations for grain yield with the support of grain quality analysis to meet the demand for food nutrition.

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References

Ahmad, M., Alam, S., Ahmad, W., Jan, I., and Zia, A. (2018). Application of the 4R nutrient stewardship concept for growing off-season tomatoes in high tunnels. *Journal of Soil Science and Plant Nutrition*, *18*(4), 989–1001. https://doi.org/10.4067/S0718-95162018005002803

Alemayehu, B., Adgo, E., and Amare, T. (2022). Nutrients Limiting Tef [Eragrostis tef (Zucc.) Trotter] Crop Yield on Vertisols in Yilmana Densa, Upper Blue Nile Basin of Ethiopia. *Journal of Plant Growth Regulation 2022*, 1–13. https://doi.org/10.1007/S00344-022-10741-Y

Aleminew, A and Legas, A. (2015). *Grain quality and yield response of malt barley varieties to nitrogen fertilizer on brown soils of Amhara Region, Ethiopia, 11(3):135–143. 11*(3), 135–143. https://doi.org/http://doi.org/10.5829/idosi.wjas.2015.11.3.94283

Amede, T., Gashaw, T., Legesse, G., Tamene, L., Mekonen, K., Thorne, P., and Schultz, S. (2020). Landscape positions dictating crop fertilizer responses in wheat-based farming systems of East African Highlands. *Renewable Agriculture and Food Systems, April*. https://doi.org/10.1017/S1742170519000504

Argaw, A. and Tsigie, A. (2015). *Indigenous rhizobia population influences the effectiveness of Rhizobium inoculation and need of inorganic N for common bean (Phaseolus vulgaris L.) production in eastern Ethiopia. Chemical and Biological Technologies in Agriculture, 1–13.* https://doi.org/http://doi.org/10.1186/s40538-015-0047-z

Ayalew, A. (2011). *Application of NP fertilizers for better production of teff (Eragrostis tef (zucc.) trotter) on different types of soils 1(1):6–16. 1*(1), 6–16.

Barłóg, P., Grzebisz, W., and Łukowiak, R. (2022). Fertilizers and Fertilization Strategies

Mitigating Soil Factors Constraining Efficiency of Nitrogen in Plant Production. *Plants*, *11*(14). https://doi.org/10.3390/plants11141855

Birhan, A., Sofiya, K., Temesgen, D., Kassu, T., Mihreteab, H., Fana, G., Abera, T., Tilahun, A., and Degefie Tibebe. (2017). *Section 2 Crop response to fertilizer application in Ethiopia : a review 3* (No. 443; Issue October).

Bremner, J. M. and C. S. Mulvaney. (1982). *Nitrogen-total, In A. L. Page ed. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. Agronomy 9. Madison, Wisconsin*. 595-624.

Cochran, W. G. (William G., & Cox, G. M. (1992). *Experimental designs*. 611. https://www.wiley.com/en-us/Experimental+Designs%2C+2nd+Edition-p-9780471545675

EMA, (Ethiopia Metreological Agency). (2020). *Records of weather data from 2008 to 2018 in Bahir Dar Branch*.

EthioSIS, (Ethiopian Soil Information System). (2016). *Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia.*

Ferguson, R. B. (2006). *Crops in Nebraska for in Nebraska*.

Gessesew, W. S., Elias, E., Gebresamuel, G., & Tefera, W. (2022). Soil type and fertilizer rate affect wheat (*Triticum aestivum* L.) yield, quality and nutrient use efficiency in Ayiba, northern Ethiopia. *PeerJ*, *10*, e13344. https://doi.org/10.7717/peerj.13344

Habtegebrial, K and Singh, B. (2009). Response of wheat cultivars to nitrogen and sulfur for crop yield, nitrogen use efficiency, and protein quality in the semiarid region. *Journal of Plant Nutrition*, *32*(10), 1768–1787. https://doi.org/http://dx.doi.org/10.1080/01904160903152616

Habtegebrial, K. (2013). Nitrogen and sulfur fertilizers effects on yield, nitrogen uptake and nitrogen use efficiency of upland rice variety on irrigated Fulvisols of the Afar region, Ethiopia. *Journal of Soil Science and Environmental Management*, *4*(3), 62–70. https://doi.org/http://dx.doi.org/10.5897/JSSEM13.0389

Hirpa, A., Meuwissen, M. P. ., Lans, I. A. Van der, Lommen, W. J. M., Oude, L. A. G. J. M., Tsegaye, A., and Struik, P. C. (2012). Farmers' opinion on seed potato management attributes in Ethiopia: A conjoint analysis. *Agronomy Journal, 104*, 1413–1424.

Houba, V.J.G. Novozamsky, I. Huybregts, A.W.M. and Van der Lee, J. J. (1986). Comparison of soil extractions by 0.01M CaCl2, by EUF, and by some conventional extraction procedures. *Plant and Soil*, *96*(3), 433-437.

Kebede D. Ketema M. (2017). Why do smallholder farmers apply inorganic fertilizers below the recommended rates? Empirical evidence from potato production in eastern Ethiopia. *Adv. Crop Sci Tech, 5*.

Kihara, J., Gurmessa, B., Tamene, L., Amede, T., and Sommer, R. (2022). Understanding factors influencing wheat productivity in Ethiopian highlands. *Experimental Agriculture*, *58*, 1–18. https://doi.org/10.1017/S0014479721000296

Kolawole, G. O., Eniola, O., and Oyeyiola, Y. B. (2018). Effects of nutrient omission on maize growth and nutrient uptake in three dominant soil types of southwestern Nigeria. *Journal of Plant Nutrition*, *41*(15), 1903–1915. https://doi.org/10.1080/01904167. 2018.1482909

Lean, E. O. (1982). Soil PH and Lime Requirement. In Methods of Soil Analysis Part 2. edited by D. AL, Miller, RH and Keeney. In *American Society of Agronomy*.

Mann, M and Warner, J. (2015). *Ethiopian Wheat Yield and Yield Gap Estimation: A Small Area Integrated Data Approach*.

Nega, Emru and Heluf, G. (2009). Influence of land use changes and soil depth on cation exchange capacity and contents of exchangeable bases in the soils of Senbete watershed, Western Ethiopia. *Ethiopian Journal of Natural Resources*, *11*(2), 195-206.

Nziguheba, G., Diels, J., Franke, L., & Nwoke, O. C. (2009). Assessment of nutrient deficiencies in maize in nutrient omission trials and long-term field experiments in the West African Savanna Assessment of nutrient deficiencies in maize in nutrient omission trials and long-term field experiments in West Africa. *Plant Soil*, *July*, 1–16. https://doi.org/10.1007/s11104-008-9714-1

Olsen, S.R. and Sommers, L. E. (1982). *Phosphorus Analysis. In: L. Miller, R.H. and Keeney. Wisconsin (ed.).*

Rawal, N., Khatri, N., Gc, C. B., & Chaurasiya, B. P. (2018). Determination of indigenous nutrient supplying capacity of soil through omission plot experiment for wheat in Western Terai of Nepal. In *J. Inst. Agric. Anim. Sci* (Vol. 35).

Scherer H.W. (2001). Sulfur in crop production. *European J. Agron*, *14*, 81–111.

Tadele, Amare Amlaku, Alemayehu Bitewlign, Kerebih Zerfu, Bazie Erikhun, Alemu Assefa, Derebe Tesfaye, Feyisa Abebe, Getu Sefinew, Wale and Dessalegn, G. (2019). Verification of crop responses to potassium and zinc and boron-containing fertilizers in the Northwestern Amhara Region. *Workshop Proceedings of Amhara Agricultural Research Institute (ARARI)*, *1*, 148–161.

Tadele, Amare Zerfu, Bazie Erkihun, Alemu Asmare, Wubet Birhanu, Agumas Mengistu, Muche Tesfaye, Feyisa and Desalew, F. (2018). Crops response to balanced nutrient application in Northwestern Ethiopia. *Blue Nile Journal of Agricultural*, *1*(1), 1–14.

Tadesse, Dessalegn Bedada Girma TS, Payne CS, and van Deventer, M. L. (2000). Sources of variation for grain yield performance of bread wheat in northwestern Ethiopia. *In: The Eleventh Regional Wheat Workshop for Eastern, Central and Southern Africa*, 16–24.

Tadesse, T., I. Haque, A., and Aduayi, E. A. (1991). *Soil, plant, water, fertilizer, animal manure and compost analysis manual.pdf* (No. B13).

Tamene, L Amede, T Kihara, J., and Tibebe, D and Schulz, S. (2017). *A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- and context-specifc fertilizer recommendation. CIAT Publication No. 443. International Center for Tropical Agriculture (CIAT), Addi* (No. 443). http://hdl.handle.net/10568/82996

Tefera, N., Ayele, G., Abate, G., and Rashid, S. (2012). *Fertilizer in Ethiopia: Policies, Value Chain, and Profitability. A report submitted for the Ethiopian Agricultural Transformation Agency*.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and, and Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. , 339:35-50. *Plant and Soil*, *339*, 35–50.

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, *37*, 29-38.

Zeleke, G., Agegnehu, G., Abera, D., and Rashidhid, S. (2010). *Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system*.

Soil-test Crop Response Based Phosphorus Calibration Study under Balanced Fertilization of Bread Wheat (*Triticum aestivum* L.) on Nitisols in North West of Ethiopia

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Abstract

In Ethiopia, phosphorus (P) is the second major yield limiting nutrient next to nitrogen. Hence efficient management of P nutrient is critically needed in Northwestern Ethiopia where higher amount of crop is produced. Six years (2014-2019) research on permanent fields were conducted to develop phosphorus requirement equation to recommend P fertilizer based on soil test results for improving wheat (Triticum aestivum L.) productivity. The experiment was started by creating different artificial phosphorus gradient fields in the first 2 years (2014-2015). For the other three consecutive cropping years (2017-2019), plot based field experiment was conducted on different P level gradient fields. The field experiment had seven treatments (0, 10, 20, 30, 40, 50 and 60) P kg ha^{-1}*. Randomized complete block design (RCBD) with 3 replications was used. All treatments received equal levels of N, K and S nuutreints in all gradient fields through out the cropping years. Urea, Triple Supper-Phosphate (TSP), Muriate of Potash (KCl) and Calcium sulfate (CaSO4) were used as N, P, K and S sources, respectively. Improved bread whaet variety (TAY) was used as a test crop. In all cropping years, P, K and S fertilizers were applied in band at planting while, N was applied in three equal splits (1/3 at planting, 1/3 at 40-45 days after planting and 1/3 at booting). All other crop management practices were implemented as per the recommendations. Soil samples were taken in P gradient formation period, as well as in all cropping years from each experimental plot from 0-20cm depth and selected chemical soil parameters (pH, SOC, and available P) were analyzed. The yield and yield components such as plant height, grain and biomass yield of bread wheat showed a highly significant difference (p≤0.0001) among treatment means due to different phosphorus rate for both each and combined years. Soil phosphorus values also showed increasing trend as the applied phosphorus amount increased within the defined treatments. Finally, 10 mg kg*$^{-1}$ *of soil P was determined as phosphorus critical point (Pc) and 7.5 phosphorus requirement factor (Pf) values were obtained from over-year combined analysis result using the Cate-Nelson graphical method. Using these two critical values, it is better to conduct a verification study on the farmer' fields with similar agro-ecology and soil types to validate whether the developed equation is economically acceptable or not.*

Keywords: Bread wheat, Crop Response, Phosphorus, Soil test based

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most staple food crops in the world as well as in Ethiopia. In Ethiopia it stands fourth in both area coverage and total annual production. But, in yield potential, it is 2nd ranked next to maize (CSA, 2017). Ethiopia is the largest wheat producer in sub-Saharan Africa (SSA) with about 0.75 and 1 million ha of durum and bread wheat respectively. Even though its area coverage is over 1.7 million ha, its productivity is as low as 2.9 t ha^{-1} compared to the average cereal yields of 3 t ha^{-1} in the developing world due to poor soil fertility and crop management practices (Kiflemariam et al., 2022).

However, soil fertility depletion became critical challenge for bread wheat production in Ethiopia. To reverse the situation and advices best fit recommendations for small holder farmers, monitoring and frequent reviewing of soil fertility status are important. In Ethiopia nitrogen (N) and phosphorus (P) are the most yield limiting soil nutrients (Tadele *et al.,* 2018). It has been considered as a major factor for limiting crop productivity and recommended to apply in large amounts on the soil since the green revolution to sustain production of agricultural systems (Tilman *et al.,* 2002). Relative to N, recovery of P fertilizers by plants is very low due to its high fixation capacity in the soil (Balemi and Negisho, 2012).

One of the best methods for nutrient recommendations is to calibrate and validate the nutrient requirements using long term experimental data. Nutrient calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current nutrient recommendations (McKenizie and Kryzanowski, 1997). It enables to revise fertilizer recommendations based on soil and crop types, pH and soil moisture content at time of planting. Soil tests are designed to help farmers to know the available nutrient status of their soil. Once the nutrient status determined, it is possible to decide how much nutrients to be applied to get economically acceptable yields (Getachew and Berhane, 2013 and (Getachew *et al.,* 2015).

However, for P calibration and validations, determination of soil P critical and soil P requirement factor for bread whaet on major agro ecology and soil types for Western Amhara is lacking. Hence, to bridge this gap, Adet Agricultural Research Center (AARC) proposed a long-term soil test-based and site-specific P calibration study under balanced fertilization for bread whaet on nitisols. Therefore, the objective of this research was to develop P calibration equation and recommendations of P fertilizer requirement factor for bread wheat on nitisol for western Amhara region.

Materials and Methods

The experiment was conducted from 2014-2019 on Nitisols permanent plot of AARC research station. At the beginning of the study (2014) the experimental field was divided into 4 sub plots which received equal doses of N, potassium (K) and sulfur (S) using the rates of 92 kg ha^{-1} N, 90 kg ha^{-1} K_2O and 30 kg ha^{-1} S, respectively. By considering 115 kg ha^{-1} P_2O_5 as base line rate, the four fields were received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5. In 2015, each sub-plot divided in to four sub-sub plot and received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5 and formed 16 total fields having different P gradient levels. The same amount of NKS fertilizers was applied on the sub-sub plots for the second year.

After creating different P gradient fields (2014-2015), plot based experiment was started on each P gradient fields using seven levels of P nutrient rates (0, 10, 20, 30, 40, 50 and 60 kg ha^{-1}). Randomized complete block design (RCBD) with three replications was used. Similar to the gradient formation years, equal amount of N, K and S were applied on each experimental plot. The plot based experiment was implemented for two cropping years (2018-2019) at all P gradient fields. Artificially created P gradient fields were used as a simulation for three categories of soil with low; medium and high P content.

Improved bread wheat variety (TAY) was used as test crop for this experiment. Urea, triple supper-phosphate (TSP), *muriate*of potash (KCl) and Calcium sulfate ($CaSO_4$) were used as the sources of N, P, K and S, respectively. P, K and S fertilizer sources were normally applied in band at planting while, N was applied in 3 equal splits which was 1/3 at planting, 1/3 at 40-45 days after planting and the remaining 1/3 at booting stage. The other crop management practices were implemented as per the recommendation.

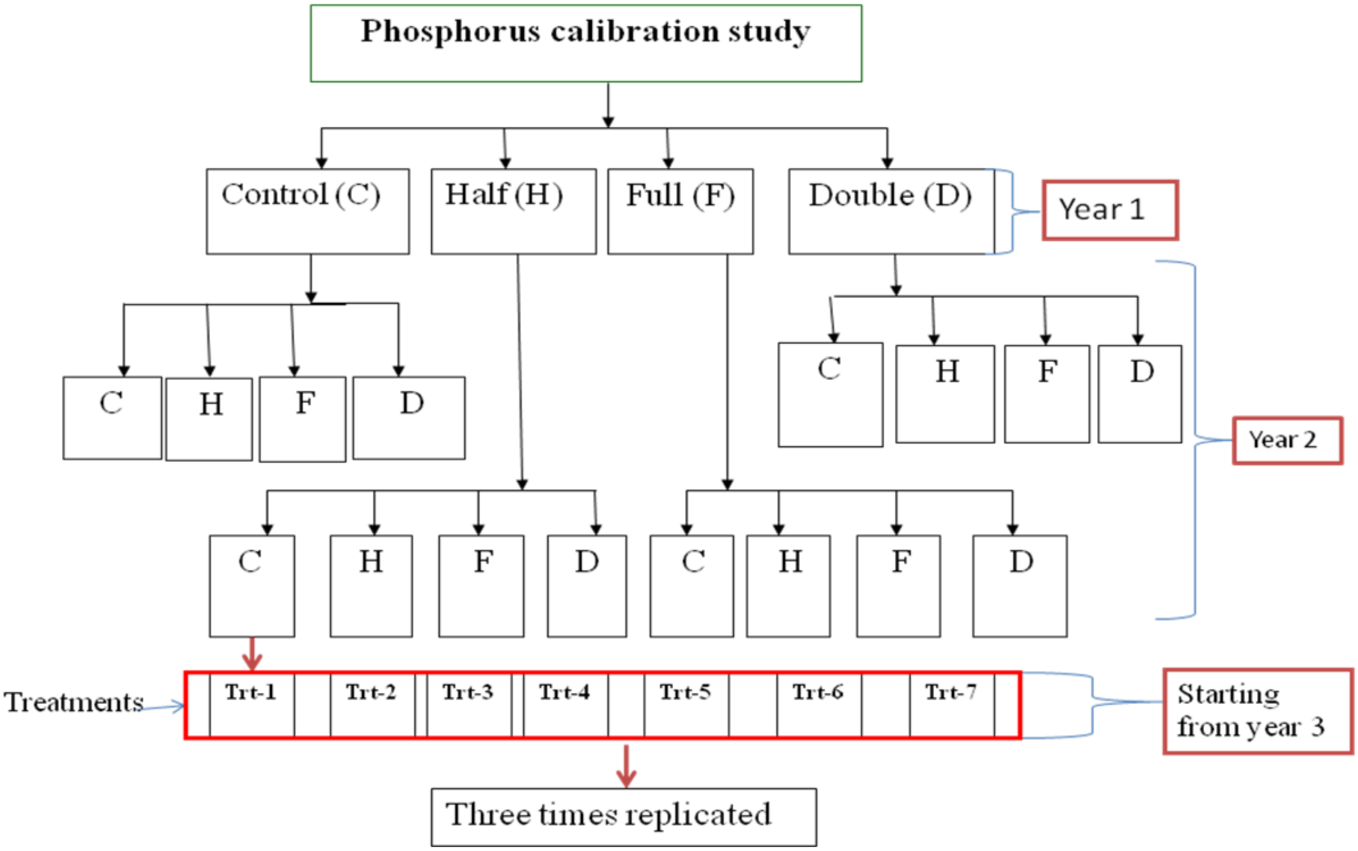

Figure 8. Schematic field layout for the above mentioned experiment

Soil Sampling and Analysis Procedure

One initial, 4 in 2015 (from 1st year gradient fields) and 16 in 2016 (from 2nd year gradient fields) composite soil samples were taken at the depth of 0-15cm. All the collected composite soil samples were subjected for some chemical soil parameters analysis (pH, SOC, and available P) in AARC soil laboratory. According to Landon (1991) available P value for initial soil was under low ratting level (3.3 P mg kg^{-1}) (Table 1). Similarly, artificially created fields were catagorized as low (<5 P mg kg^{-1}), medium (5-15 P mg kg^{-1}) and high (>15 P mg kg^{-1}). Therefore, from the total of 16 artificial P gradient fields, we got 5 low, 10 medium and 1 high P gradient fields which served as experimental field. Each experimental field was taken as repilication (Table 2).

Similar to gradient formation years, soil samples were collected continuously from each experimental plot at 0-15cm depth before the testing crop planted and were taken as avialble P values for phosphorus critical (PC) value determination. The sampled soils in each year were air dried and sieved (≤2 mm) for analysis. From these, soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Taye *et al.* (2002) while, available phosphorus (AP) was analyzed using Olsen method (Olsen, 1954) and soil organic carbon (SOC) was determined following the method stated by Nelson and Sommer (1982).

Table 34. Initial and four P gradient fields (2014) soil data values

				Year 1 (2014)	
Soil parameters	Initial	control plot	Plot received Half (57.5 kg ha^{-1} P_2O_5)	Plot received Full (115 kg ha^{-1} P_2O_5)	Plot received Double (230 kg ha^{-1} P_2O_5)
pH- H_2O (1:2.5)	5.70	5.79	5.54	5.61	5.59
Ava. P (ppm)	3.30	3.04	4.08	5.50	7.51
SOC (%)	1.659	1.505	1.881	1.610	1.756

Table 35. Each P gradient field soil data values in the second year (2015)

								Year 2 (2015)								
Soil parameters	ZZ	ZH	ZF	ZD	HZ	HH	HF	HD	FZ	FH	FF	FD	DZ	DH	DF	DD
pH	5.58	5.58	5.56	5.56	5.57	5.45	5.34	5.39	5.6	5.53	5.55	5.46	5.64	5.57	5.51	5.56
Pppm	4.34	2.65	6.99	7.25	4.21	4.14	4.47	6.54	12.11	5.11	6.99	9.84	10.36	12.63	12.37	15.16
SOC	0.837	0.817	1.111	1.045	0.898	1.431	1.266	0.893	1.061	1.396	1.623	1.130	1.023	0.963	1.372	1.252

Note: *ZZ=zero, zero, ZH=zero, half, ZF=zero, full, ZD=zero, double, HZ=half, zero, HH= half, half, HF=half, full, HD=half, double, FZ=full, zero, FH=full, half, FF=full, full FD=Full, double, DZ= double, zero, DH= double, half, DF= double, full, DD=double, double.*

Determination of critical P concentration (Pc)

Critical P value was determined following the Cate-Nelson graphical method where soil P (available form) values were put on the X-axis and the relative grain yield values on the Y-axis. Relative yield was calculated using equation 1 in excel. The Cate-Nelson graphical method was divided the Y-X scatter diagram into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson LA and RL Anderson, 1997).

Steps for Cate-Nelson graphical methods in Pc determination:

1. Relative grain yield percentage values were obtained from all artificial created fields using the formulas indicated below.

Relative Grain yield percentage (RGY) = $\frac{Yield\ from\ each\ unit}{Maximum\ Yield} * 100 \ldots\ldots Eq\ 1$

2. Soil test values for the nutrient being studied should be obtained from all the locations. The control plot test values should be averaged. Thus, there will be a single percentage yield and one soil test value for each location.
3. The scatter diagram of relative percentage yield (Y-axis) versus soil test value (X-axis) is plotted on arithmetic paper. The range in values on the Y-axis is 0 to 100%.
4. A piece of clear plastic having roughly one and one-half the dimensions of the graph is cut out for use as an overlay. A pair of intersecting perpendicular lines is drawn on the overlay with black ink in such a way that it is divided in to four quadrants.
5. The overlay is moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). The positions of the lines on the overlay with respect to the axes of the graph are transferred to the graph by making marks on the edges of the graph. The two intersecting lines are then drawn lightly on the graph with pencil. The point where the vertical line crosses the X-axis is defined as ‘critical soil test level.

Determination of P requirement factor (Pf)

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1 mg kg^{-1} soil. Pf is used to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level. It was calculated using available P values in samples collected from unfertilized and fertilized plots. Therefore, Phosphorous requirement factor and the rate of Phosphorus fertilizer to be applied were calculated as follows:

$$\text{Pf}= \frac{kg\ P\ applied}{\Delta\ soil\ P} \ldots\ldots\ldots\ldots\text{Eq 2}$$

$$\text{Rate of P2O5 kg/ha fertilizer to be applied} = (Pc - Pi) * Pf \ldots\ldots\ldots\ldots Eq\ 3$$

Where: Pc=critical P concentration, ΔP= available P value taken after one year P fertilizer applied in each treatment –minus initial P values for the site, Pi= initial P values for the site and Pf=P-requirement factor

Agronomic data collected

Agronomic parameters such as mean plant height (5-10 plants), mean spike length (5-10 spikes), grain and dry biomass yields were collected. To estimate above ground biomass and grain yields of the test crop (bread wheat) 7.8-m^2 was harvested at crop maturity stage in each year. The actual grain yield was adjusted to 12.5% of moisture content.

Data management and analysis

All the collected agronomic and soil data were properly managed using Microsoft excel. The collected data were analyzed using general linear model in SAS software version 9.0 (SAS Institute, 2002). When ever treatment difference existed, Least Significant Difference (LSD) at 5% probability was used for mean sepration.

Results and discussion

Yield and yield components

Plant height and spike length

In each and over year combined results, plant height (PH) of bread wheat showed highly significant difference ($p \leq 0.0001$) among treatment means due to the applied P fertilizer rates which is in agreement with the findings mentioned by (Getachew *et al.*, 2015). Over year combined result as well as the results obtained in each year indicated that minimum PH values were observed at zero level of P (Table 3). Whereas maximum PH values were observed at 60 kg ha^{-1} P during the 2017 and 2019 cropping season while at 30 P kg ha^{-1} in 2018 and over years combined results.

In contrast of PH, spike length (SL) of bread wheat didn’t show any significant difference among the treatment means except 2018 result. But similar to PH, minimum SL values were observed at zero P level with the exception of 2018 value. The maximum SL values were recorded at 40 P kg ha^{-1} P fertilizer rate used in all years (Table 3).

Table 36. Response of applied P fertilizer on bread wheat plant height and spike *length*

Treatment P kg ha^{-1}	Plant height (cm)			Year Combined	Spike length (cm)			Year Combined
	2017	2018	2019		2017	2018	2019	
0	100.0	93.7	69.1	87.6	8.96	9.48	6.83	8.43
10	102.9	97.3	74.6	91.6	9.01	9.54	7.33	8.63
20	104.1	98.6	76.4	93.0	9.09	9.37	7.40	8.62
30	104.2	103.5	77.5	95.1	9.10	9.35	7.39	8.61
40	104.5	101.0	77.5	94.3	9.10	9.67	7.48	8.75
50	104.6	100.9	77.9	94.5	9.09	9.41	7.23	8.58
60	105.3	101.8	77.9	95.0	9.06	9.40	7.29	8.58
Mean	**103.7**	**99.5**	**75.8**	**93.0**	**9.06**	**9.46**	**7.28**	**8.60**
LSD (0.05)	1.5	3.8	1.8	1.5	0.17	0.60	0.20	0.22
Pr.	**	**	**	**	NS	NS	**	NS
CV (%)	3.5	9.6	5.8	6.9	4.6	15.9	7.0	11.0

Grain and Biomass yields

As shown the in Table 4, grain yield (GY) of bread wheat showed a highly significant difference ($p \leq 0.0001$) among treatment means due to the applied P levels in each cropping season as well as in the combined analysis over-year. Including the over-year combined result, GY showed a linearly increasing trend without a turning point as the rate of P applied increased in all cropping years which is in lined with the results reported by (Getachew et al., 2015). Therefore, minimum and maximum values of GY values were recorded on the control treatment (zero P) and treatment which received maximum P levels (60 P kg ha^{-1}), respectively.

Similar to the GY values, biomass yield (BMY) of bread wheat also subjected for a highly significant difference ($p \leq 0.0001$) among the treatment means due to the use of different levels of P fertilizers which is again agreed with the findings stated by Getachew et al. (2015). Although some irregularity (in 2017 and 2018) observed on BMY trends, the overall biomass mean values showed an increasing trend as P levels added increased. The minimum and maximum BMY values were recorded on the control treatment (zero P) and treatment which received maximum P level (60 P kg ha^{-1}), respectively in all cropping years (Table 4).

Table 37. Response of applied P fertilizer on bread wheat grain and biomass yields

Treatment P kg ha^{-1}	Grain yield (kg ha^{-1})			Year Combined	Biomass yield (kg ha^{-1})			Year Combined
	2017	2018	2019		2017	2018	2019	
0	3761.0	2997.1	2262.2	3006.8	8763.4	8397.4	5203.0	7454.6
10	4042.5	3557.3	2959.4	3519.8	9214.7	9254.8	6725.4	8398.3
20	4208.9	3890.8	3310.1	3803.3	9738.2	9647.4	7505.3	8963.7
30	4297.9	4048.0	3498.6	3948.2	10098.0	10029.4	7943.4	9356.9
40	4357.6	4101.5	3583.4	4014.2	10109.5	9783.7	8295.9	9396.4
50	4386.8	4292.2	3698.8	4125.9	10162.9	9978.6	8450.9	9530.8
60	4489.9	4411.1	3716.4	4205.8	10154.9	10272.4	8476.0	9634.4
Mean	4220.7	3899.7	3289.8	3803.4	9748.8	9623.4	7514.3	8962.2
LSD (0.05)	158.6	171.3	166.3	98.5	356.1	711.2	337.1	298.1
Pr.	**	**	**	**	**	**	**	**
CV (%)	9.4	10.9	12.6	11.2	9.1	18.4	12.5	14.4

Critical P concentration (Pc) and P requirement factor (Pf)

In general, available soil P values showed a linear trend as the applied P fertilizer increased in all cropping years. However, when we observe across years trend, 2018 available P values by far differ and higher than other two cropping years (2017 and 2019) in each treatment levels which might be happened due to climatic variations (Figure 2).

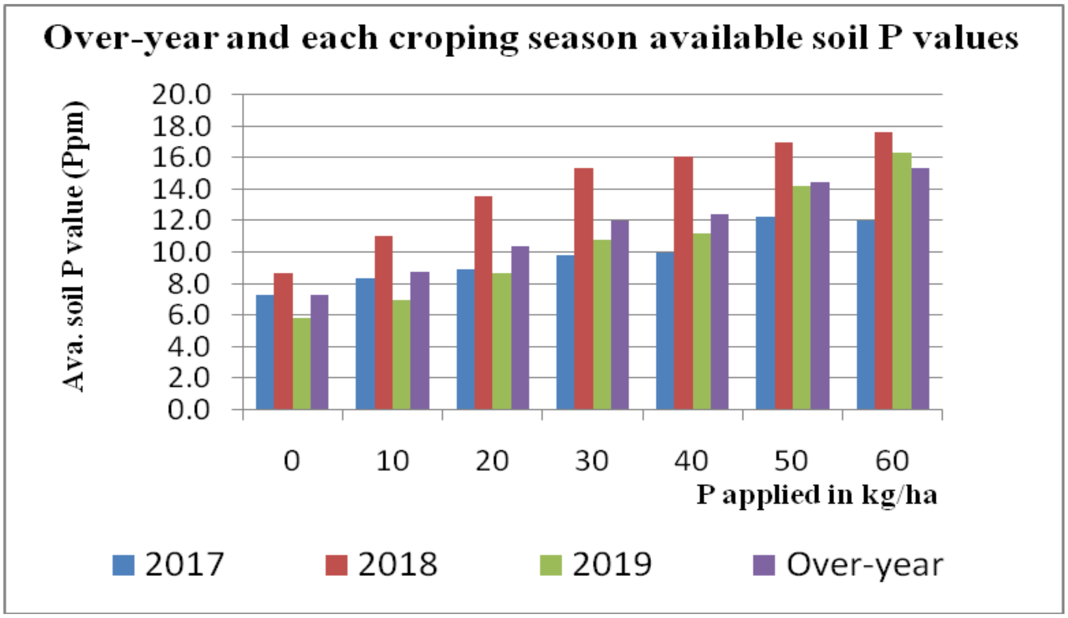

Figure 9. Applied P verses available soil P values for three trial seasons and year combined

The critical P concentration (Pc) values were determined from the scatter diagram drawn using relative grain yields of wheat and the corresponding soil test P values obtained one year after the application of P levels (0–60 kg ha^{-1}). Based on Cate-Nelson Pc determination method, the Pc values in 2017, 2018, 2019 and over-year combined were 9, 12, 9 and 10 P mg kg^{-1} soil, respectively (Figure 3).

All Pc values could help to achieve a minimum of 70% of the wheat grain yeild production without any stress if other factors were found normal. However, if an initial soil P value found below the critical levels, additional P nutreint is needed. Hence, to quantify the required P to achieve the required grain yield, calculating of P nutrient based on equation 3 is required. The P requirement factor (*Pf*) one the other hand the amount of P required to raise the soil P by (1 Ppm) and could be computed from the difference between available soil test P values from plots which received (0–60) kg P ha^{-1} and initial P using the formula indicated in (Eq 2). Therefore, in this study, the calculated Pf values in 2017, 2018, 2019 and their over-year combination were 12.0, 5.2, 6.9 and 7.0, respectively (Table 5).

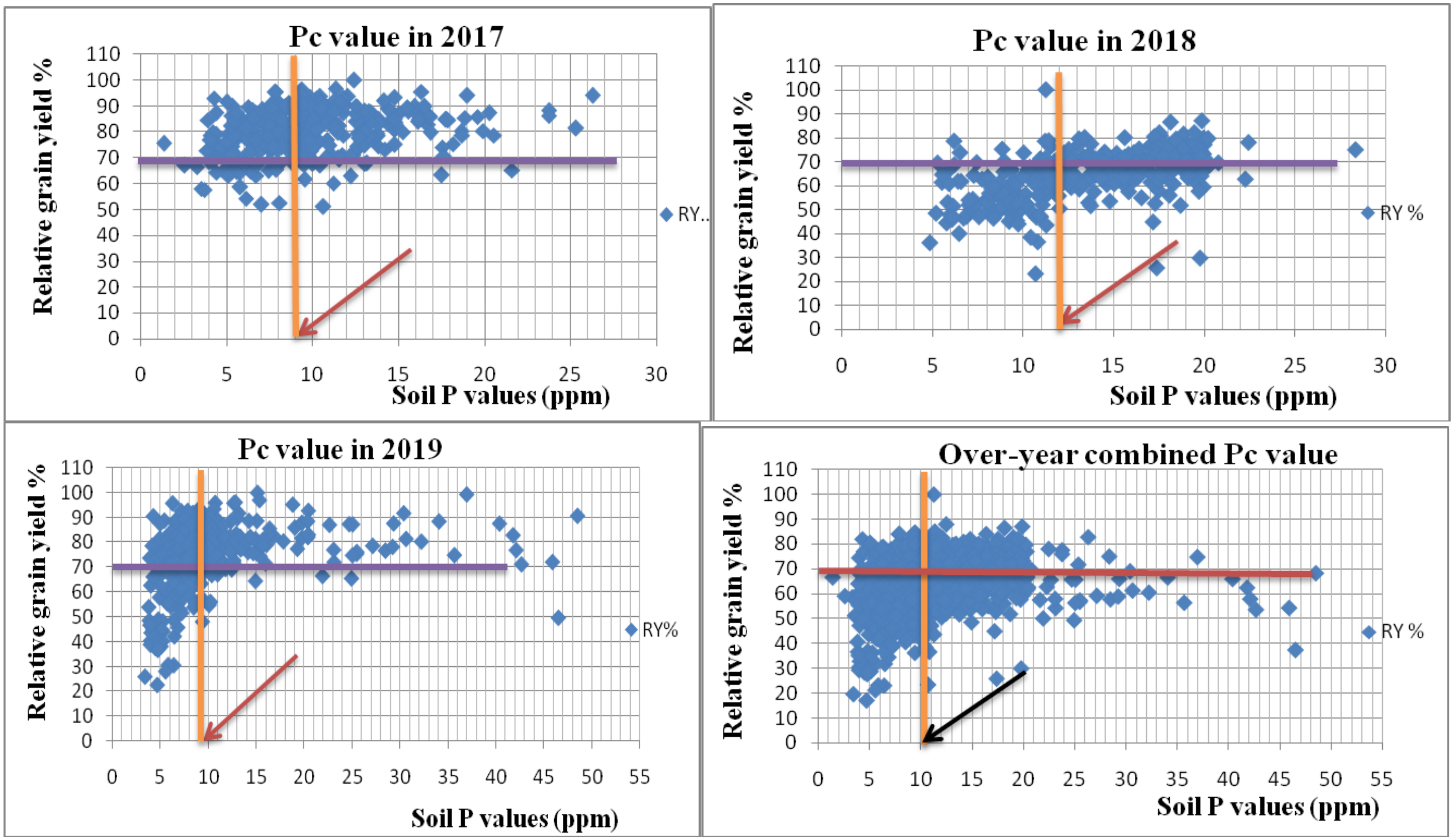

Figure 10. Cate-Nelson graphics for Pc values determination. The point on arrows indicates Pc for wheat on Nitisols

Table 38. The three years and their over-year combined phosphorus requirement factors (Pf) values.

P (kg ha^{-1})	2017				2018			
	range	Mean	P increase over control	Pf	range	Mean	P increase over control	Pf
0	1.4-17.6	7.4	-		4.8-17.4	8.7	-	
10	4.2-17.7	8.4	1.1	9.5	5.5-19.0	11.1	2.3	4.3
20	4.0-18.2	9	1.6	12.5	5.5-22.3	13.6	4.8	4.1
30	4.0-26.3	9.8	2.5	12.1	6.5-19.8	15.4	6.7	4.5
40	4.3-17.8	10	2.7	14.9	6.2-19.9	16.1	7.4	5.4
50	4.4-23.8	12.3	4.9	10.1	10.0-22.4	17	8.3	6.1
60	4.4-25.3	12.1	4.7	12.7	10.9-28.4	17.7	8.9	6.7
				12.0				5.2

	2019				Combined over year			
P (kg ha^{-1})	range	Mean	P increase over control	Pf	range	Mean	P increase over control	Pf
0	4.8-17.4	5.9	-		1.4-17.6	7.3	-	
10	5.5-19.0	7	1.1	8.8	4.2-17.7	8.8	1.5	6.7
20	5.5-22.3	8.7	2.8	7.1	4.0-18.2	10.4	3.1	6.5
30	6.5-19.8	10.8	4.9	6.1	4.0-26.3	12	4.7	6.4
40	6.2-19.9	11.3	5.4	7.4	4.3-17.8	12.5	5.2	7.8
50	10.0-22.4	14.3	8.4	6	4.4-23.6	14.5	7.2	7
60	10.9-28.4	16.3	10.5	5.7	4.4-25.3	15.4	8	7.5
				6.9				7.0

Conclusion and recommendations

Plant height, grain and biomass yield of the testing crop showed a highly significant difference ($p \leq 0.0001$) among treatment means due to phosphorus fertilization in both separate and over-year combined analysis results. Except some inconsistancey, all the above mentioned parameters showed linearly increasing trends as the amount of applied phosphorus increased in both separat and over year results. The obtained Pc and Pf values could be helpful to calculate site specific soil test based P_2O_5 fertilizer to acuire the required bread wheat yield on Nitisols in North West Ethiopia.Avialable soil phosphorus values showed an overall increasing trend due to the applied phosphorus amounts over years. Finally, 10 mg kg^{-1} Pc and 7.0 mg kg^{-1} soil Pf values were obtained from over-year combined analysis result. Using these two important values, it is better to do a validation study on the farmer fields having similar agro ecology and soil types to determine either the developed equation is economically acceptable or not.

References

CSA (Central Statistical Agency). (2017). Agricultural sample survey 2016/2017.Vol I. Report on the area and production for major crops (private peasant holdings, Meher Season Statistical Bulletin Central Statistical Agency). Addis Ababa, Ethiopia.

Getachew Agegnehu, PN Nelson , MI Bird, and C van Beek. (2015). Phosphorus Response and Fertilizer Recommendations for Wheat Grown on Nitisols in the Central Ethiopian Highlands. Communications in Soil Science and Plant Analysis, 46, 2411–2424.

Getachew Agegnehu and Berhane Lakew. (2013). Soil test phosphorous calibration for malt barley production on Nitisols of Ethiopian highlands. Trop. Agric., 90, 177–187.

Getachew Agegnehua, Paul N. Nelson, Michael I. Bird, and C. van B. (2015). Phosphorus Response and Fertilizer Recommendations for Wheat Grown on Nitisols in the Central Ethiopian Highlands Phosphorus Response and Fertilizer Recommendations for Wheat Grown on Nitisols in the Central Ethiopian Highlands. Communications in Soil Science and Plant Analysis, (September). https://doi.org/10.1080/00103624.2015.1081922

Kiflemariam Yehuala , Ndegwa Henry, Waga Mazengia, Bantalem Zeleke, and F. L. (2022). Yield Gaps of Major Cereal and Grain Legume Crops in Ethiopia : A Review Yield Gaps of Major Cereal and Grain Legume Crops in Ethiopia : A Review. Agronomy, (October). https://doi.org/10.3390/agronomy12102528

McKenizie RH and L Kryzanowski. (1997). “Soil testing methods calibrated to phosphate fertilizer trials.” Better Crops : 81, 17–19.

Nelson and Sommer. (1982). Photometric adaptation of Somogy method for the determination of glucose. Production, New York. 657p. Journal of Biological Chemistry, 153, 375–380.

Nelson LA and RL Anderson. (1997). Partitioning soil test-crop response probability. In Soil testing : Correlating and interpreting the analytical results, ed T.R.Peck, 19-39. Madison, WI: American Society of Agronomy.

Olsen, Sterling Robertson, C.V. Cole, F. S. W. and L. A. D. (1954). Estimation of available phosphorus in soils by extraction with sodium carbonate.

SAS Institute. (2002). A Business Unit of SAS. SAS Institute Inc, Cary, NC. 2751. USA.

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet1, Birhanu Agumas, Mengistu Muche, Tesfaye Feyisa and Desalew Fentie. (2018). Crops Response to Balanced Nutrient Application in Northwestern Ethiopia. Blue Nile Journal of Agricultural, 1(1).

Tilman, D., Cassman, K.G., Matson, P.A., N., & R., and P. (2002). Agricultural sustainability and intensive production practices. Nature, 418, 671–677.

Soil-test Crop Response Based Phosphorus Calibration Study under Balanced Fertilizationof Maize (*Zea mays* L.) on Nitisols in North West of Ethiopia

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Abstract

Phosphorus is the second yield limiting nutrient next to nitrogen in the major maize growing area of west Amhara, Ethiopia. Hence, efficient management of P nutrient is critically required. A field experiment was conducted for six years (2014-2019) on permanent fields to develop phosphorus requirement equation to recommend P fertilizer based on soil test results for improving maize (Zea mays L.) productivity. The experiment was started by creating different artificial phosphorus gradient fields in the first 2 years (2014-2015). For the two consecutive cropping years (2018-2019), plot based field experiment was conducted on different P level gradient fields. The field experiment had seven treatments with the levels of (0, 10, 20, 30, 40, 50 and 60) P kg ha^{-1}*. Randomized complete block design (RCBD) with 3 replications were used. All treatments received equal levels of N, K and S fertilizers in all gradient fields through the cropping years. Urea, Triple Supper-Phosphate (TSP), Muriate of Potash (KCl) and Calcium sulfate (CaSO4) were used for N, P, K and S fertilizer sources, respectively. Improved maize variety (BH-540) was used for this experiment. In all cropping years, P, K and S fertilizers were applied in band at planting while, N was applied in three equal splits (1/3 at planting, 1/3 at 40-45 days after planting and 1/3 at knee height). All other crop management practices were implemented as per the recommendations. Soil samples were taken in P gradient formation period, as well as in all cropping years from each experimental plot at 0-20cm depth and selected chemical soil parameters (pH, SOC, and available P) were analyzed at Adet Agricultural Research Center (AARC) soil laboratory. The yield and yield components such as plant height, grain and biomass yield of maize showed a highly significant difference (*$p \leq 0.0001$*) among treatment means due to different phosphorus rate for both each and combined years. Soil phosphorus values also showed increasing trend as the applied phosphorus amount increased within the defined treatments. Finally, 8 mg kg*$^{-1}$* of soil P was determined as phosphorus critical point (Pc) and 17.3 phosphorus requirement factor (Pf) values were obtained from over-year combined analysis result using the Cate-Nelson graphical method. Using these two critical values, it is better to do a verification study on the farmer fields with similar agro ecology and soil types to validate whether the developed equation is economically acceptable or not.*

Keywords: Cate-Nelson, equation, maize, phosphorus, requirement,

Introduction

Maize is one of the three most important cereals following wheat and rice for food security at the global level and very important in the diets of the poor in Africa and Latin America (Bekele *et al.*, 2011 and FAOSTAT, 2010). In many developed countries and the emerging economies of Asia and Latin America, maize is increasingly being used as an essential ingredient in the formulation of livestock feed (Bekele *et al.*, 2011). In Ethiopia, maize is the most widely cultivated cereal crop with 16% area coverage, 26% production potential and 6.5 million tons of production (CSA, 2014). Estimated average yields of maize for smallholder farmers in Ethiopia is about 4.2 tons ha^{-1} (Kiflemariam *et al.,* 2022). To solve soil fertility problems and maximizing maize yield, different research activities have been undertaken in Ethiopia using various fertilizer sources (Birhan *et al.,* 2017).

However, soil fertility depletion became critical challenge for maize production in Ethiopia. To reverse the situation and advices best fit recommendations for small holder farmers, monitoring and frequent reviewing of soil fertility status are important. In Ethiopia nitrogen (N) and phosphorus (P) are the most yield limiting soil nutrients (Tadele *et al.,* 2018). It has been considered as a major factor for limiting crop productivity and recommended to apply in large amounts on the soil since the green revolution to sustain production of agricultural systems (Tilman *et al.,* 2002). Relative to N, recovery of P fertilizers by plants is very low due to its high fixation capacity in the soil (Balemi and Negisho, 2012).

One of the best nutrient recommendations is to calibrate and validate the nutrient requirements using long term experimental data. Nutrient calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current nutrient recommendations (McKenizie and Kryzanowski, 1997). It enables to revise fertilizer recommendations based on soil and crop types, pH and soil moisture content at time of planting. Soil tests are designed to help farmers to know the available nutrient status of their soil. Once the nutrient status determined, it is possible to decide how much nutrients to be applied to get economically acceptable yields (Getachew and Berhane, 2013 and (Getachew *et al.,* 2015).

However, for P calibration and validations, determination of soil P critical and soil P requirement factor values for major crops at major agro ecology and soil types for Western Amhara is lacking. Hence, to bridge this gap, Adet Agricultural Research Center (AARC) proposed a long-term soil test-based and site-specific P calibration study under balanced fertilization for maize on Nitisols.Therefore, the objective of this research were to develop P calibration equation and recommendations of P fertilizer requirement factor for maize on nitisol for western Amhara region

Materials and Methods

The experiment was conducted from 2014-2019 on Nitisols permanent plot of AARC research station. At the beginning of the study (2014) the experimental field was divided into 4 sub plots which received equal dose of N, potassium (K) and sulfur (S) using the rates of 92 kg ha^{-1} N, 90 kg ha^{-1} K_2O and 30 kg ha^{-1}S, respectively. By considering 115 kg ha^{-1} P_2O_5 as base line rate, the four fields were received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5. In 2015, each sub-plot divided in to four sub-sub plot and received 0, half (57.5 kg ha^{-1}), full (115 kg ha^{-1}) and double (230 kg ha^{-1}) rates of P_2O_5 and formed 16 total fields having different P gradient levels. The same amount of NKS fertilizers was applied on the sub-sub plots for the second year.

After creating different P gradient fields (2014-2015), plot based experiment was started on each P gradient fields using seven levels of P nutrient rates (0, 10, 20, 30, 40, 50 and 60 kg ha^{-1}). Randomized complete block design (RCBD) with three replications was used. Similar to the gradient formation years, equal amount of N, K and S were applied on each experimental plot. The plot based experiment was implemented for two cropping years (2018-2019) at all P gradient fields. Artificially created P gradient fields were used as a simulation for three categories of soil with low; medium and high P content.

Improved maize variety (BH-540) was used as test crop for this experiment. Urea, triple supper-phosphate (TSP), *muriate*of potash (KCl) and Calcium sulfate ($CaSO_4$) were used as the sources of N, P, K and S, respectively. P, K and S fertilizer sources were normally applied in band at planting while, N was applied in 3 equal splits which was 1/3 at planting, 1/3 at 40-45 days after planting and the remaining 1/3 at knee height stage. The other crop management practices were implemented as per the recommendation.

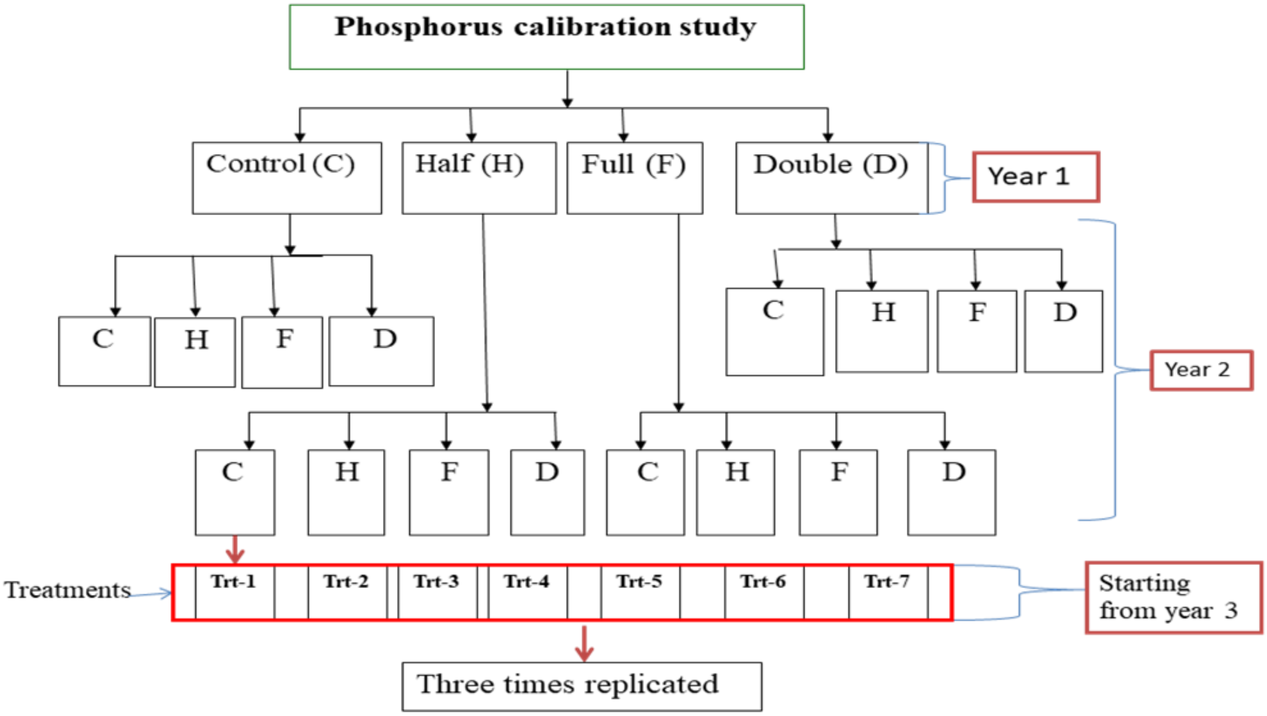

Figure 1. Schematic field layout for the above mentioned experiment

Soil Sampling and Analysis Procedure

One initial, 4 in 2014 (before second gradient formation) and 16 in 2015 (before plot level experiment started) composite soil samples were taken from each artificially created low, medium and high P containing field with the depths 0-15cm. All the collected composite soil samples were subjected for some chemical soil analysis (soil pH, SOC, available P). Following Landon (1991) available P value for initial soil was under low ratting level (3.3 P mg kg^{-1}) (Table 1). Similarly, artificially created fields were classified as low (<5 P mg kg^{-1}), medium (5-15 P mg kg^{-1}) and high (>15 P mg kg^{-1}) categories after 2015 cropping season. Therefore, from the total of 16 sub-sub plots, 3 were in low category, 9 were in medium and the remaining 4 were in high category and we considered as replications (Table 2).

Similar to gradient formation years, during experimentation period soil samples were collected continuously from each piece of plot at a depth 0-15cm before the next crop planting. All the sampled soils were air dried and sieved (≤2 mm) for analysis of the required parameters. From these, soil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Taye *et al.* (2002) while, AP was analyzed using (Olsen, 1954) and SOC was also determined following (Nelson and Sommer, 1982) method.

Table 1. Initial soil data values of the four P gradient fields (2014)

Soil parameters	Initial	P gradient fields (2014)			
		Zero (0 kg ha^{-1} P_2O_5)	Half (57.5 kg ha^{-1} P_2O_5)	Full (115 kg ha^{-1} P_2O_5)	Double (230 kg ha^{-1} P_2O_5)
pH- H_2O	5.70	5.6	5.63	5.73	5.68
Ava.P (Ppm)	3.30	3.56	4.79	3.1	5.44
SOC (%)	1.659	1.812	1.592	1.372	1.847

Table 2. Soil data values for each P gradient field in the second year (2015)

Soil parameters	P gradient fields (2015)															
	ZZ	ZH	ZF	ZD	HZ	HH	HF	HD	FZ	FH	FF	FD	DZ	DH	DF	DD
pH- H_2O	5.50	5.58	5.64	5.51	5.66	5.72	5.64	5.61	5.78	5.63	5.55	5.41	5.64	5.58	5.58	5.30
Ava.P (Ppm)	4.08	5.31	8.55	16.52	5.05	4.01	7.19	9.65	4.59	6.99	14.38	16.00	7.64	8.35	18.40	21.32
SOC (%)	1.384	1.165	1.321	1.137	1.319	1.514	1.537	1.311	1.402	1.376	1.277	1.341	1.404	1.260	1.704	1.521

Note: *ZZ=zero,zero, ZH=zero,half, ZF=zero,full, ZD=zero,double, HZ=half,zero, HH= half,half, HF=half,full, HD=half,double, FZ=full,zero, FH=full,half, FF=full,full FD=half, double, DZ= double,zero, DH= double,half, DF= double,full, DD=double, double.*

Determination of critical P concentration

Critical P value was determined following the Cate-Nelson graphical method where soil P values were put on the X-axis and the relative grain yield values on the Y-axis. The Cate-Nelson graphical method was divided the X-Y scatter diagram into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson LA and RL Anderson, 1997).

Steps for Cate-Nelson graphical methods for Pc determination:

1. Relative grain yield percentage values were obtained from all artificialy created fields using the formulas indicated below.

$$\text{Relative yield percentage (RYP)} = \frac{Yield\ from\ each\ unit}{Maximum\ Yield} * 100 \ldots\ldots Eq1$$

2. Soil test values for the nutrient being studied should be obtained from all the locations. The control plot test values should be averaged. Thus, there will be a single percentage yield and one soil test value for each location.
3. The scatter diagram of relative yield percentage (Y-axis) versus soil test value (X-axis) is plotted on arithmetic paper. The range in values on the Y-axis is 0 to 100%.

4. A piece of clear plastic having roughly one and one-half the dimensions of the graph is cut out for use as an overlay. A pair of intersecting perpendicular lines is drawn on the overlay with black ink in such a way that it is divided in to four quadrants.
5. The overlay is moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). The positions of the lines on the overlay with respect to the axes of the graph are transferred to the graph by making marks on the edges of the graph. The two intersecting lines are then drawn lightly on the graph with pencil. The point where the vertical line crosses the X-axis is defined as 'critical soil test level.

Determination of P requirement factor (Pf)

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1 mg kg^{-1} soil when the initial soil available P is below the Pc value. It was calculated using available P values in samples collected from unfertilized and fertilized plots. Therefore, Pf and the rate of P fertilizer to be applied were calculated as follows:

$$Pf= \frac{kg\ P\ applied}{\Delta\ soil\ P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eq 2}$$

P_2O_5 kg ha^{-1} fertilizer to be applied = $(Pc - Pi) * \text{Pf} \ldots\ldots\ldots..\text{Eq3}$

Where: Pc=critical P concentration, ΔP= available P value taken after one year P fertilizer applied in each treatment –minus initial P values for the site, Pi= initial P values for the site and Pf=P-requirement factor

Agronomic data collected

Agronomic data like plant height, ear length, ear diameter and all biological yields (grain + biomass) were collected. Actual grain yields were adjusted to 12.5% of moisture content.

Data management and analysis

Both agronomic and soil data were properly managed using Microsoft excel. The collected data were analyzed using SAS software version 9.0 (SAS Institute, 2002). Least significant difference (LSD) at 5% probability was used for mean comparison analysis.

Results and discussion

Yield and yield components

Plant height and Ear length

The plant height of maize showed highly significant difference ($p \leq 0.0001$) among treatment means due to the applied phosphorus fertilizer rates through both the cropping years and the combination of the two cropping seasons. Including the combined mean result, minimum plant height means in each year was recorded at zero input of phosphorus fertilizers used. However, the maximum plant height values were observed at different levels of phosphorus fertilizer used. However, as compared to other treatments maximum plant height was observed when 50 P kg ha^{-1} phosphorus fertilizers was applied (Table 3).

In contrast to plant height, ear length of maize didn't show any significant difference among the treatment means. In this parameter, we observed an irregular trend of ear length among the treatment means (Table 3).

Table 3. Response of the applied phosphorus fertilizer on maize plant height and ear length

Treatment	Plant height (cm)			Ear length (cm)		
	2018	2019	Year-combined	2018	2019	Year-combined
0	190.5	209.8	200.2	17.5	18.5	18.0
10	196.3	212.8	204.5	17.5	18.7	18.1
20	197.3	219.6	208.5	17.8	18.8	18.3
30	197.5	220.8	209.1	17.4	18.4	17.9
40	196.2	222.3	209.2	17.3	18.5	17.9
50	200.1	229.2	214.6	17.2	18.5	17.8
60	199.9	227.0	213.5	17.6	18.2	17.9
Mean	196.8	220.2	208.5	17.5	18.5	18.0
LSD(0.05)	4.8	5.3	4.9	0.5	0.5	0.4
Pr.	**	**	**	NS	NS	NS
CV(%)	6.1	6.0	8.3	7.2	7.0	7.6

Grain and Biomass yields

As shown in the results in Table 4, grain yield of maize showed a highly significant difference ($p \leq 0.0001$) among the treatment means due to the applied phosphorus fertilizers in each cropping season as well as the combined result over years. Except slightly irregularities, grain yield of maize showed linearly increasing trend as the rate of phosphorus fertilizer used increased in all cropping years as well as in over-year combined result. The minimum value of grain yields was recorded at the control treatment (zero P input). While, the maximum one recorded at treatments received 50 and 60 P kg ha^{-1} (Table 4). Similar to the grain yield values, the minimum maize biomass yield was recorded on the control treatment (zero P input) in each cropping years as well as in combined result. Furthermore, maximum biomass yields were also obtained at treatments received 50 and 60 P kg ha^{-1} in 2018 and 2019, respectively (Table 4).

Table 4. Response of the applied phosphorus fertilizer on maize grain and biomass yields

Treatment	Grain yield (kg)			Biomass yield (kg)		
	2018	2019	Year-combined	2018	2019	Year-combined
0	5992.3	5186.6	5589.4	14050.9	16800.9	15425.9
10	6663.4	6447.6	6555.5	16074.1	20511.6	18292.8
20	7302.4	7076.0	7189.2	17722.2	22412.0	20067.1
30	7551.7	7414.1	7482.9	18259.3	24201.4	21230.3
40	7489.5	7641.5	7565.5	17546.3	24171.3	20858.8
50	7574.3	7792.8	7683.6	18652.8	24745.4	21699.1
60	7747.0	7754.7	7750.9	18606.5	25270.8	21938.7
Mean	7188.7	7044.8	7116.7	17273.1	22587.6	19930.4
LSD(0.05)	442.8	384.7	295.3	1291.8	1168.2	1164.6
Pr.	**	**	**	**	**	**
CV(%)	15.3	13.6	14.6	18.6	12.9	20.6

Critical P concentration (Pc) and P requirement factor (Pf)

Available soil P values showed a linear increasing trend as the applied P fertilizer increased in all cropping years as well as in the combined years result. However, when we compare across years, 2019 available P values showed slightly a decreasing trend from 2018 result which might be happened due to climatic variations (Figure 2).

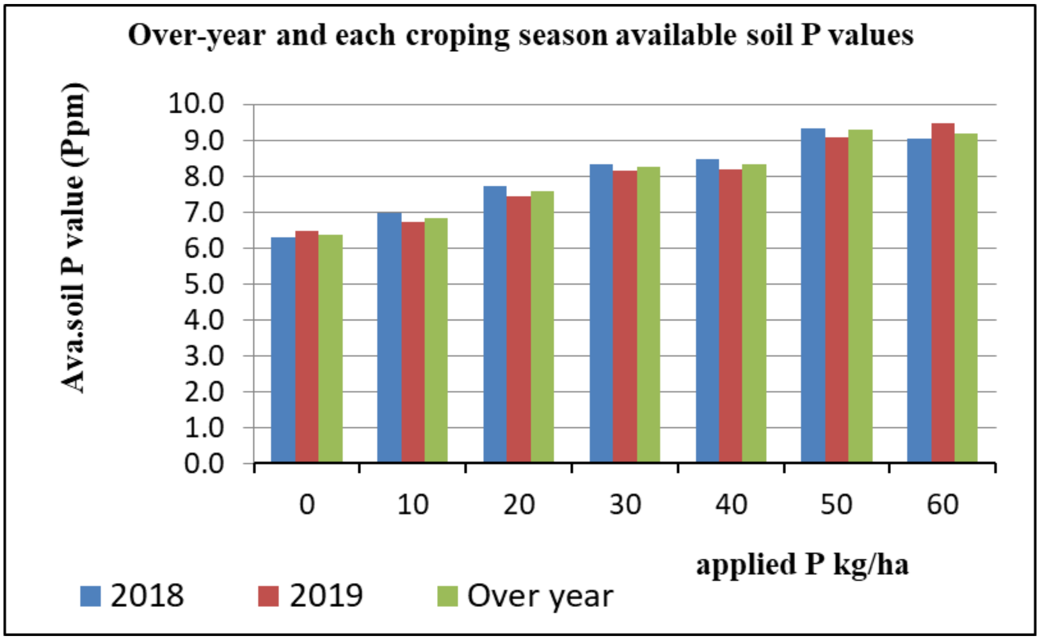

Figure 11. Applied P verses available soil P values for two trial seasons and combined over years

The critical P concentration (*Pc*) values were determined from the scatter diagram drawn using relative grain yields of maize and the corresponding soil test P values for all P levels (0–60 kg ha^{-1}). Based on the Cate-Nelson Pc determination method, Pc values in 2018, 2019 and over-year combined were 7, 8 and 8 P mg kg^{-1}, respectively (Figure 3) which is by far different from the findings reported by (Yihenew *et al,* 2003). All the mentioned Pc values could help to achieve a minimum of 70% of the maize grain yield production without any stress if other factors were found normal.

However, if the soil test values found below the critical levels, additional information is needed on the amount of P required for elevating the soil P to the required level. This is the P requirement factor (*Pf*) which is defined as the amount of P required to raise the soil P by 1 mg kg^{-1}soil and computed from the difference between available soil test P values from plots which received (0–60) kg P ha^{-1} using the formula indicated at (Eq 2). Therefore in the study, calculated Pf values in 2018, 2019 and their over-year combined results were 14.7, 16.3 and 17.3, respectively (Table 5).

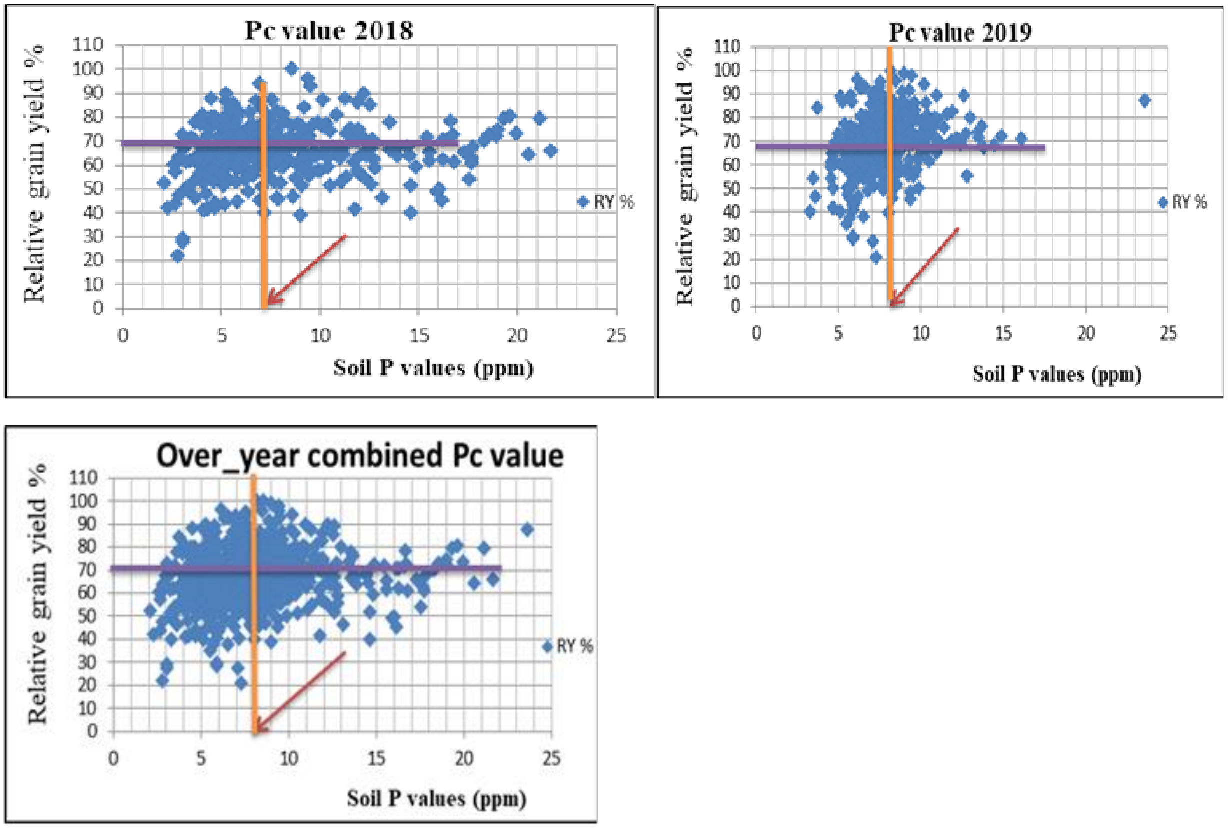

Figure 12. Cate-Nelson graphics for Pc values determination. The point on arrows indicates Pc for maize on Nitisols

Table 5. The two years and over-year combined phosphorus requirement factors (Pf) values on maize

P (kg /ha)	2018				2019				Over-year combined			
	Range	Mean	P increase over control	Pf	Range	Mean	P increase over control	Pf	Range	Mean	P increase over control	Pf
0	2.1-14.8	6.31			3.3-9.6	6.40			2.08-14.83	6.35		
10	2.7-14.4	6.98	0.9	11.0	4.6-9.9	6.71	0.6	15.6	2.65-14.43	6.84	0.6	17.2
20	3.0-18.3	7.72	1.7	12.1	4.8-10.9	7.44	1.4	14.6	3.03-18.29	7.58	1.3	15.2
30	3.0-17.8	8.33	2.3	13.3	4.6-12.8	8.15	2.1	14.4	2.97-17.75	8.24	2.0	15.2
40	3.5-19.3	8.48	2.4	16.6	5.1-13.5	8.18	2.1	19.0	3.47-29.30	8.33	2.1	19.3
50	4.0-20.6	9.33	3.3	15.3	5.1-23.6	9.28	3.2	15.6	4.01.8-23.60	9.31	3.0	16.4
60	3.2-21.7	9.05	3.0	20.1	5.7-16.1	9.34	3.3	18.3	3.14-21.66	9.20	2.9	20.4
				14.7				16.3				17.3

Pf =is phosphorus requirement factor

Conclusion and recommendations

The study provided acceptable Pc and Pf values which could help users as a baseline for soil-test crop response based phosphorus fertilizer recommendation for increasing maize productivity on Nitisols in North West Ethiopia after a validation study done. In this study, the yield and yield components such as plant height, grain and biomass yield of maize showed a highly significant difference ($p \leq 0.0001$) among treatment means due to different phosphorus rate application for both individual and over years combined analysis.

Soil phosphorus values also showed an overall increasing trend due to the accumulation of applied phosphorus amounts over years. Finally, 11.5 P mg kg^{-1} Pc and 23.8 Pf values were obtained from over-year combined analysis result. Using these two important values, it is better to do a verification study on the farmer fields having similar agro ecology and soil types with the study site to determine either the developed equation is economically acceptable or not in farm get price level on maize production.

References

Balemi and Negisho. (2012). Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. J. Soil Sci. Plant Nutr. 12, 547–561.

Bekele Shiferaw, Prasanna, B. M., Hellin, J. and Bänziger, Marianne. (2011). Crops that feed the world 6 . Past successes and future challenges to the role played by maize in global food security. Food Sec, 307–327.

Birhan Abdulkadir, Sofiya Kassa, Temesgen Desalegn, Kassu Tadesse, Mihreteab Haileselassie, Girma Fana, Tolera Abera, Tilahun Amede and Degefie Tibebe. (2017). Crop response to fertilizer application in Ethiopia a review.

FAOSTAT. (2010). Statistical databases and data-sets of the Food and Agriculture Organization of the United Nations.

Getachew Agegnehu, PN Nelson, MI Bird, and C van Beek. (2015). Phosphorus response and fertilizer recommendations for wheat grown on nitisols in the central Ethiopian highlands. Communications in soil science and plant analysis 46, 2411–2424.

Getachew Agegnehu and Berhane Lakew. (2013). Soil test phosphorous calibration for malt barley production on Nitisols of Ethiopian highlands. Trop. Agric., 90, 177–187.

Kiflemariam Yehuala , Ndegwa Henry, Waga Mazengia, Bantalem Zeleke, and F. L. (2022).

Yield Gaps of Major Cereal and Grain Legume Crops in Ethiopia : A Review Yield Gaps of Major Cereal and Grain Legume Crops in Ethiopia : A Review. Agronomy, (October). https://doi.org/10.3390/agronomy12102528

McKenizie RH and L Kryzanowski. (1997). Soil testing methods calibrated to phosphate fertilizer trials. Better Crops :81, 17–19.

Landon J.R. (1991). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. (John Wiley and Sons Inc. Ed.). New York.

Nelson and Sommer. (1982). Photometric adaptation of somogy method for the determination of glucose. Production, New York. 657p. J. of Biological Chemistry, 153, 375–380.

Nelson LA and RL Anderson. (1997). Partitioning soil test-crop response probability. In Soil testing: Correlating and interpreting the analytical results, ed T.R.Peck, 19-39. Madison, WI: American Society of Agronomy.

Olsen, Sterling Robertson, C.V. Cole, F. S. W. and L. A. D. (1954). Estimation of available phosphorus in soils by extraction with sodium carbonate.

SAS Institute. (2002). A Business Unit of SAS. SAS Institute Inc, Cary, NC. 2751. USA.

Tadele Amare, Zerfu Bazie, Erkihun Alemu, Asmare Wubet1, Birhanu Agumas, Mengistu Muche, Tesfaye Feyisa and Desalew Fentie. (2018). Crops Response to Balanced Nutrient Application in Northwestern Ethiopia. Blue Nile Journal of Agricultural, 1(1).

Taye Bekele, Yesuf Assen, Sahlemedhin Sertsu, Amanuel Gorfu, Mohammed Hassena, D.G. Tanner, Tesfaye Tesemma, and Takele Gebre. (2002). Optimizing fertilizer use in Ethiopia: Correlation of soil analysis with fertilizer response in Hetosa Wereda, Arsi Zone. Addis Ababa. *Sasakawa-Global, 2000.*

Tilman, D., Cassman, K.G., Matson, P.A., N., & R., and P. (2002). Agricultural sustainability and intensive production practices. Nature, 418, 671–677.

Yihenew G. Selassie, Suwanarit A., Suwannarat C. and Sarobol E. (2003). Equations for estimating phosphorus fertilizer requirements from soil analysis for maize (Zea mays L.) grown on Alfisols of Northwestern Ethiopia. Kasetsart Journal, 37((3): 284–295.

II. Agricultural water management

Evaluating the performance of AquaCrop model for potato production under deficit irrigation

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Abstract

Crop modeling is a powerful tool for estimating yield and water use efficiency in this regard, and it plays an important role in determining water management strategies. This study was performed in Lasta district, for two successive years. The aim was to evaluate the performance of Aquacrop model for potato producing area and study the effects of water shortage on potato production and water use efficiency. The irrigation water levels for potatoes were 100% ETC, 75% ETC, and 50% ETc. A randomized complete block design was used to arrange six treatments. Observed weather parameters for specific site together with measured crop parameters from optimum experiment conducted during 2018/19 were used to develop climate, soil and crop files in Aquacrop and to calibrate the model. Observations from the 2019/20 growing season and independent data were used to validate the model. Model calibration showed a good fit Coefficient of determination (R^2) = 0.98, Root mean square error (RMSE) = 9.6%, Nash-Sutcliffe efficiency (E) = 0.92, index of agreement (d) = 0.98 and coefficient of residual moss (CRM) = -0.07 for canopy cover (CC) as well as good prediction for biomass (R^2 = 0.98, RMSE = 1.8t/ha, E = 0.96, d = 0.99, CRM = -0.13). Model validation showed good simulation for CC by 100% water application at development and mid growth season and the other stages applied 75% (T3) (R^2 = 0.98, RMSE = 9.4%, E = 0.94, d = 0.98, CRM = -0.12) conditions. The model prediction biomass (R^2 = 0.98, RMSE = 2.2t/ha, E = 0.94, d = 0.98, CRM = -0.2) reasonably well for field with pooled data (T3). The highest yield (33.27t/ha) and water use efficiency (8.23kg/m^3) were obtained when 100% irrigation water was applied during the development and mid-growth seasons, and 75% irrigation water was applied during the other stages, while the lowest yield (22.21t/ha) and water use efficiency (6.67kg/m^3) 75% irrigation water applied through out the growth stages was recorded. As a result, we conclude that the irrigation water used (75, 100, 100, and 75% ETc) is better adapted to the agro-ecological conditions in Lalibela and other similar areas. The AquaCrop model is therefore easy to use, requires fewer input data, and its sufficient degree of simulation precision makes it a valuable instrument for estimating crop production under deficit irrigation and for water management to improve the efficiency of agricultural water use.

Keywords: Biomass, Calibration, Canopy cover, Validation, Water use efficiency

Introduction

Potatoes (Solanum sp.) are the fifth most common crops globally, after sugar cane, maize, rice, and wheat (Montoya *et al.,* 2016). It is one of the tuber crops full-grown in Ethiopia by more than one million farmers (CSA, 2018/2019). Potato is gazed as a high-potential sustenance security crop since of its bent to convey a high yield of high-quality product per unit input with a little crop cycle usually less than 120 days than main cereal crops (Hirpa *et al.*, 2010). Ethiopia is blessed with suitable climatic, soil, and topographic conditions for potato production. The national average yield is about 7-8 tons/ha, which is currently low as opposed to the world's average output of 15t ha^{-1} (FAO, 2011). Some of the teething troubles for the small yield of potato production are drought and flood, pests and diseases, soil erosion, the shift in rainfall pattern, and deterioration in available water (Deressa *et al.,* 2009).

As a result, better water utilization efficiency for potato production is needed in order to produce more crops per drop while reducing irrigation resources. The limited availability of water resources needs the development of new approaches to save water and energy, the utmost of which should emphasize on improving water use efficiency (Shahnazari *et al.,* 2007, Soomro *et al.,* 2020). To ensure food security, it is essential to use the water wisely in order to increase food production while saving water as much as possible or to increase field crops water use productivity. The world's population is growing by the day, posing a serious threat to future agricultural production, particularly in areas where water is the scarcest resource. Deficit irrigation is a technique, which enhances the economic use of water (Fereres and Soriano, 2006, Domínguez *et al.,* 2012); moreover, this approach can have a resilient effect on potato crops, by means of declines in crop yield and tuber quality (Shock *et al.,* 1998, Fabeiro *et al.,* 2001, Kashyap and Panda, 2003, Onder *et al.,* 2005, Vos and Haverkort, 2007, Ierna and Mauromicale, 2012, Gebremedhin *et al.*, 2015).

AquaCrop, a water-driven model for use as a decision-making support mechanism in planning and scenario analysis in various seasons and locations (Foster *et al.,* 2017, Mibulo and Kiggundu, 2018, Corbari *et al.,* 2021). Even if the model is comparatively simple, it elaborates on the fundamental process involved in crop productivity and the response to water deficits, both from a physiological and agronomic perspective (Tefera and Mitiku, 2021). It is intended to combine simplicity, precision, and robustness, and is suited to resolve situations where water is a primary limiting factor in crop production (Banchu, 2020). It necessitates fewer input data than other models (Hsiao *et al.*, 2009; Steduto *et al.*, 2009). Once validated, the model is easy and needs fewer resources and it could be a useful tool in irrigation scheduling to reduce crop risk (Tsubo *et al.*, 2005, Soltani and Hoogenboom, 2007). As well, AquaCrop may be used to investigate and evaluate another management that increases water productivity and achieves more sustainable water use (Bessembinder *et al.*, 2005, Amirouche *et al.*, 2021). It simulates crop yield and biomass variation under various irrigation water scenarios. Observing the regular water balance is needed to understand the inward and outgoing water. A critical issue is the development of the most favorable strategies for using and managing available water resources in agricultural production (Smith, 2000, Boudhina *et al.*, 2017).

The model related to water input as the primary constraint to crop development, particularly in arid and semiarid areas(Bradford and Hsiao, 1982, Boudhina *et al.*, 2019). Deficit irrigation is a good potential irrigation approach, according to several reports, (Ali and Talukder, 2008, Behera and Panda, 2009, Blum, 2009), in which less water is used than expected during in the planting season.

Zand-Parsa *et al.* (2006), created a maize simulation model, whereas (Farahani *et al.*, 2009, García-Vila *et al.*, 2009) used the AquaCrop model besides cotton both full and deficit irrigation agriculture. They stated that in order to evaluate the effect of changes in irrigation water quantity for quinoa, sunflower, and maize in the AquaCrop model, the critical parameters for calibration, including such normalized water productivity, canopy cover, and total biomass, should be tested under a variety of environment, soil, cultivar, irrigation technique, and field management conditions (Geerts and Raes, 2009, Heng *et al.*, 2009). The model, according to both scientists, can be used for scenario analysis and provides a good balance of robustness and performance precision.

Drought is the main climate-linked risk in the northeastern Amhara especially north wollo and wag-himra and generally in some parts of northern Ethiopia. The rainfall is, however, short, inconsistent, and inadequate, and also the landscape of the area is rising and falling, which impacts the crop productivity in the area. So, deficit irrigation could be a promising irrigation water management technique for these areas, allowing farmers to apply restricted amounts of water to their crops in the time and amount necessary for optimum crop water productivity. Crop type and cropping pattern, soil, depth and fertility, climate, water quality, and irrigation system type all contribute to this degree of water deficit. Most of the farmers were using the furrow irrigation system, but the irrigation is not properly managed on top of the prevailing water scarcity in the area calling for more interventions such that water has to be managed properly and efficiently. The goal of this research was to use the AquaCrop model to better understand deficit irrigation and develop optimal deficit irrigation water management strategies for potato production.

Material and methods

Study area description

The research was conducted two years in 2018/19 and 2019/20 at Kechne Abeba irrigation schemes at Lasta woreda, North Wollo (Figure1). The geographical location of the area is between 11°57’38.44” north of latitude and 39°4’4.91” east of longitude with an altitude of 2103 m.a.s.l. The rainfall is seasonal varying in-depth, space, and time. The mean long-term annual rainfall (January 2000-March 2020) in the area is about 799.3mm and it is erratic and uneven in distribution. The average minimum and maximum temperatures in the area are11.8 $^{o}{}_{C}$ and 27.4 ^{o}c respectively (Figure 2 a & b). The study site was chosen to be representative of the woreda's diverse soil and climate conditions. The area is intensively cultivated and the production is subsistence farming. Rain-fed agriculture is the main practice in the study area.

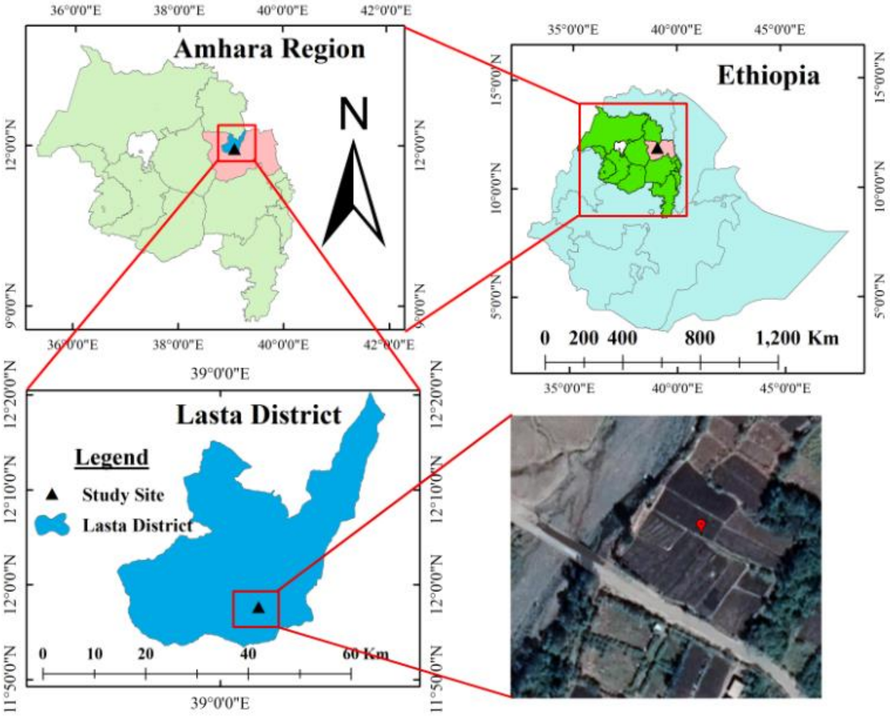


Figure1.1 Location map of the study area

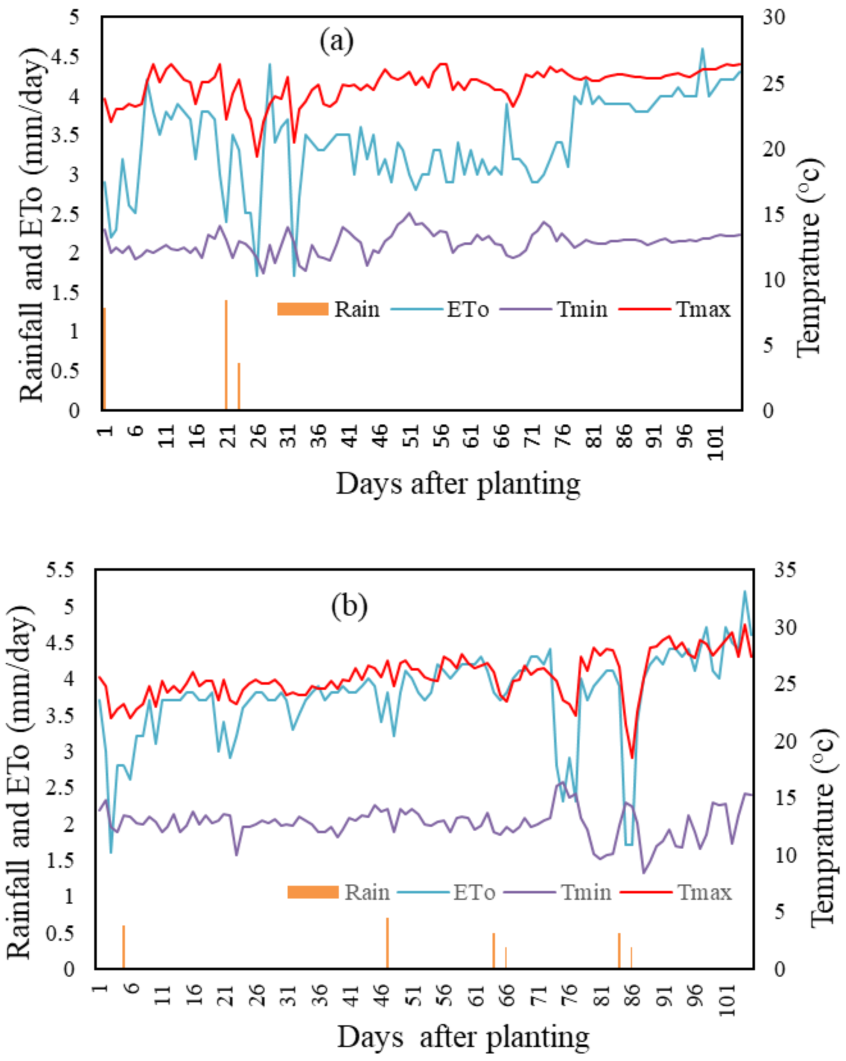


Figure 2. (a) and (b) weather conditions for the 2018/19 and 2019/20 crop growing season respectively.

Experimental design and treatments

The design of the experiment was based on a randomized complete block design with three replications. Three irrigation treatments (100, 75, and 50%) with the fourth growth stages of potato of water application methods were tested in the field experiment. The plot size of the experiment was 3m * 3.75m and the spacing among plots and each block was 1m and the total experimental area was 23m *13.25m. The test crop potato (Belete variety) was selected since it is widely used in the area and also recommended for the area. The tubers were directly sown on October 16, 2018, and November 20, 2019. Well, sprouted potato tubers were planted on prepared ridges with the spacing of 75 and 30cm between row and plants, respectively (Abdalhi and Jia, 2018, Beshir *et al.,* 2018, Gebremedhin *et al*, 2015). In the 2018/19 and 2019/20 growing seasons, harvesting occurred when tubers reached maturity, which occurred 105 days after planting.

Fertilizer was applied at the rate of 300kg/ha urea half at planting and a half at 45 days after sowing and 50kg/ha triple super phosphate (TSP) at planting. The frequency of irrigation water was used at five days interval (Gebreslassie, 2009). Prior to planting all plots were irrigated with an equivalent volume of water up to the field capacity limits. Weeding, furrow maintenance, fertilizer application, water application, diseases, and pest management techniques were all completed on time and in the same order for each treatment.

Table 1.1 Total number of treatment combinations

	Potato crop growth stages			
Treatment	Initial stage	Development stage	Mid-season stage	Late season stage
T1	100%	100%	100%	100%
T2	75%	75%	75%	75%
T3	75%	100%	100%	75%
T4	50%	100%	100%	50%
T5	75%	100%	100%	50%
T6	100%	75%	75%	50%

Water requirement of potato

The fixed schedule and crop water demand for irrigation were determined using the CROPWAT computer model version 8.0, according to FAO 56 methodology (Allen *et al.*, 1998). The crop coefficients (Kc) used in the reference irrigation treatment (100%) depending on FAO 56 which would have been the different as per the vegetative growth stage of the potato crops 0.5 at the onset of growth, 1.15 at tuber formation, and 0.75 before ripening. Crop factor (Kc) for each growth stage was obtained from (Allen *et al.*, 1998) and ETc was determined using equation 1.

$$ET_C = ET_O * K_C \qquad (1)$$

Where; ETc is crop evapotranspiration in mm and ETo is reference crop evapotranspiration in mm. Since it would be based on evapotranspiration, it is able to quantify net irrigation water demand (NIR) by subtracting effective rainfall(Pe) during the experimental season, which can be described using equation 2.

$$NIR = ET_C - Pe \qquad (2)$$

Furrow irrigation application efficiencies, in general, vary from 45-60% (Allen *et al.*, 1998). Using equation 3, the requirement of gross irrigation (GIR) was calculated with an application efficiency (Ea) of 60%.

$$GIR = NIR/Ea \qquad (3)$$

Statistical analysis

The effects of different treatments were statistically evaluated using the analysis of variance methodology, and mean separation was calculated using Least Significance Difference (LSD) at 5% significance levels using XLSTAT 2018 to identify optimal deficit irrigation management practices based on yield-related parameters and water use efficiencies.

AquaCrop model input data

It's a crop water productivity model that simulates herbaceous crop yield to water (Steduto *et al.*, 2012). The setup of the model needs input data containing climatic parameters, crop, soil and field, and irrigation management data.

Climate data

The weather parameter was collected from Lalibela meteorological station located closer to the experimental farm. Meteorological data required by the model are daily values of minimum and maximum temperature, rainfall, reference crop evapotranspiration, and mean annual atmospheric carbon dioxide concentration. ETo was estimated using the ETo calculator using the daily maximum and minimum temperature, wind speed at two-meter above the ground surface, solar radiation and mean relative humidity. The model uses 369.41ppm as a reference standard for atmospheric carbon dioxide concentrations, which would be the average of CO_2 concentrations in the atmosphere from 1902 to today at Mauna Loa Observatory in Hawaii, according to IPCC projections for the A1B scenario (Abedinpour *et al.*, 2012, Gebremedhin *et al.*, 2015, Montoya *et al.*, 2016).

Crop parameters

Canopy cover, above-ground biomass, tuber yield, and plant height data samples were taken out every 20 days for each irrigation treatment and replicate based on the recommendation stated in (Bitri *et al.*, 2014, Karunaratne *et al.*, 2011). The overhead mobile camera was used to capture the canopy cover. Then the captured picture was analyzed using GreenCrop Tracker image analyzer software (Kale, 2016). At each sample, two plants were removed from each experimental plot, and the dry biomass of leaves, stems, and tubers was collected (Montoya *et al.*, 2016). The above-ground dry biomass of each sample was determined by weighing it after it had been held in an oven for 48 hours at 65°$_C$ (Abedinpour *et al.*, 2012) and the tuber dry matter for 72 hours at 65°$_C$ (Gebremedhin *et al.*, 2015). The date of emergence, initial and maximum canopy cover, period of flowering, the start of senescence, and maturity were recorded. In addition, the coefficient of the crop for transpiration at full canopy cover, canopy decline coefficient, soil water depletion beginnings for prevention of leaf growth and transpiration, and canopy senescence acceleration are used (Hsiao *et al.*, 2009). These criteria should apply to a wide range of conditions and should not be limited to a single crop cultivar (Heng *et al.*, 2009).

Soil characteristics

The physical and chemical properties such as soil texture, EC, PH, organic matter, bulk density, field capacity, permanent wilting point, and saturation of soil were analyzed and characterized in samples taken from the study area at different depths of 0-20cm, 20-40cm, and 40-60cm (Demelash, 2013) (Table 2). The saturated hydraulic conductivity was determined using the empirical equations' pedo transfer function (Saxton and Rawls, 2006). Because the soils were all the same texture, the soil water retention curves did not show any variation for most superficial horizons.

The hydrometer process was used in the laboratory to estimate the soil texture of the field. The bulk density was calculated from an undisturbed soil sample taken with a core sampler and considered as the proportion of the oven-dry weight of soil to a known core sampler volume. It differs considerably and the measurements were taken at three different soil depths of the soil profile (0-20, 20-40, 40-60) and three samples across the experimental field. The gravimetric approach was used to assess the soil moisture content and measured as a dry weighted fraction (Demelash and Alamirew, 2011). In the laboratory, the water content at field capacity and permanent wilting point were determined by applying 0.33 and 15 bars to a saturated soil sample, respectively, using a pressure plate. Soil PH was determined from saturation pest extract using a PH meter (Demlash, 2013, Gebreslassie *et al.*, 2015).

Irrigation and field management

Irrigation management consists of data applying to both the conditions of full irrigation and deficit irrigation with four growth stages. In the deficit, irrigation water was applied on the same day as the entirely irrigated plot, but the irrigation depths were decreased to 75 and 50% of the full irrigation. Water was applied in a known volume of watering-can which could be converted and the handheld watering-can was used to control the quantity of water entering each furrow of the experimental plot (Yihun, 2015). The volume of applied water can be calculated as follows equation 4.

$$V = A*D \tag{4}$$

Where V = volume of applied water (lit)

A = area of irrigated plot (m^2)

D = depth of application (mm)

The field management components were recorded like the soil fertility levels, weed infestation, irrigation method, application depth and time of irrigation event, and furrow end bunds to remove surface runoff. Equation 5 was used to calculate water use efficiency (WUE), which indicates the amount of yield (Y, kg ha^{-1}) given per unit of water used (ETc, m^3 ha^{-1})and evaluates the most efficient use of water.

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{ETc}} \tag{5}$$

Model Calibration

The model was performed via an iterative method that provided the data values which better simulated the primary crop growth variables canopy cover, biomass, crop yield, and water use efficiencies. These parameters are calibrated for the optimal goodness of match between both the measured and the simulated values (Afsharmanesh *et al.*, 2014, Afshar and Neshat, 2013, Gebreselassie *et al.*, 2015). The values were used to form the findings of the study data from the 2018/19 irrigation season. The crop cultivar-dependent conservative and non-conservative parameters were regarded as constants. The non-conservative parameters were adjusted according to the field measurements. The crop growth coefficient (CGC) and crop senescence coefficient (CDC), as well as normalized water productivity (WP*), are conservative parameters that are calibrated using field sample results. The CGC and CDC were calculated using the estimates suggested by Raes *et al.* (2012b) and data such as maximum canopy cover (CCx) and initial canopy cover (CC_0). Thus, the CGC and CDC are determined using a nonlinear resolve to achieve the best possible match between the measured and simulated canopy cover.

Model Validation

The model was run out with the experimental data for the year 2019/20 growing season (Afsharmanesh *et al.*, 2014, Afshar and Neshat, 2013, Gebreselassie *et al.*, 2015). The calibrated model was used to simulate with the data input of the experimental during the year 2018/19 to predict the yield, water use efficiency, biomass, and canopy cover. Furthermore, such predicted values were compared to the experiment's actual results, and the model validation output statistics were assessed.

Model Evaluation Criteria

During the calibration and validation processes, the AquaCrop model simulation findings of water use efficiency, biomass, yield, and canopy cover were evaluated. The prediction error statistics were used to verify the internal consistency between the simulated and observed values. To evaluate the model's efficiency (performance), the following statistical approaches were used. The total values or average deviation of measured values from determined values is indicated by the normalized root mean square error (NRMSE or CV). Equation 6 was used to calculate the NRMSE formula.

$$\mathrm{NRMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{Si}-\mathrm{Mi})^2} \times {}^{100}/_{\overline{\mathrm{M}}} \qquad (6)$$

Where Si and Mi are the simulated and measured values, separately, and n is a number of observations. The NRMSE unit is the same for all variables, and the average of the n measured results was used.

The root mean square error (RMSE) represents a measurement of the total, or it is the mean values of Mi mean deviation between the observed and simulated values which is a synthetic predictor of the absolute model uncertainty. Values of mean residual and mean relative error close to 0 indicate minor deviations between simulated and observed mean thus suggesting slightly systematic deviation and bias in the entire data collection.

The RMSE (Heng *et al.*, 2009) was calculated in equation 7.

$$\mathrm{RMSE} = \sqrt{1/n\sum_{i=1}^{n}(\mathrm{Si}-\mathrm{Mi})^2} \qquad (7)$$

The coefficient of determination (R^2) estimates the combined distribution against the independent dispersion of the measured and simulated series. The values of 0 mean there is no correlation at all, while a value of 1 means that perhaps the dispersion of the simulated is equal to that of the observed, in equation 8.

$$R^2 = \frac{(\sum_{i=1}^{n}(Mi - \overline{M})(Si - \overline{S})}{\sqrt{\sum_{i=1}^{n}(Mi - \overline{M})^2}\sqrt{\sum_{i=1}^{n}(Si - \overline{S})^2}} \qquad (8)$$

The coefficient of efficiency (E) varies from −∞ to one (perfect fit), and an efficiency of less than zero indicates that the calculated mean values might have been a better simulator than the model.

The E (Nash and Sutcliffe, 1970) was determined using equation 9.

$$E = 1 - \frac{\sum_{i=1}^{n}(Mi - Si)^2}{\sum_{i=1}^{n}(Mi - \overline{M})^2} \qquad (9)$$

The Willmott index of agreement, d (Willmott and Matsuura, 2005) was also used and determined through equation 10.

$$d = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}(|Si - MO| + |Oi - MO|)^2} \qquad (10)$$

Where; Oi is the measured value; MO is the mean value of n measured values, and n is the number of measurements.

Using equation 11, the Coefficient of Residual Moss (CRM) was measured, which shows the model's tendency for exaggeration or underestimation of value relative to observed values (Eitzinger *et al.*, 2004)

$$CRM = \frac{\sum_{i=1}^{n} Mi - \sum_{i=1}^{n} Si}{\sum_{i=1}^{n} Mi} \qquad (11)$$

Results and discussion

Soil properties

Water at field capacity and permanent wilting point of the soil is determined to be 33.50 and 21.13%, respectively (Table 2). On a volumetric basis, the water content at field capacity varied between 35.3 and 33.5%. The top 0 to 20cm had a larger average water content of field capacity value of 35.3%, while the subsurface 40 to 60cm had a lower value of field capacity that was 33.5%. The moisture content at the permanent wilting point varied with depth, with values as high as 21.9% at the top (0 to 20cm) and as low as 20.2% at the subsurface (40 to 60cm). The difference in field capacity and the permanent wilting point is directly related to total available moisture (TAW), which is the depth of water that a crop can absorb from its root system. The total average available soil moisture was 133.67mm m^{-1} of soil depth and the maximum infiltration rate of the soil was 40mm h^{-1}. As a result, the optimum degree of TAW is present in topsoil; while lower concentrations are located in the subsurface soil (Table 2).

Table 2. Physical and chemical characteristics of the soil at the research site.

Soil parameters	Soil depth (cm)			
Particle size distribution (%)	0 – 20	20 - 40	40 - 60	Average
Clay	35.15	32.39	36.50	34.68
Silt	31.72	32.56	30.83	31.70
Sand	33.13	35.05	32.67	33.62
Texture	Clay loam	Clay loam	Clay loam	Clay loam
Bulk density (g/cm3)	1.441	1.522	1.535	1.499
OM (%)	1.12	1.01	1.01	1.05
PH	6.5	6.6	6.8	6.63
TN (%)	0.06	0.05	0.03	0.05
Ava.P (ppm)	13.72	18.28	9.57	13.86
ECe (ds/m)	0.11	0.23	0.17	0.17
Water content				
FC (vol. %)	35.3	34.7	33.5	34.50
PWP (vol. %)	21.9	21.3	20.2	21.13
Sat (vol. %)	45.3	44.9	44.4	44.87
TAW (mm/m)	134	134	133	133.67
Ksat (mm/day)	61.2	66.96	80.4	69.52
Irrigation water				
PH			6.9	
ECw (ds/m)				0.21

Yield of potato

The result indicates that the yield was substantially ($p<0.05$) affected by the deficit irrigation for certain treatments and showed no significance for other treatments when evaluated with T1 and among treatments (Table 3). The highest tuber yield was obtained in T1 (33.94t/ha) which corresponds to the whole growth stage at full irrigation application 100% of ETc. This was similar to the findings of Patel and Rajput, (2013) which were reported that water application with no deficit of 100% of ETc at any stage of plant growth gave the highest yield. T3 produced comparable yield (33.27t/ha) with T1 despite a water deficit at the beginning and end of the season (75% of ETc), while the other stages were irrigated at full demand (100% of ETc).

Stressing the potato crop by 25% deficit irrigation at the early and late growth stages with roughly the same irrigation period resulted in a tuber yield compared to a 0% deficit with the entire growing season of potato. This result was consistent with both the finding of Yihun (2015), Bekele and Tilahun (2007) that shows' stressing the crops during initial and late-season stage does not impact the crop yield significantly. The lowest tuber yield was found under T6 (21.80t/ha) which would have been a 25% deficit at the development and mid-season stage, 50% deficit at late-season stages as compared to T1, T3, and T5 (Table 3). This result shows that the potato crop is sensitive at the development and mid-season that are affected by deficit irrigation on tuber yield. The result agrees with the finding of Pereira and Shock (2006) that states the potato is a relatively sensitive crop in terms of both yield and quality under conditions of restricted water supply at development and flowering/tuber bulking. Other findings have also reported that potato is known to be very prone to water stress during the initiation of tuber and bulking stages (Ierna and Mauromicale, 2012, Ierna and Mauromicale, 2006, Pavlista, 2015). The result was also similar to those found in other studies (Fabeiro *et al.*, 2001, Ferreira and Carr, 2002) the optimum irrigation applications at a sensitive stage of potato would increase tuber yield and water consumption efficiency. Total potato tuber yield was proportional to the availability of water but as stress intensity increased total tuber yield decreased (Demelash, 2013).

Water use efficiency (WUE)

The outcput of this analysis showed that water consumption efficiency was variable based on the treatments of irrigation applications (Table 3). The optimum WUE was obtained from T3 and T1 which were 8.23kg/m^3 and 7.65kg/m^3, respectively. Water consumption efficiency was found to be lowest in T2 and T4. During the early and late stages of the growing season, applying 75% of the maximum irrigation water depth instead of 100% with a five-day irrigation interval improved water use efficiency.

These results are similar to those reported by Demelash (2013) and Onder *et al.* (2005). Implementing deficit irrigation techniques would result in major cost savings in irrigated agriculture without sacrificing yield. The result is now in line with Fabeiro *et al.* (2001), Shock and Feibert (2002) which described that water deficit is effective in improving water consumption and water productivity without causing significant yield reductions for the different crops, including potato. Similarly, Kirnak *et al.* (2005), Sarkar *et al.* (2008), and Woldetsadik (2003) reported that the efficiency of water use was higher at lower levels of available soil moisture. The difference in total tuber yield between T1 and T3 was only 0.67t/ha, which was statistically insignificant in terms of yield change.

However, a significant depth of water was saved 9% in T3 (Table 3). The result showed that a significant depth of water (387m^3/ha) was saved without significant yield reduction in T3 as compared to T1. Hence diverting this saved water to another irrigable land to improve the field irrigated can account for decreases in agricultural productivity. This will be used to irrigate an additional land of 0.1ha with a yield benefit of 3.33t/ha of potato crop production.

The results from field trials confirmed that with deficit irrigation strategies it is possible to increase WUE and save water for irrigation. This could be especially important for areas facing drought and limited water resources for the agricultural production of potatoes. Mansouri-Far *et al.* (2010) stated that irrigation water could be preserved and yield maintained (as a responsive crop to drought stress) in water-limited conditions. The deficit irrigation treatments saved a significant depth of water to irrigation, leading to an increase in WUE. Similar data were obtained by other authors (Liu *et al.*, 2005, Shahnazari *et al.*, 2007). Water productivity and water use efficiencies increase under deficit irrigation, relative to its value under full irrigation, as shown experimentally for many crops (Fan *et al.*, 2005, Zwart and Bastiaanssen, 2004).

This result described that adding 75% of ETc during the beginning and late-season stages of the crop growth stages have improved water efficiency than applying other deficit treatments in potato tuber yield. The highest amount of water was saved in T6 (28.6%) and 9% water was saved in T3 taking into account T1 as control 100% of ETc. When the treatments are compared in terms of yield reduction T3 had 1.9% which shows there is the lowest yield reduction than other treatments and T6 (35.7%) the highest yield reduction (Table 3).

Plant height of potato

The irrigation treatments on the mean plant height of potatoes were statistically significant ($P<0.05$) (Table 3). During the sensitive stages of potato, variation in the level of the water application had a major impact on plant height. When full irrigation was used during the growing season, the plants reached a maximum height of 45.53cm. The shortest plant height (37.43cm) was obtained with a 0% deficit at the development and mid-season stages, and a 50% deficit at the early and late-season growth stages of the potato. There were no statistically significant variations in plant height between the irrigation treatments T1, T3, and T5 ($P<0.05$).

The beneficial effect of water in maintaining the turgidity of the cell, which is a major prerequisite for growth, is demonstrated by the growing plant height with sufficient application depth of irrigation in the development and mid-season stages (Vaux Jr and Pruitt, 1983). On the contrary, shortening of plant height underwater moisture stress may be due to stomatal closure and reduced CO_2 and reduce nutrient uptake by the plants, hence, photosynthesis and other biochemical process are hampered, affecting plant growth (El-Shawadfy *et al.*, 2014). The plant's height is a good indicator of water stress. Deficit irrigation, according to some authors, causes plant height to be reduced (Pandey *et al.*, 2000). This result is consistent with Gadissa and Chemeda (2009), who reported that pepper plant height decreased with reduced irrigation levels and increased with increased irrigation levels. The availability of water in the sensitive stage of the plant was proportional to its height.

The findings of this study were also in line with those of Al-Moshileh (2007), who noticed that increasing soil water supply increased plant growth parameters significantly. Irrigation, according to Kumar et al. (2007), had a major impact on plant height, which in turn affected crop yield.

Table 3. Effects of various parameters on irrigation techniques.

Treatments	Marketable yield (t/ha)	Unmarketable yield (t/ha)	Total yield (t/ha)	Water use efficiency (kg/m^3)	Plant height (cm)	Irrigation water (m^3/ha)	Water saved (%)	Yield reduction (%)
T1	32.66a	1.27a	33.94a	7.65ab	45.53a	4437	0	0
T2	21.14c	1.06a	22.21c	6.67d	38.46b	3329.5	25	34.6
T3	31.84a	1.43a	33.27a	8.23a	41.56ab	4050	9	1.9
T4	22.48c	1.23a	23.71c	6.50d	37.43b	3662.3	17.5	30.1
T5	26.51b	1.29a	27.80b	7.38bc	41.50ab	3775.3	14.9	18
T6	20.67c	1.13a	21.80c	6.89cd	38.65b	3166.7	28.6	35.7
LSD(0.05)	2.06	0.42	2.06	0.58	4.58			
CV (%)	6.21	26.83	5.91	6.29	8.79			

Model sensitivity, calibration, and validation

Sensitive parameters

The most important variable in AquaCrop was obtained by sensitivity analysis testing (Geerts *et al.* 2009 and Salemi *et al.*2011). The result of the sensitivity of the model (Table 4) shows that the crop transpiration coefficient when canopy cover is complete, canopy growth coefficient, canopy decline coefficient, reference harvest index, maximum canopy cover, and normalized water productivity had the highest sensitivity. The finding of Afshar and Neshat (2013), who conducted a potato experiment and found that the model is sensitive to the normalized water productivity and reference harvest index. Incomparable research by Casa *et al.* (2013) conducted a field experiment to simulate potato crop yield, maximum canopy cover, canopy growth coefficient, canopy decline coefficient, and water productivity are sensitive parameters. In another study, Montoya *et al.* (2016) performed a field experiment, where the effects of various potato irrigation treatments, the canopy growth coefficient, the coefficient canopy decline, and the normalized water productivity are sensitive parameters.

Table 4.1 Sensitive parameters from calibrated during 2018/19

Parameters	Calibrated values	Original values
Crop transpiration coefficient(K_{cTr})	1.45	1.1
Canopy growth coefficient(CGC)	20%/day	17.3%/day
Canopy decline coefficient(CDC)	17%/day	8.0%/day
Reference harvest index(HIo)	85%	70.0%
Normalized water productivity(WP*)	20.0g/m2	17.0g/m2
Maximum canopy cover(CCx)	95%	85%

Model calibration

The conservative and non-conservative crop input parameters were calibrated through the AquaCrop water productivity model. The calibrated model was validated with the independently measured experimental dataset to verify the model for a series of data under different deficit irrigation scenarios. For all levels of water application scenarios, the AquaCrop model simulates the observed canopy cover, biomass, water use efficiency, irrigation water, and yield. The full 100% irrigation water application scenario was used to describe crop development under the non-limiting condition in the model. Based on the computed data of full and deficit irrigation water application treatments, the model has been adjusted.

The main calibrated parameters for canopy cover are the CGC, CDC, water stress (P_{upper}, $P_{lower,}$ and the shape factor) which affect the leaf expansion and early senescence. Canopy cover per seedling was determined according to the knowledge of the crop characteristics by specifying row spacing and plant spacing. Then, the simulation was done for the above crop phenology and the effects were correlated with the observed values. In the model initial canopy cover (CCo) was estimated based on the data from agronomic practices from row planting, row spacing 0.75m, and plant spacing 0.30m. Hence, the estimated initial canopy cover for the given potato crop has been found 0.22% (4.4 plants/m^2 or 44,444 plants/ha). To estimate the canopy expansion rate, the phenological data of the crop criteria described in Table 5 such as dates of emergency, maximum canopy cover, senescence, and maturity were used. The model results in the fast canopy expansion and moderate canopy decline coefficient. The canopy decline coefficient and canopy growth coefficient were used 17%/day and 20%/day, respectively. The stress parameters such as canopy expansion and canopy senescence coefficient were modified and readjusted to approximate the measured canopy cover. The reference harvest index was calibrated as 85%, which was well within the range recommended by Raes *et al.* (2012b) for potato crops (70-85%).

Table 5.2 Crop parameters and their calibrated model values during 2018/19

Parameters	Unit	Value
Crop phenology		
Planting to emergence	DAS	7
Planting to maximum canopy	DAS	50
Planting to start tuber formation	DAS	54
Planting to maximum rooting depth	DAS	60
Planting to start of canopy senescence	DAS	85
Planting to maturity	DAS	105
Crop growth and development		
Base temperature	^{o}c	10
Upper temperature	^{o}c	30
Planting density	Plants/m^2	4.4
Initial canopy cover (CCo)	%	0.22
Canopy growth coefficient (CGC)	%/day	20.0
Canopy decline coefficient (CDC)	%/day	17.0

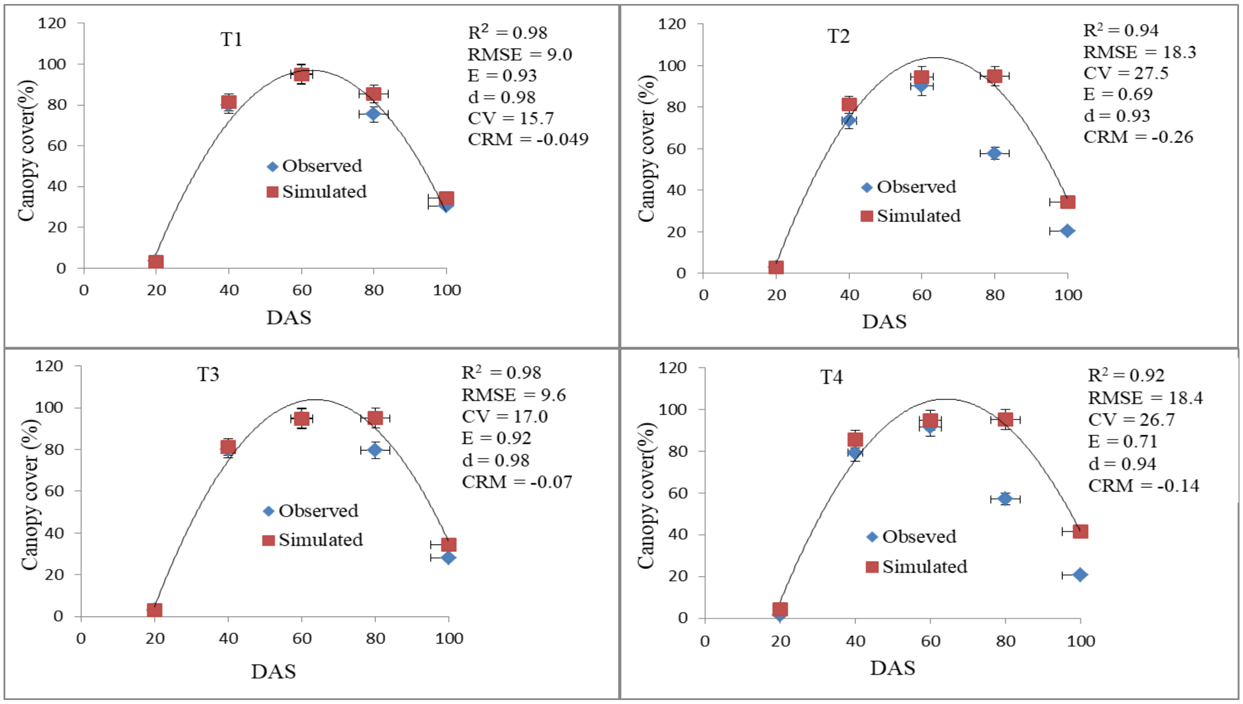
Maximum canopy cover (CCx)	%	95
Length to build up of HI	DAS	46
Normalize water productivity (WP*)	g/m^2	20
Water extraction pattern throughout the effective root zone	%	40,30,20,10
Maximum root extraction over the effective root zone	mm/day	18.0
Crop transpiration coefficient	-	1.45
Canopy shelter in late season	%	60
Maximum rooting depth (m)	Meters	0.6
Shape factor for effective rooting deepening	%	1.5
Yield formation		
Reference harvest index (HIo)	%	85
Water stress before the start of yield formation positive impact on HI as a consequence of restricted growth in the vegetative cycle	-	Strong
Water stress during yield formation positive effect on HI result of affecting leaf expansion	-	Strong
Water stress during yield formation negative effect on HI as just a result of water stress-inducing stomatal closure	-	small
Water stress		
The upper threshold for water stress for canopy expansion(P_{upper})	-	0.1
The lower threshold for water stress for canopy expansion(P_{lower})	-	0.45
The upper threshold for soil water stress effect on stomatal closure(P_{upper})	-	0.45
Water stress on early canopy senescence (P_{upper})	-	0.55
Aeration stress sensitivity for waterlogging	Vol%	8.0
Shape factor for canopy expansion	-	3
Shape factor for stomatal closure		3
Shape factor for early canopy senescence		3

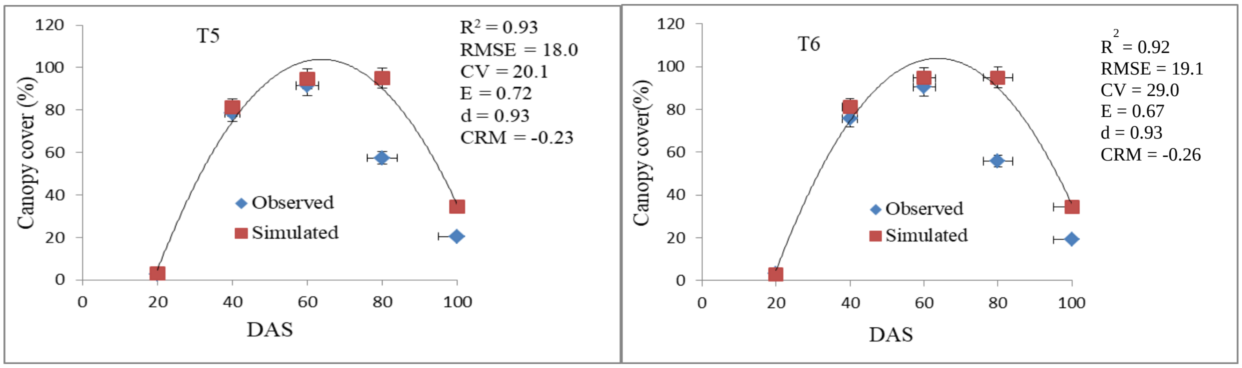
Canopy Cover (CC)

Crop parameters were used to model the CC to obtain a good agreement between both the simulated as well as the values of the observed potato crop (Table 5). Just after the method of calibration, the normalized water productivity was calculated as 20.0 gm^{-2}, and so this value was within the range suggested by Raes *et al.* (2012b) for C_3 crops (15-20 gm^{-2}) and the confidence level defined within the field results. The result of the calibration indicating that the model was capable of simulating CC under different water conditions (Figure 3). In general, the model predicted the seasonal trend in CC as well. However, the model tended to overestimate CC during 80 days after sowing in all treatments (Greaves and Wang, 2016).

The observed and the simulated CC developments were fitted well for treatment receiving full irrigation throughout the growth stage was confirmed by the statistical values in Figure 3. The result of this study revealed which model was able to simulate correctly the CC development, but it was seen that the value of CC was overestimated from the senescence to the end of a cropping season in the calibration period 2018/19.

Montoya *et al.* (2016) showed that a strong ability of AquaCrop in simulating CC of potato in the calibration of various water application scenarios. This research is in accordance with other authors (Ngetich *et al*, 2012) who describe a remarkable match between both the measured and simulated CC on different irrigation treatments. The statistical parameter, coefficient of residual moss having values of negative meant that the model exaggerates the CC. From Figure 3 it is clear that the CC was overstated by the model especially 80 and 100 days after sowing, during crop senescence of potato. Pawar *et al.* (2017), Amirouche *et al.* (2021) who confirmed that the model overestimates CC during the mid-season stage of the crop supported with the CRM value was negative. The calibration was satisfactory as the measured and expected CC values of E ranged from 0.67 to 0.93 at different water application scenarios.





Figugre 3. Model calibration of simulated and observed canopy cover during 2018/19

Biomass

The model simulated and measured biomass within full and deficit irrigation conditions (Figure 4). Most of the treatment receiving both irrigation applications shows overestimated biomass at 40, 60, and 80 days after sowing. This was maintained by the mathematical values of the CRM was negative values. The finding of Ndambuki (2013) which indicated that the model overestimated the biomass on flowing and maturity of the correctly simulated, the values of a CRM is negative. The treatment delivery of deficit irrigation (T3) described a good fit with the simulated biomass. As seen from Figure 4 the calibrated of deficit irrigation (T3) there was a close association between the observed and predicted biomass. The model was calibrated with model efficiency E of 0.96. This study is in agreement with Greaves and Wang (2016) who identified that the AquaCrop model is a good fit with the measured and simulated biomass of the statistical values of $R^2 = 0.99$, RMSE = 1.16, E = 0.97, and d = 0.99 getting deficit irrigation.

In general, the observed and estimated values are in good condition, as shown by the low RMSE, high D, and E values. The value of the statistics mentioned in the current study is similar to those found in other crops. Abedinpour *et al.* (2012) confirmed that the coefficient of efficiency found that various irrigation treatments were applied between 0.65 and 0.99. The AquaCrop model can be adjusted to simulate potato biomass, yield, and efficiency of water in the study site and becomes a valuable method to help the decision for irrigation purposes.

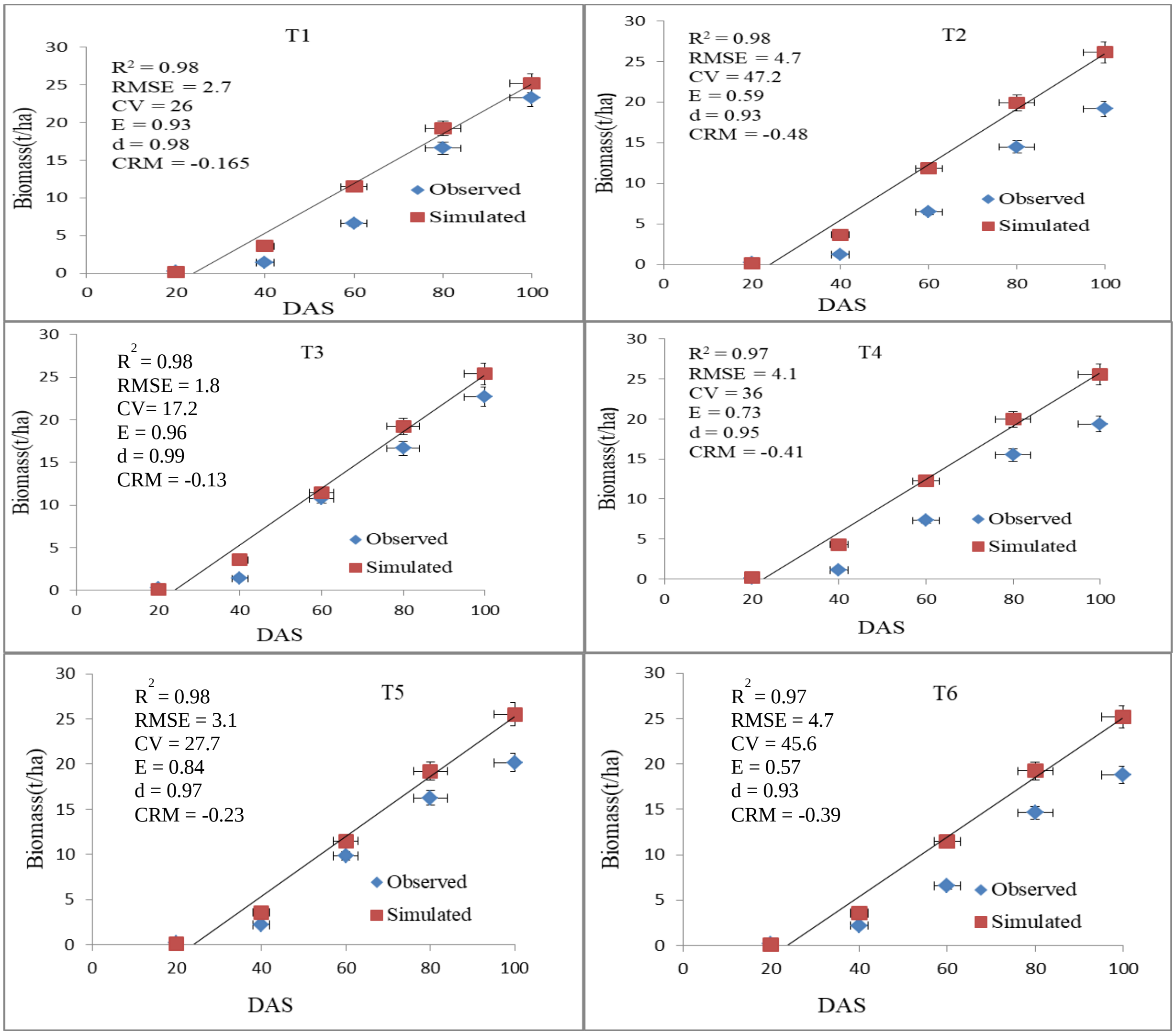


Figure 4. Model calibration of simulated and observed during 2018/19

Harvest index

The value of the harvest index for the different irrigation water application scenarios is derived from the field experiment. For the treatment receiving full irrigation, the harvest indexes obtained was 0.82. The harvest index value displays a decreasing trend under water stress condition that is 0.81, 0.69, and 0.68 for T3, T2, and T6, respectively. A similar trend was reported by Demelash (2013), Farré and Faci (2009), and Yihun (2015) for potato, maize, sorghum, and teff for water stress conditions. Karunaratne *et al.* (2011) also reported on Bambara groundnuts in critical growth stages to show a decreasing trend in the harvest index for water stress conditions.

Since soil water stress has a strong impact on the potato harvest index, the effect of soil water stress on different growth stages was recorded and modified in the model. According to the study, water stress prior to flowering has a strong positive impact on the harvest index due to reduced vegetative growth. Water stress during yield formation had a strong positive and small negative impact on harvest index (Table 5) as both a result of water stress affecting leaf expansion and inducing stomatal closure respectively. The result indicates that irrigation application stress at the development and mid-season periods affect potato yield.

Yield, WUE, and Irrigation water

The measured potato tuber yields in the field experiment range between 22.89 and 35.15t/ha, while the simulated values range between 18.99 and 34.08t/ha (Table 6). The experiment in 2018/19, deviations of -3.02 and -20.53% values of both the simulated and measured were found. The yield reduction mainly occurs when stress is experienced during the potato-sensitive growth stages like development and mid-season. This result is supported by the finding of Casa *et al.* (2013) and Montoya *et al.* (2016).

The discrepancy in the seasonal water demand between the simulation results and the field measurements for the different irrigation treatments is presented in Table 6. AquaCrop consistently overestimated the seasonal requirements of crop water and the deviations increased as the water deficit increased. The deviations range from 9.22 to 16.85% for the experimental treatments. The study is in accordance with Katerji *et al.* (2013), who observed that AquaCrop scientifically overestimated the seasonal ETc and the deviations generally increased as stress levels increased. Although the linear regression between simulated and the observed values for all seasons produced an overall R^2 value of 0.98 the values were relatively distributed, suggesting that model prediction of ETc is fair. As a result of some important mismatch between some of the simulated and actual crop water demand values, the disparity between the calculated and simulated water use efficiency of tuber yields is high for T2 and T6 compared to other deficit treatments (Table 6). The analysis reveals there was no general opinion that the deviations in water use efficiency values were a function of crop water stress. However, the observed efficiency of water use was obviously better in the T3, suggesting that the opportunity for water savings was comparable to that achieved in the full irrigation and other deficit treatments during the planting season for potatoes.

Table 6.3 Selected parameters of simulated and measured values for calibration period

Treatment	Yield			WUE			IW		
	Simulated	Measured	Dev	Simulated	Measured	Dev	Simulated	Measured	Dev
T1	34.08	35.15	-3.14	7.35	8.06	-9.65	483.1	435.80	9.79
T2	19.95	23.29	-16.74	6.12	7.43	-21.40	386.8	326.85	15.49
T3	33.5	34.51	-3.02	8.31	8.78	-5.66	433.1	393.12	9.22
T4	22.01	24.81	-12.72	6.21	7.08	-14.01	404.2	350.45	13.29
T5	26.01	28.88	-11.03	7.15	7.91	-10.62	412.3	364.97	11.47
T6	18.99	22.89	-20.53	6.03	7.31	-21.22	376.7	313.22	16.85

Model validation

The crop parameters that were calibrated were used to validate the model. The validation simulation of the seasonal growth of canopy cover and the accumulation of biomass was carried out during the 2019/20 irrigation season.

Canopy cover (CC)

The data obtained for the 2019/20 irrigation season were used for validation of the model (Figure 5) and show the result of the statistical parameters. The AquaCrop model overestimated the canopy cover during the crop senescence 80 &100 days after sowing, in all treatments because of high evapotranspiration during these periods (Figure 5). The model, overestimated comparatively high canopy cover from flowing to the harvesting of deficit irrigation, was obviously insufficient in deficit irrigation at critical growth stages (flowing and tuber bulking) due to water stress. Similarly, Casa *et al.* (2013), Greaves and Wang (2016) announced which model overestimated the estimated canopy cover under the water deficit condition of sensitive stages of potato and maize. The validation of critical stages of potato at development and mid-season phases indicates the application of 100% and 75% irrigation water offers good match between the predicted and observed canopy cover of the T3 (Figure 5).

The high values of E and d for the T1 and T3 indicate the overall good agreement between the projected and measured CC. The T6 recorded a high d value of 0.93 but a moderate efficiency value of 0.68. T3 compared to other deficit treatments, showing high model accuracy simulating canopy cover. The test statistics reflect the fitness of the model seen between observed and estimated canopy cover, as shown in (Figure 5). The stress in the development and mid-season phases of the potatoes, as measured and simulated by the coefficient of efficiency, was poor, indicating that the model's output was acceptable in this level's stressed condition. During the validation period, the model's overall performance was overestimated canopy cover, and the coefficient of residual moss value was negative.

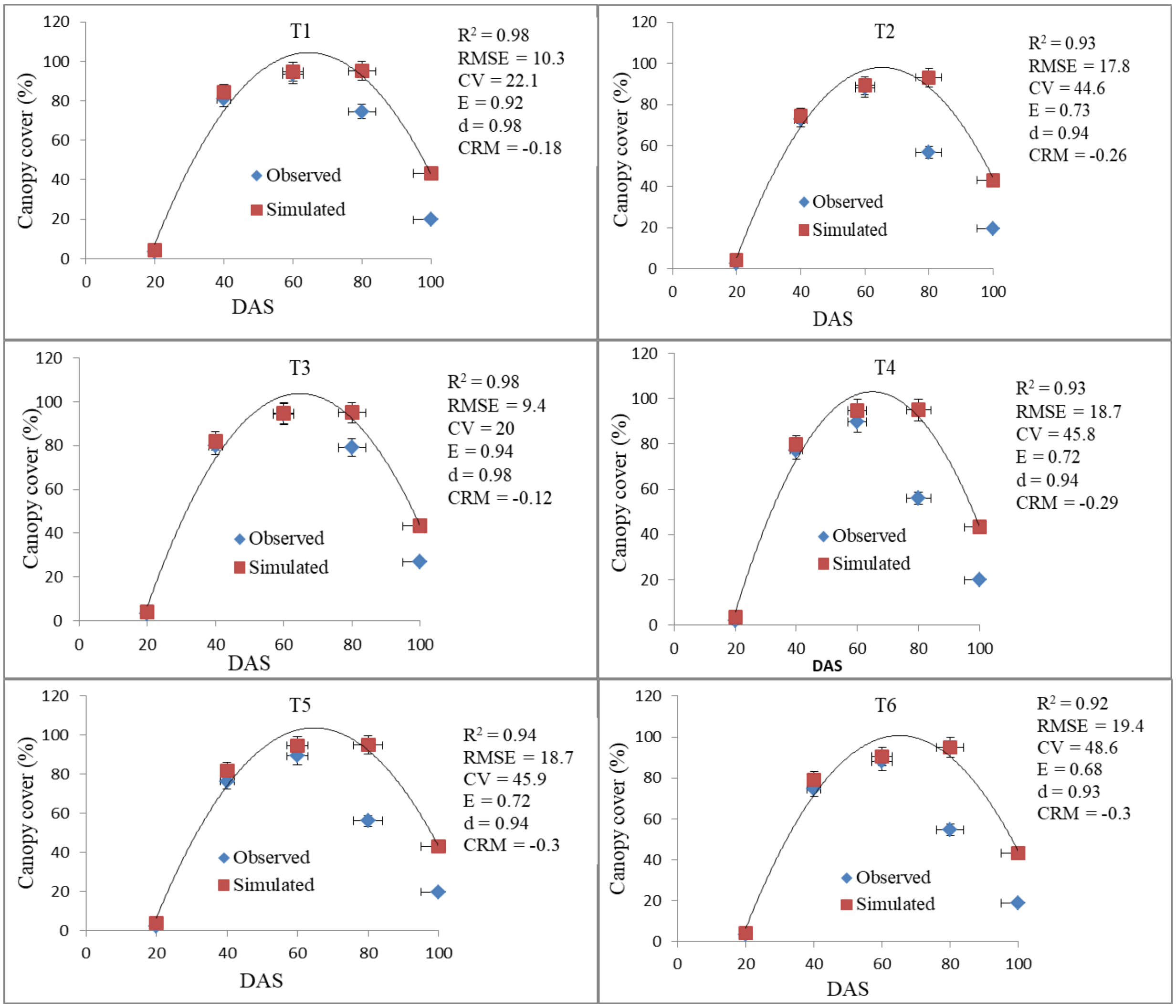


Figure 5. Model validation of simulated and observed canopy cover during 2019/20

Biomass

To validate and calibrate crop parameters for field-grown potato, the biomass obtained at 20-day intervals during the field experiment was compared to the AquaCrop model prediction (Figure 6). There is generally a fair match between the data sets measured and simulation, with the exception of the crop deficit sensitive stages and the 50% deficit in the early and late seasons. Except for the initial stage at 20 days after sowing in all treatments, the model tends to indicate an overestimation of biomass. The model's efficiency in potato biomass was overestimated, and the value of the residual moss coefficient was negative.

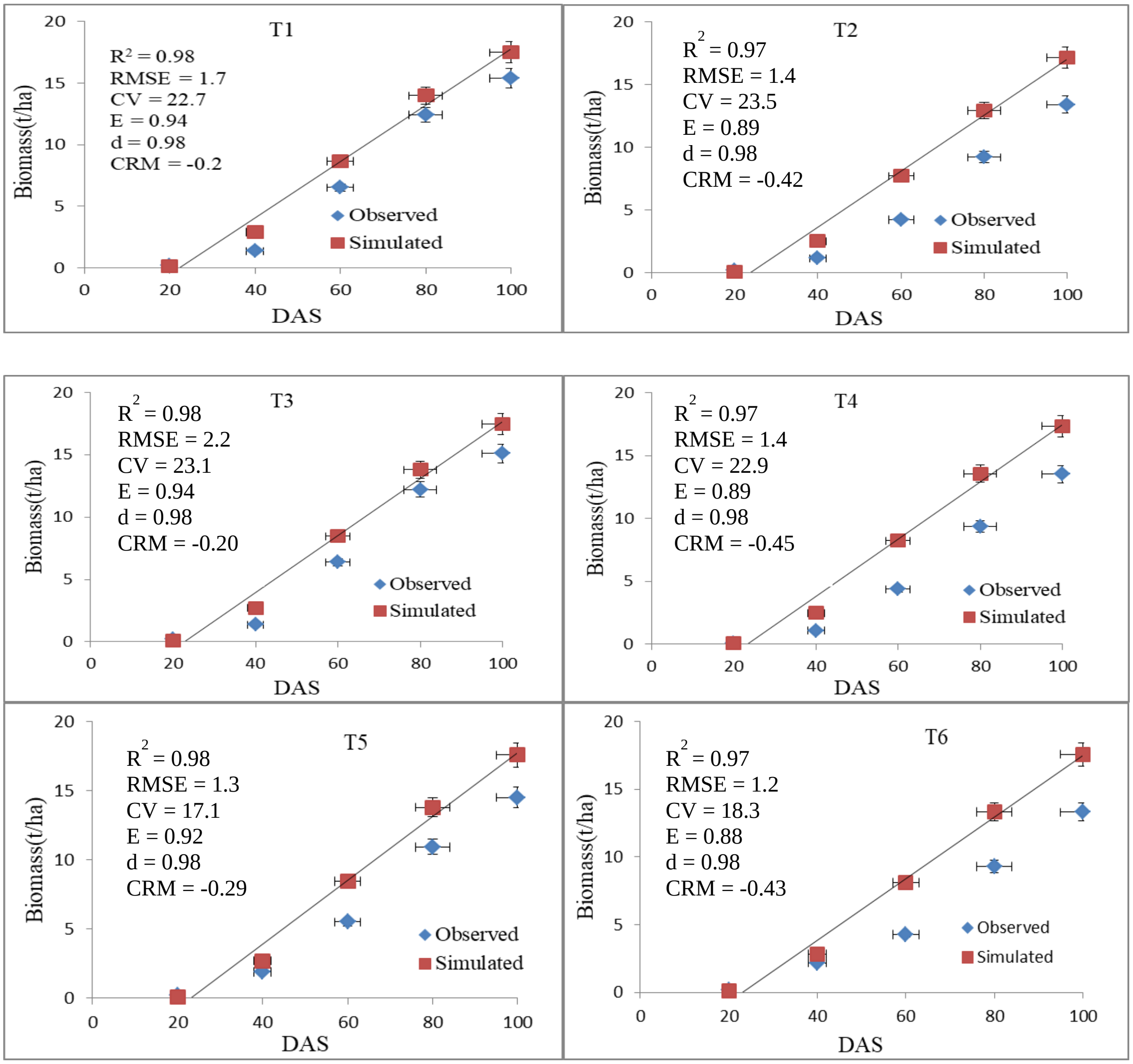


Figure 6. Model validation of simulated and observed biomass during 2019/20

Yield, efficiency of water use, and irrigation water

Potato yields measured in field experiments ranged from 20.72 to 32.74 t/ha, while simulated values varied from 16.82 to 31.67 t/ha (Table 7). During 2019/20, a difference of between -3.3 and -23.2% was found between the simulated and measured values. The reduction in potato yield usually occurs when stress occurs during the sensitive growth stages, such as development and mid-season. The above result is in agreement with the finding of Casa et al. (2013) and Montoya et al. (2016). For the deficit at critical points, the simulated yield deviation from the observed yield was greater than 12%, signifying that the model accuracy decreases under conditions of extremely stressed water environments. Similar observations were discussed by (Evett &Tolk, 2009).

For the various irrigation treatments, the disparity in seasonal crop water between simulation results and measurements identified in the field experiment. The seasonal crop water requirements were consistently overestimated by AquaCrop, and the deviations grew as the water deficit increased. For the experimental treatments, the variations range from 4.6 to 12% (Table 7). The findings are consistent with those of Katerji *et al.* (2013), who found that AquaCrop overestimated the seasonal ETc and that the deviations increased as stress levels increased. The gap between measured and simulated water use efficiency of potato yield is high for T2 and T6 as compared to other deficit treatments, due to a significant mismatch between simulated and observed crop water requirement values. However, calculated water use efficiency appeared to be better in the T3, implying the potential for water savings, provided that the yield was comparable to that obtained in the full irrigation during the growing season of potato and other deficit treatments.

Table 7. Validation parameter of measured and simulated results.

Treatment	Yield			WUE			IW		
	Simulated	Measured	Dev	Simulated	Measured	Dev	Simulated	Measured	Dev (%)
T1	31.67	32.74	-3.4	6.54	7.25	-10.9	4789	4516	5.7
T2	17.78	21.12	-18.8	4.92	6.23	-26.6	3789	3390	10.5
T3	31.03	32.04	-3.3	7.22	7.69	-6.5	4369	4169	4.6
T4	19.82	22.62	-14.1	5.05	5.92	-17.2	4156.5	3819.5	8.1
T5	23.85	26.72	-12.0	6.09	6.85	-12.5	4173.5	3900.5	6.5
T6	16.82	20.72	-23.2	5.19	6.47	-24.7	3636.5	3201.5	12.0

Conclusion and recommendation

One of the irrigation management strategies that could save water is deficit irrigation. By keeping the moisture content of the soil below the optimum level during particular growth stages of the season or during the growing season, it is possible to define the periods during which the water deficit will have a limited impact on crop production. Deficit irrigation saves water and improves water productivity while maintaining an optimal yield close to maximum irrigation. According to field experiments, 75 and 50% late-season (T6) of the total requirement of crop water showed higher yield reductions than other deficits irrigation. Deficit irrigation, on the other hand, had a yield reduction of 75% at the beginning, late season, and 100% at all other stages of irrigation water application on potato production.

It proposed that the water deficit could have a major effect on yield at the development and mid-season stages of the potato. With deficit irrigation strategies, it's indeed possible to increase yield, water use efficiency, and save significant water depth for irrigation, according to the findings of this report. T1 and T3 produced the highest yields of potato tubers, with yields of 33.94t/ha and 33.27t/ha, respectively. T6 had the lowest yield of potato tubers (21.8 t/ha). Meanwhile, the yield difference between T1 and T3 was $P<0.05$, which was not important. Taking the above findings into account, it can be concluded that the potato crop has responded positively to mild water stress conditions at our study site. Identifying the sensitive growth stages of a specific cultivar under local weather and soil fertility conditions allows for irrigation scheduling that maximizes crop yield while conserving scarce water. As a result, we discovered that the most vulnerable times for potatoes to be irrigated at 100% ETc were during the second and third periods.

The AquaCrop model must be calibrated and validated for each crop, soil, and environment. Data from 2018/19 was used to calibrate the system, and data from 2019/20 was used to validate it. The sensitivity analysis on canopy cover and biomass of calibration treatments showed that Kc_{Tr}, CGC, CDC, HIo, WP*, and CCx had the highest sensitivity. The findings of this study revealed that such a model can simulate biomass, canopy cover, yield, and water productivity/use efficiency for full supplied irrigation and treatment with some stages of water deficit; however, the model was less satisfactory under water deficit (75 and 50%) at the most important physiological stage of potato compared to the full irrigation at sensitive stages. The highest and lowest accuracy for predicting canopy cover, biomass, yield, and water use efficiencies were obtained at T3 and T6, respectively. According to field experiments and modeling, the AquaCrop model can predict potato biomass, canopy cover, water efficiency, and yield with reasonable accuracy under various irrigation and growth conditions.

The highest yield of potatoes and water efficiency was found from T3 (33.27t/ha) and (8.23kg/m^3) by providing 75% ETc during the early and late seasons, while 100% receiving the development and mid-season stages, which is still better than 100% ETc all through the growing period. As a result, we believe that irrigation water applied (75, 100, 100, and 75% ETc) is better suited to Lalibela and other similar agro-ecological conditions. This finding could help to improve food security by increasing crop yields, particularly in areas where water is scarce.

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References

Abedinpour, M., Sarangi, A., Rajput, T., Singh, M., Pathak, H. & Ahmad, T. 2012. Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. *Agricultural Water Management,* 110**,** 55-66.

Afshar, A. & Neshat, A. 2013. Evaluation of Aqua Crop computer model in the potato under irrigation management of continuity plan of Jiroft region, Kerman, Iran. *Int. J. Adv. Biol. Biom. Res,* 1**,** 1669-1678.

Afsharmanesh, A. A. G. R., Adeli, M. & Malekian, A. 2014. Assessment of aquacrop model in the simulation of potato yield and water use efficiency under different water regimes. *Journal of Biological and Environmental Sciences,* 8.

Al-Moshileh, A. 2007. Effects of planting date and irrigation water level on onion (Allium cepa L.) production under central Saudi Arabian conditions. *Scie. J. King Faisal University (Basic and Applied Sciences),* 8**,** 75-85.

Ali, M. & Talukder, M. 2008. Increasing water productivity in crop production a synthesis. *Agricultural water management*, 95**,** 1201-1213.

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. 1998. FAO Irrigation and drainage paper No. 56. *Rome: Food and Agriculture Organization of the United Nations,* 56**,** e156.

Amirouche, M., Smadhi, D. & Zella, L. 2021. Calibration and validation of the Aquacrop model for the culture lettuce (lactuca sativa l.) under fertilization levels in pluvial condition. *Agricultural Engineering International: CIGR Journal*, 23**,** 36-46.

Banchu, B. 2020. *Evaluation of the applicability of Aquacrop Model to simulate crop response to deficit irrigation.* ASTU.

Behera, S. & Panda, R. 2009. Integrated management of irrigation water and fertilizers for wheat crop using field experiments and simulation modeling. *Agricultural water management,* 96**,** 1532-1540.

Bekele, S. & Tilahun, K. 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural Water Management,* 89**,** 148-152.

Bessembinder, J., Leffelaar, P., Dhindwal, A. & Ponsioen, T. 2005. Which crop and which drop, and the scope for improvement of water productivity. *Agricultural water management,* 73**,** 113-130.

Bitri, M., Grazhdani, S. & Ahmeti, A. 2014. Validation of the AquaCrop model for full and deficit irrigated potato production in environmental condition of Korça Zone, south-eastern Albania. *International Journal of Innovative Research in Science, Engineering and Technology,* 3**,** 12013-12020.

Blum, A. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field crops research,* 112**,** 119-123.

Boudhina, N., Masmoudi, M., Alaya, I., Jacob, F. & Mechlia, N. B. 2019. Use of AquaCrop model for estimating crop evapotranspiration and biomass production in hilly topography. *Arabian Journal of Geosciences,* 12**,** 259.

Boudhina, N., Masmoudi, M. M., Mechlia, N. B., Zitouna, R., Mekki, I., Prévot, L. & Jacob, F. 2017. Evapotranspiration of Wheat in a Hilly Topography: Results from Measurements Using a Set of Eddy Covariance Stations. *Water and Land Security in Drylands.* Springer.

Bradford, K. & Hsiao, T. 1982. Physiological responses to moderate water stress. *Physiological plant ecology II.* Springer.

Casa, A. D. L., Ovando, G., Bressanini, L. & Martínez, J. 2013. Aquacrop Model Calibration in Potato and Its Use to Estimate Yield Variability under Field Conditions. *Atmospheric and Climate Sciences,* 03**,** 397-407.

Chimdi, A., Gebrekidan, H., Kibret, K. & Tadesse, A. 2012. Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences,* 2**,** 57-71.

Corbari, C., Ben Charfi, I. & Mancini, M. 2021. Optimizing irrigation water use efficiency for tomato and maize fields across italy combining remote sensing data and the AquaCrop Model. *Hydrology,* 8**,** 39.

Demelash, N. 2013. Deficit irrigation scheduling for potato production in North Gondar, Ethiopia. *African J. Agric. Res,* 8**,** 1144-1154.

Demelash, N. & Alamirew, T. 2011. *Deficit Irrigation Scheduling for Potato Production in North Gondar Zone, Ethiopia.* Haramaya University.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T. & Yesuf, M. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global environmental change,* 19**,** 248-255.

Domínguez, A., De Juan, J., Tarjuelo, J., Martínez, R. & Martínez-Romero, A. 2012. Determination of optimal regulated deficit irrigation strategies for maize in a semi-arid environment. *Agricultural Water Management,* 110**,** 67-77.

Eitzinger J, Trnka M, Hosch J, Zalud Z, Dubrovsky M (2004). Comparison of CERES, WOFOST and SWAP models in simulating soil water content during growing season under different soil conditions. Ecol, Model. 171:223–246.

El-Shawadfy, M. A., El-Ansary, M. Y., El-Bahnasawy, A. H., Awad, M. A. & El-Noemani, A.-S. A. 2014. Sunflower yield, water use efficiency and soil moisture content as affected by irrigation systems and regimes in old land of Egypt. *American-Eurasian Journal of Sustainable Agriculture***,** 1-12.

Evett, S. R. & Tolk, J. A. 2009. Introduction: Can water use efficiency be modeled well enough to impact crop management? Agronomy Journal, 101, 423-425.

Fabeiro, C., De Santa Olalla, F. M. N. & De Juan, J. 2001. Yield and size of deficit irrigated potatoes. *Agricultural Water Management,* 48**,** 255-266.

Fan, T., Stewart, B., Payne, W. A., Wang, Y., Song, S., Luo, J. & Robinson, C. A. 2005. Supplemental irrigation and water–yield relationships for plasticulture crops in the Loess Plateau of China. *Agronomy Journal,* 97**,** 177-188.

Fao, F. 2011. Available online at: http://faostat. FAO. org/site/291/default. aspx. *Food and Agriculture Organization*.

Farahani, H. J., Izzi, G. & Oweis, T. Y. 2009. Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. *Agronomy journal,* 101**,** 469-476.

Farré, I. & Faci, J. M. 2009. Deficit irrigation in maize for reducing agricultural water use in a Mediterranean environment. *Agricultural Water Management,* 96**,** 383-394.

Fereres, E. & Soriano, M. A. 2006. Deficit irrigation for reducing agricultural water use. *Journal of experimental botany,* 58**,** 147-159.

Ferreira, T. & Carr, M. 2002. Responses of potatoes (Solanum tuberosum L.) to irrigation and nitrogen in a hot, dry climate: I. Water use. *Field Crops Research,* 78**,** 51-64.

Foster, T., Brozovic, N., Butler, A. P., Neale, C. M., Raes, D., Steduto, P., Fereres, E. & Hsiao, T. C. 2017.AquaCrop-OS: A tool for resilient management of land and water resources in agriculture. EGU General Assembly Conference Abstracts, 2842.

Gadissa, T. & Chemeda, D. 2009. Effects of drip irrigation levels and planting methods on yield and yield components of green pepper (Capsicum annuum, L.) in Bako, Ethiopia. *Agricultural Water Management,* 96**,** 1673-1678.

García-Vila, M., Fereres, E., Mateos, L., Orgaz, F. & Steduto, P. 2009. Deficit irrigation optimization of cotton with AquaCrop. *Agronomy journal,* 101**,** 477-487.

Gebremedhin, Y., Berhe, A. & Nebiyu, A. 2015. Performance of AquaCrop model in simulating tuber yield of Potato (Solanum tuberosum L.) under various water availability conditions in Mekelle area, northern Ethiopia. *JNSR,* 5**,** 123-30.

Gebreselassie, Y., Ayana, M. & Tadele, K. 2015. Field experimentation based simulation of yield response of maize crop to deficit irrigation using AquaCrop model, Arba Minch, Ethiopia. *African Journal of Agricultural Research,* 10**,** 269-280.

Geerts, S. & Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural water management,* 96**,** 1275-1284.

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J.A., Taboada, C., Mendoza, J., Huanca, R., Mamani, A., Condori, O. 2009. Simulating yield response of quinoa to water availability with AquaCrop. Agron. J.101, 499–508.

Greaves, G. & Wang, Y.-M. 2016. Assessment of FAO AquaCrop Model for Simulating Maize Growth and Productivity under Deficit Irrigation in a Tropical Environment. *Water,* 8**,** 557.

Heng, L. K., Hsiao, T., Evett, S., Howell, T. & Steduto, P. 2009. Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agronomy Journal,* 101**,** 488-498.

Hirpa, A., Meuwissen, M. P., Tesfaye, A., Lommen, W. J., Lansink, A. O., Tsegaye, A. & Struik, P. C. 2010. Analysis of seed potato systems in Ethiopia. *American journal of potato research,* 87**,** 537-552.

Ierna, A. & Mauromicale, G. 2006. Physiological and growth response to moderate water deficit of off-season potatoes in a Mediterranean environment. *Agricultural Water Management,* 82**,** 193-209.

Ierna, A. & Mauromicale, G. 2012. Tuber yield and irrigation water productivity in early potatoes as affected by irrigation regime. *Agricultural Water Management,* 115**,** 276-284.

Kale, S. 2016. Assessment of AQUACROP model in the simulation of wheat growth under different water regimes. *Scientific Papers-Series A, Agronomy,* 59**,** 308-314.

Karunaratne, A., Azam-Ali, S., Izzi, G. & Steduto, P. 2011. Calibration and validation of FAO-AquaCrop model for irrigated and water deficient bambara groundnut. *Experimental Agriculture,* 47**,** 509-527.

Kashyap, P. & Panda, R. 2003. Effect of irrigation scheduling on potato crop parameters under water stressed conditions. *Agricultural water management,* 59**,** 49-66.

Katerji, N., Campi, P. & Mastrorilli, M. 2013. Productivity, evapotranspiration, and water use efficiency of corn and tomato crops simulated by AquaCrop under contrasting water stress conditions in the Mediterranean region. *Agricultural Water Management,* 130**,** 14-26.

Kirnak, H., Higgs, D., Kaya, C. & Tas, I. 2005. Effects of irrigation and nitrogen rates on growth, yield, and quality of muskmelon in semiarid regions. *Journal of plant nutrition,* 28**,** 621-638.

Kumar, S., Imtiyaz, M., Kumar, A. & Singh, R. 2007. Response of onion (Allium cepa L.) to different levels of irrigation water. *Agricultural Water Management,* 89**,** 161-166.

Liu, F., Jensen, C. R., Shahanzari, A., Andersen, M. N. & Jacobsen, S.-E. 2005. ABA regulated stomatal control and photosynthetic water use efficiency of potato (Solanum tuberosum L.) during progressive soil drying. *Plant Science,* 168**,** 831-836.

Mansouri-Far, C., Sanavy, S. A. M. M. & Saberali, S. F. 2010. Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semi-arid climatic conditions. *Agricultural Water Management,* 97**,** 12-22.

Mibulo, T. & Kiggundu, N. 2018. Evaluation of FAO AquaCrop model for simulating rainfed maize growth and yields in Uganda. *Agronomy,* 8**,** 238.

Montoya, F., Camargo, D., Ortega, J., Córcoles, J. & Domínguez, A. 2016. Evaluation of Aquacrop model for a potato crop under different irrigation conditions. *Agricultural Water Management,* 164**,** 267-280.

Nash, J. E. & Sutcliffe, J. V. 1970. River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology,* 10**,** 282-290.

Ndambuki, J. 2013. Application of AquaCrop model in deficit irrigation management of cabbages in Keiyo Highlands. *International Journal of Water Resources and Environmental Engineering,* 5**,** 360-369.

Ngetich, K., Raes, D., Shisanya, C., Mugwe, J., Mucheru-Muna, M., Mugendi, D., Diels, J., Books, R., Sheets, F. & Oer, R. 2012.Calibration and validation of AquaCrop model for maize in sub-humid and semi-arid regions of central highlands of Kenya. Proceedings of the Conference of RUFORUM Third Biennial Conference, Entebbe, Uganda, 24-28.

Onder, S., Caliskan, M. E., Onder, D. & Caliskan, S. 2005. Different irrigation methods and water stress effects on potato yield and yield components. *Agricultural water management,* 73**,** 73-86.

Pandey, R., Maranville, J. & Admou, A. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment: I. Grain yield and yield components. *Agricultural water management,* 46**,** 1-13.

Patel, N. & Rajput, T. 2013. Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation. *International Journal of Plant Production,* 7**,** 417-435.

Pavlista, A. D. 2015. Scheduling reduced irrigation on 'Atlantic'potato for minimal effect. *American journal of potato research,* 92**,** 673-683.

Pawar, G., Kale, M. & Lokhande, J. 2017. Response of AquaCrop model to different irrigation schedules for irrigated cabbage. *Agricultural Research,* 6**,** 73-81.

Pereira, A. & Shock, C. 2006. Development of irrigation best management practices for potato from a research perspective in the United States. *Sakia. org e-publish,* 1**,** 1-20.

Raes, D., Steduto, P., Hsiao, T. & Fereres, E. 2012a. Aquacrop reference manual p. Rome, Ithaly FAO. *Land and Water Division*.

Raes, D., Steduto, P., Hsiao, T. & Fereres, E. 2012b. Reference Manual AquaCrop (Version 4.0). *AquaCrop Website http://www. fao. org/nr/water/aquacrop. html*.

Rhoades, J. & Chanduvi, F. 1999. *Soil salinity assessment: Methods and interpretation of electrical conductivity measurements,* Food & Agriculture Org.

Salemi, H., Soom, M.A.M., Lee, T.S., Mousavi, S.F., Ganji, A., KamilYusoff, M. 2011. Application of AquaCrop model in deficit irrigation management of Winter wheat in arid region. Afr. J. Agric. Res. 6, 2204–2215.

Sarkar, S., Goswami, S., Mallick, S. & Nanda, M. 2008. Different indices to characterize water use pattern of micro-sprinkler irrigated onion (Allium cepa L.). *Agricultural Water Management,* 95**,** 625-632.

Saxton, K. E. & Rawls, W. J. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil science society of America Journal,* 70**,** 1569-1578.

Shahnazari, A., Liu, F., Andersen, M. N., Jacobsen, S.-E. & Jensen, C. R. 2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. *Field Crops Research,* 100**,** 117-124.

Shock, C. & Feibert, E. 2002. Deficit irrigation of potato. *Deficit irrigation practices.*

Shock, C., Feibert, E. & Saunders, L. 1998. Potato yield and quality response to deficit irrigation. *HortScience,* 33**,** 655-659.

Smith, M. 2000. The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. *Agricultural and Forest Meteorology,* 103**,** 99-108.

Soltani, A. & Hoogenboom, G. 2007. Assessing crop management options with crop simulation models based on generated weather data. *Field Crops Research,* 103**,** 198-207.

Soomro, K. B., Alaghmand, S., Shahid, M. R., Andriyas, S. & Talei, A. 2020. Evaluation of AquaCrop model in simulating bitter gourd water productivity under saline irrigation. *Irrigation and Drainage,* 69**,** 63-73.

Steduto, P., Hsiao, T., Fereres, E. & Raes, D. 2012. Crop yield response to water. FAO Irrigation and Drainage Paper No. 66, Food and Agriculture Organization of the United Nations, Rome, Italy. ISBN 978-92-5-107274-5.

Tadesse, A., Ayalew, A., Getu, E. & Tefera, T. 2006. Review of research on post-harvest pests. *Increasing crop production through improved plant protection,* 2**,** 475-563.

Tadesse, T., Haque, I. & Aduayi, E. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis manual.

Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P. M., Shiferaw, B. & Banziger, M. 2011. The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop protection,* 30**,** 240-245.

Tefera, A. H. & Mitiku, D. T., 2021. Models comparative study for estimating crop water requirement and irrigation scheduling of maize in Metekel Zone, Benishangul Gumuz Regional State, Ethiopia. *International Journal of Agricultural Economics,* 6**,** 59.

Tsubo, M., Walker, S. & Ogindo, H. 2005. A simulation model of cereal–legume intercropping systems for semi-arid regions: I. Model development. *Field crops research,* 93**,** 10-22.

Vaux Jr, H. J. & Pruitt, W. O. 1983. Crop-water production functions. *Advances in irrigation.* Elsevier.

Vos, J. & Haverkort, A. 2007. Water availability and potato crop performance. *Potato Biology and Biotechnology*. Elsevier.

Willmott, C. J. & Matsuura, K. 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate research,* 30**,** 79-82.

Woldetsadik, K. 2003. *Shallot (Allium cepa var. ascolonicum) responses to plant nutrients and soil moisture in a sub-humit tropical climate*.

Yihun, Y. M. 2015. *Agricultural water productivity optimization for irrigated Teff (Eragrostic Tef) in water scarce semi-arid region of EthiopiaAgricultural water productivity optimization for irrigated Teff (Eragrostic Tef) in water scarce semi-arid region of Ethiopia*, CRC Press/Balkema.

Zand-Parsa, S., Sepaskhah, A. & Ronaghi, A. 2006. Development and evaluation of integrated water and nitrogen model for maize. *Agricultural Water Management,* 81**,** 227-256.

Zwart, S. J. & Bastiaanssen, W. G. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural water management,* 69**,** 115-133.

Determination of irrigation water requirement and scheduling of onion at low land area of Wag-Himra.

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Abstract

Irrigation technologies that save water are necessary to assure the economic and environmental sustainability of commercial agriculture. Precision irrigation scheduling is critical to improving irrigation efficiency. A field experiment was conducted in two consecutive years at Abergelle irrigation schemes. The aim of the study was to determine crop water requirement and irrigation schedule of onion (when and how much to irrigate) for most market-oriented crops. The treatments were arranged with a factorial randomized complete block design with three replications. Three levels of CROPWAT, fixed application depth (125, 100 and 75%) and three levels of irrigation interval (3, 4, and 5days) were used as experimental treatments. Additionally, one treatment, farmer practices irrigation depth and interval were included as a control. These results showed that 75% CROPWAT fixed depth in 3-day interval achieved high WP values as compared to others, and it saved 2873m^3 ha^{-1} and 253.8 m^3 ha^{-1} of irrigation water as compared to farmers' practices and 100% of CROPWAT fixed application depth in 3-day interval (optimum irrigation) respectively. That would irrigate an additional land of 0.84ha and 0.074ha with a yield gain of 10.44ton ha^{-1} and 1ton ha^{-1} respectively. Therefore, 75 % of irrigation water depth every 3 days of irrigation interval was recommended for the optimum yield and water productivity of onion crop.

Key words: Irrigation, Onion, Water productivity, Yield

Introduction

In arid and semiarid areas, irrigation may supply all or most of the crops water needs (Pejić et al., 2008). All crops require certain amount of water during each stage of development mainly their initial stage, crop development stage, mid-growing and maturity stage and will transpire water maximum rate when the soil water is at field capacity. However, the amount, intensity, duration, frequency and distribution of rain needed to meet the actual water requirement of the crop to achieve full production potential is rarely realized in nature (Shaibu et al., 2015, Bossie et al., 2009). To ensure the highest crop production with the least water use, that is important to know the water requirement of the crop. The right amount of water for the crop appropriate irrigation scheduling can be designed, which can lead to improvements in yield, income, and water-saving (Dirirsa et al., 2020, Woldetsadik, 2003).

Determination of crop yield response to irrigation is crucial for crop selection, economic analysis, and for practicing effective irrigation management strategies. This enables to know the time of irrigation as well as to optimize yield, water use efficiency, and ultimate profit (Payero et al., 2009). Water scarcity is the most common factor for crop production in the dry-land areas of the Abergele district. Lack of crop water requirement studies for major crops is a challenge for appropriate utilization of water resources 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, Mebrahtu et al., 2019). The management of water is important for getting optimizing crop production per unit of water and sustaining irrigated agriculture on permanent footing (Kirda, 2002). Proper irrigation water applications are a crucial decision for a farm manager. The field experiment was planned to determine crop water requirement and irrigation schedule of onion (when and how much to irrigate) for most market-oriented crops.

Materials and Methods

Site description

The field experiment was conducted for two consecutive irrigation seasons (2018/19 and 2019/20) in Abergelle district, Wag-himra zone of Amhara region. The study sites are located at 12.90 North latitude and 38.95 East longitudes at an altitude of 1308m.a.s.l. The sites are characterized by clay textural soils. Composite soil samples were collected using auger from the experimental sites before irrigation at a depth 0-20, 20-40, and 40-60cm and samples were characterized in terms of Field capacity (FC) and Permanent wilting point

(PWP) of the sites are 20.46, 23.3 and 24.29, and 12.61, 15.65, and 15.05 percent respectively for Abergelle at bare small scale irrigation scheme.

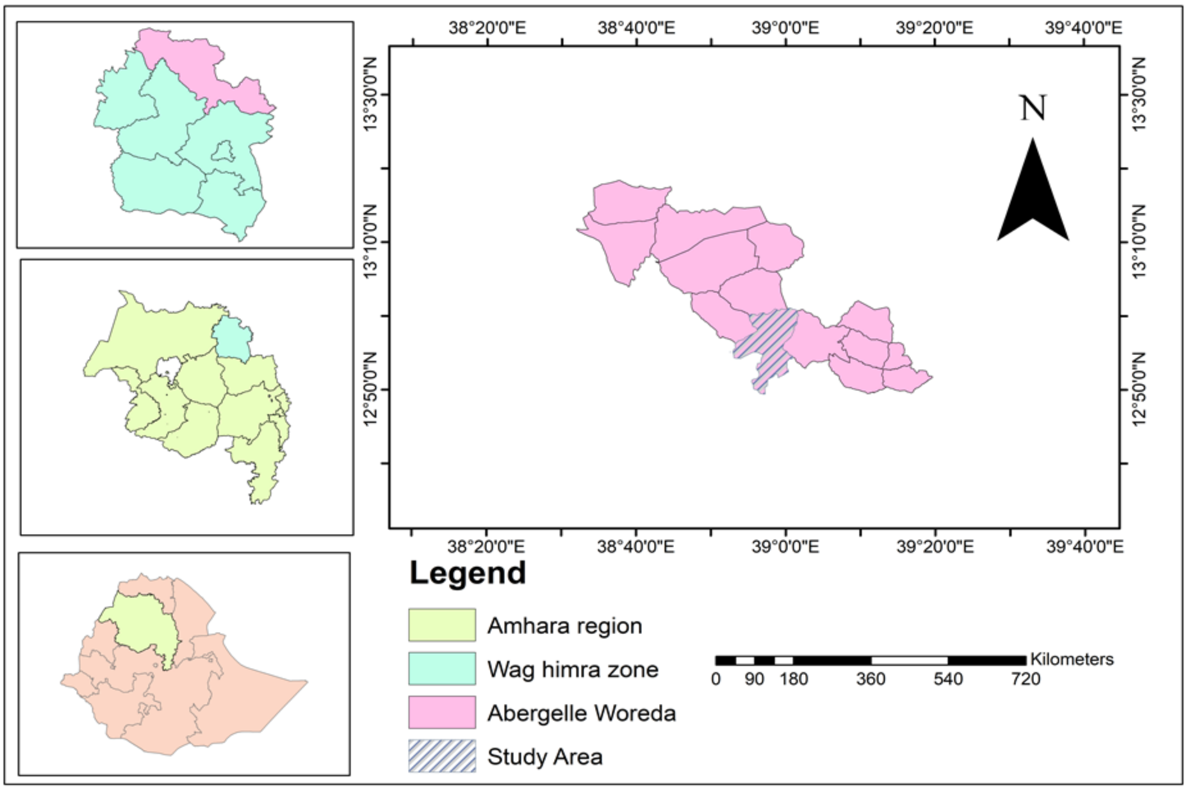

Figure1. Location map of the study area

The 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/Kc values, stage days) was used. Then, ETC was calculated as the product of reference evapotranspiration (ETo) and crop coefficient (Kc) (Equation 1). Climate data as inputs for ETo determination

$$ETc = Kc \times ETo \qquad (1)$$

Crop type and growth stage

Due to the lack of actual Kc of onion in the study area, it was accessed from FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The total period of onion from the instant of planting was fixed as 120 days (25 initial stages, 40 development stages, 30 mid-stage, and 25 late stages).

Experimental procedures and design

The experiment was designed with three irrigation depths (75, 100, and 125% of the CROPWAT 8.0 generated depth) and three-irrigation frequency (3, 4 & 5 days) with a randomized complete block design. The treatments and their arrangements in the experimentation are shown in Table 1. The treatments were replicated three times. All agronomic practices were carried out uniformly for each treatment. The plot size of 2.4m x 3m double row planting of onion variety Bombay red with a spacing of 40cm x 20cm x10cm. Urea fertilizer was applied at a rate of 92 kgha^{-1} half at planting and half at 45 days after planting.

The mode of applying water used in this experiment was a canning system. The ETC of onion 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 onion vegetative 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 effective rainfall by USDA methods in the CROPWAT 8.0 model.

$$\text{NIR} = \text{ETC} - \text{Pe} \qquad (2)$$

$$\text{GIR} = \text{NIR} + \text{losses, or GIR} = \text{NIR}/\text{Ea} \qquad (3)$$

Where ETC is evapotranspiration of the crop (mm/Season), Pe is effective rainfall in mm/Season, NIR is net irrigation requirement in mm/Season, GIR is gross irrigation requirement in mm/Season and Ea is application efficiency (taken as 70%)

Data collection

The data collected were number of stand count, plant height, bulb diameter, bulb weight, marketable yield, unmarketable yield, and water use efficiency. Water use efficiency was calculated as the ratio of total yield (kg) to total water delivered up to the harvesting (m^3) (Equation 4).

$$\text{Water use efficiecy} = \frac{\text{Total yield of onion}}{\text{water delivered up to harvesting}} \qquad (4)$$

Table 1. Treatment combination and amount of applied water (mm)

Treatments	Amount of applied water (mm)
125% Cropwat fixed depth and optimal time of application at 3 days interval	507.3
100% Cropwat fixed depth and optimal time of application at 3 days interval	368.2
75% Cropwat fixed depth and optimal time of application at 3 days interval	342.95
125% Cropwat fixed depth and optimal time of application at 4 days interval	457.35
100% Cropwat fixed depth and optimal time of application at 4 days interval	354.3
75% Cropwat fixed depth and optimal time of application at 4 days interval	336.65
125% Cropwat fixed depth and optimal time of application at 5 days interval	440.1
100% Cropwat fixed depth and optimal time of application at 5 days interval	358.1
75% Cropwat fixed depth and optimal time of application at 5 days interval	331.7
Farmer practice irrigation depth and irrigation interval in days	630.25

NB. Farmers practice are not at fixed days interval, rather than own interest of users.

Data analysis

Analysis of variance (ANOVA) and correlation was performed using SAS (Statistical Software Version 9.1). Mean comparison was done by using least significant difference test at 5% probability level.

Result and Discussion

Crop growth and physiology parameter

Analysis of variance has shown non-significant ($P< 0.05$) in plant height and unmarketable yield and significant in bulb diameter and bulb weight yield of onion (Table 2 & 3). Numerical among the treatments the highest plant height, bulb diameter, bulb weight and unmarketable yield of onion were recorded from 75 and 125% with 3 days interval, 75% with 5 days interval and 100% cropwat fixed application depth using 4days irrigation interval with the values of 45.8cm, 46.5mm, 61.97gm and 1.34tha^{-1} respectively. The shortest plant height, bulb diameter, bulb weight and unmarketable yield of onion was obtained from 125% in 3 days, 100% in 4 days and 125% cropwat fixed application depth using 5 days irrigation interval with the values of 42.8cm, 43.0cm, 54.88gm and 0.7814 tha^{-1} respectively. In plant height there is numerical difference among treatments but there is no statically significance difference.

Table 2. Interaction effect of depth and frequency on plant height and bulb diameter of onion.

Frequency	Plant height (cm)				Bulb diameter (mm)			
	Depth				Depth			
	125%	100%	75%	F_d	125%	100%	75%	F_d
3 days	42.8	43.6	45.8		46.5	45.9	44.5	
4 days	43.0	45.5	44.3		46.2	43.0	44.9	
5 days	43.7	44.3	42.8		44.2	44.8	43.7	
Ff				45.5				61.15
LSD(0.05)	Ns				3.5			
CV(%)	6.19				6.65			

***NB:** f_d = farmer practice irrigation depth, F_f = farmer practice irrigation interval*

Table 3. Interaction effect of depth and frequency on bulb weight and unmarketable yield.

Frequency	Bulb weight (gm)				Unmarketable yield (tha^{-1})			
	Depth				Depth			
	125%	100%	75%	F_d	125%	100%	75%	F_d
3 days	59.19	59.15	58.15		1.16	1.14	1.06	
4 days	56.66	54.88	55.97		0.98	1.34	1.04	
5 days	56.26	55.14	61.97		0.78	0.96	0.99	
Ff				61.15				1.12
LSD(0.05)	6.79				Ns			
CV(%)	10.04				53.15			

Marketable yield

The marketable yield of onion was highly significant ($P< 0.05$) difference on the different treatment of irrigation depth and frequency. The highest marketable yield of onion recorded from 125% CROPWAT fixed application depth using a 3 days irrigation interval with the value of 11.88 tha^{-1}and The least marketable yield of onion was obtained from 125% CROPWAT fixed application depth using a 5 days irrigation interval with the result of 8.96 tha^{-1} (Table 4). The interaction effect of irrigates depth and frequency on marketable yield (Table 4). The results of 75% CROPWAT fixed application depth using 3 days irrigation interval best marketable yield of onion crop production. This result was line with the finding of Taha et al. (2019)they reported that to meet the requirements of full irrigation with the crop that develop sufficient biomass and root system leading to increase in marketable yield under deficit irrigation.

Total yield

The total yield of onion was a highly significant ($P< 0.\ 05$) difference on the different treatment of irrigation depth and frequency. The highest total yield of onion was recorded from 125% CROPWAT fixed application depth using a 3 days irrigation interval with the value of 13 tha^{-1}. On the other hand, the lowest total yield of onion was recorded from 125% CROPWAT fixed application depth using a 5 days irrigation interval with the result of 9.74 tha^{-1} (Table 4). The interaction effect of irrigates depth and frequency on total yield (Table 4). The results showed that 75% CROPWAT fixed application depth using 3 days irrigation interval was the best yield (12.5 tha^{-1}) and the yield-related component of onion crop production. Farmer's practice irrigation depth and irrigation intervals are low yields because of excess irrigation water to irrigate and irrigation intervals. The result was in agreement with the finding of Taha et al. (2019) they reported that to meet the requirements of full irrigation along the crop to develop sufficient biomass and root system leading to an increase in marketable yield under deficit irrigation, Demelash (2013) reported that applying the right depth of irrigation and frequency of application increased the total tuber yield of potato production.

Water productivity

The interaction effect of depth and frequency was significant ($P< 0.05$) on water productivity of the crop. As shown in Table 4, the highest (4.29 kgm^{-3}) and the minimum (2.44 kgm^{-3}). The water productivity of onions was recorded from the fixed application depth of CROPWAT at 75% and 125% using irrigation intervals of 3 and 5 days, respectively. These results showed that 75% CROPWAT fixed depth in 3 day interval achieved high WP values as compared to others, and it saved 2873m^3ha^{-1} and 253.8 m^3ha^{-1} of irrigation water as compared to farmers' practices and 100% of CROPWAT fixed application depth in 3 day interval respectively. That would irrigate an additional land of 0.84ha and 0.074ha with a yield gain of 10.44 t ha^{-1} and 1 tha^{-1} respectively.

The result was in agreement with the finding of Bekele and Tilahun (2007) and (2003) reported that water productivity decrease with increasing irrigation depth. Demelash (2013)reported that deficit irrigation strategies it is possible to increase WUE and save water for irrigation.

Table 4. Interaction effect of depth and frequency on marketable yield, total yield and water productivity.

	Marketable yield (tha^{-1})				Total yield (tha^{-1})				Water productivity (kgm^{-3})			
Frequency	Depth				Depth				Depth			
3 days	125%	100%	75%	Fd	125%	100%	75%	Fd	125%	100%	75%	Fd
4 days	11.87	11.67	11.40		13.03	12.81	12.46		3.03	4.11	4.29	
5 days	9.45	10.62	11.28		10.44	11.95	12.33		2.59	4.08	4.22	
Ff	8.96	10.34	9.66		9.74	11.31	10.57		2.44	3.97	3.86	
LSD(0.05)	0.97				1.27				0.48			
CV(%)	7.97				9.42				11.56			

Table 5. Correlation coefficient of plant height, bulb diameter, bulb weight, marketable yield, unmarketable yield, total yield and water productivity from the study data.

	PH	BD	BW	MY	UMY	TY	WP
PH	1						
BD	0.236895386ns	1					
BW	0.108385009ns	0.098121835ns	1				
MY	0.36135229ns	0.41670998ns	0.073847643ns	1			
UMY	0.473049228**	0.521414195**	0.146233718ns	0.197240809ns	1		
TY	0.424763217*	0.485519357**	0.045249925ns	0.985890561***	0.358544502*	1	
WP	0.208950034ns	0.18009817ns	0.118680048ns	0.668471291***	0.136289697ns	0.659530619***	1

*($p<0.05$) *** Very highly significant, ** highly significant, * significant and* ^{ns} *non-significant*

Conclusion and recommendation

The irrigation depth and schedules had a significant effect on the yield and water productivity of crops. The study shows that the interaction of irrigation scheduling and depth had a significant effect on the yield and water productivity of onion at bare small-scale irrigation schemes. The result showed that 12.5 tha^{-1} within 3 days intervals and 4.3 kgm^{-3} water productivity was achieved with appropriate depth and schedule in 75% CROPWAT, fixed application depth at bare irrigation scheme. Therefore, the irrigation schedule is aimed at maximized yield per unit of irrigated area, 75% CROPWAT fixed application depth using a 3 days irrigation interval saved 2873 m^3ha^{-1} and 253.8 m^3ha^{-1} of irrigation water, that would irrigate an additional land of 0.84ha and 0.074ha with a yield gain of 10.44 tha^{-1} and 1tha^{-1} as compared to farmers' practices and 100% of CROPWAT fixed application depth in 3 day interval respectively. Key policy for the control of agricultural water management for dry land and water scarcity areas primary to improve agricultural productivity and thus income farmers applying an optimum amount of water and saving a significant amount of water for irrigation additional onion cropland. Considering this, 75% of CROPWAT fixed application depth using a 3 days irrigation interval recommend for Abergele bare small-scale irrigation scheme, and similar agro ecology.

References

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. 1998. FAO Irrigation and drainage paper No. 56. *Rome: Food and Agriculture Organization of the United Nations,* 56**,** e156.

Bekele, S. & Tilahun, K. 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural water management,* 89**,** 148-152.

Bossie, M., Tilahun, K. & Hordofa, T. 2009. Crop coefficient and evaptranspiration of onion at Awash Melkassa, Central Rift Valley of Ethiopia. *Irrigation and Drainage Systems,* 23**,** 1-10.

Demelash, N. 2013. Deficit irrigation scheduling for potato production in North Gondar, Ethiopia. *African Journal of Agricultural Research,* 8**,** 1144-1154.

Dirirsa, G., Hordofa, T., Tezera, K., Wendimu, T. & Tesfaye, A. 2020. Optimal Irrigation Scheduling for Pepper (Capsicum annuum L.) at Gidara Sub Center, Central Rift Valley of Ethiopia. *Results of Natural Resources Management Research*.

Kebede, M. 2003. Eurocentrism and Ethiopian historiography: deconstructing Semitization. *International Journal of Ethiopian Studies***,** 1-19.

Kirda, C. 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. *Food and Agricultural Organization of the United Nations, Deficit Irrigation Practices, Water Reports,* 22.

Mebrahtu, Y., Tamiru, H. & Mohammed, A. 2019. Determination of Optimal Irrigation Scheduling for Onion (Allium cepa L.) in Raya Valley, Northern Ethiopia. *Results of Natural Resources Management Research*.

Payero, J. O., Tarkalson, D. D., Irmak, S., Davison, D. & Petersen, J. L. 2009. Effect of timing of a deficit-irrigation allocation on corn evapotranspiration, yield, water use efficiency and dry mass. *Agricultural water management,* 96**,** 1387-1397.

Pejić, B., Gvozdanović-Varga, J., Vasić, M. & Milić, S. 2008. Water balance, bioclimatic method as a base of rational irrigation regime of onion. IV Balkan Symposium on Vegetables and Potatoes 830, 355-362.

Shaibu, A.-G., Alhassan, S. & Adongo, T. A. 2015. Effect of different water application schedules on the growth and yield of onion (Allium cepa L.) at golinga irrigation scheme in the tolon district of northern region, Ghana. *International Journal of Science and Technology,* 5.

Taha, A., Yasso, E. & Sayed, M. 2019. Response of onion productivity to deficit irrigation in calcareous soil. *Journal of Soils and Crops,* 29**,** 13-22.

Woldetsadik, K. 2003. *Shallot (Allium cepa var. ascolonicum) responses to plant nutrients and soil moisture in a sub-humid tropical climate.* Swedish University of Agricultural Sciences.

Validation of different weather generator tools under various climatic condition of North Shewa, Amhara region, Ethiopia

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Abstract

Weather data is profoundly an important input for crop simulation models and soil and water management models. However, the metrological data cannot be easily accessed and time consuming and costly. This study was designed to describe the temporal trends and spatial distribution of long-term weather data, to validate and test the performance of different weather generator tools, and to select the best-fit weather generator tools. Some of the weather generators employed in this study include ClimaGen, Markisim DSSAT, NewLocClim, and NASA data source. Long-term climatic data (1990-2020) from the three agro ecologies of North Shewa (Kewat and Majete, Minjar Shenkora and Alem ketema, Debre Birhan and Mehal Meda) was collected. In validation procedures, statistical indicators like mean, RMSE, CV, Correlation and Regression analysis was done. The temporal variability of Tmax is smallest (C.V<10%) and for rainfall (7-10%), and a bit higher in Tmin in most of stations. The spatial Variability of Rainfall and T_{min} *is higher, having a C.V of nearly above 30%. As the analysis of PCI, the rainfall distribution shows a uni-modal nature in all stations except Kewat and Majete. From Man Kendall trend analysis, rainfall has decreasing trends, while* T_{max} *and* T_{min} *have increasing trends. The smallest RMSE was observed in NewlocClim and NASA for rainfall and temperature. Similarly, the smallest C.V also was observed in NewlocClim and NASA for rainfall and temperature in most of the stations. The higher value of correlation and index of agreement for rainfall,* T_{max} *and* T_{min} *was observed in NewlocClim and NASA nearly at all stations. In general, the best-fit tools for reproducing temperature and rainfall data over space are NewLocClim and NASA. Therefore, from this study for rainfall data generation one may use NASA and NewLocClim for reproducing maximum and minimum temperature over locations.*

Key words: Climate variability, North shewa, Trend analysis, Validation, Weather generators.

Introduction

Climate variability affects the overall environment (Agriculture, health, construction, education…. etc.). Weather is a major influencing factor in agricultural production and management systems like hydrologic system, cropping system, and environmental effects in the World and the same is true in Ethiopia also. To attain a balance in crop production and productivity to the current fast-growing population, sustainable agriculture should be promoted. According to (Chinnachodteeranun *et al.,* 2016), climate data is used to simulate crop growth, planning agricultural management and farm decisions. Now a day, weather information is playing a great role in precise climate smart agricultural activities. This long-term weather data are an input for the analysis of crop simulations models and water management models. Having access to this data can guide farmers in making significant and potentially costly decisions, such as when to sow, when and how much to irrigate, when to drain and harvest.

The users can use the data to fill out missed data; to assess the impact of climate change like droughts, rainfall pattern changes and extreme temperature (Wilks and Wilby, 1999). However, these data are not easily available over locations, and hence, introducing the use of a weather generators tools is of an important. Weather generators are statistical models that are used to generate sequences of daily variables that are natural and logically consistent including daily precipitation, maximum and minimum temperature, and humidity. As per the investigation of (Chena and Brissette, 2014), the generation of precipitation and temperature are the two main components for most stochastic weather generators, especially for climate change impact studies. Similarly, these parameters are widely used by researchers in their impact models and standard component of decision support systems in agriculture, environmental management, and hydrology (Tingem *et al*., 2007).

At present time, the output from global climate models is of a poor spatial and temporal resolution and less reliable to be used directly in different models. Weather generators are necessarily in climate change-related studies and are essential tools for temporal downscaling of weather variables (Tseng *et al.*, 2012). Some of the weather generators employed in this study include ClimaGen, Markisim DSSAT, NewLocClim, and NASA data source.

The variability in monthly means of precipitation and maximum temperature in the generated data by ClimGen and observed for all the sites was nearly smaller (Tingem *et al.*, 2007). ClimGen is a stochastic weather generator that generates daily precipitation, minimum and maximum temperature, solar radiation, humidity, and wind speed data series with similar statistics to that of the historical weather data (Gayatri *et al*, 2014).

The MarkSim DSSAT weather file generator web application was used to acquire downscaled future climate data on a daily time step. For instance, only 6 out of 17 projections were significant trends over Metehara, namely: csiroMK3.0 (for 2030s in both scenarios), gfdlCM2.1 (B1 2030's) and ukmoHADCM3 (except A2 for 2050s) (Mequanint *et al.*, 2016). As per Fenta and Dessie, 2018; canESM2 CMIP5 GCM was able to reproduce more accurate long-term mean monthly precipitation but LARS-WG performed best in capturing the extreme events and distribution of daily precipitation in the whole data range. To get a metrological data, most of the times users are refer to the national metrological service agency of the country. However, this takes a too long time and sometimes it may costly. The option to address this problem is accessing WG platforms that offer Spatial and temporal climate data on a global basis. Well-validated climate models are needed to produces meteorological information for the given locations and altitudes.

However, limited information exists in the peer-reviewed literature regarding testing and validation of these tools. A rapid method of obtaining downscaled future climate data by using globally validated models to the observed datasets would therefore greatly expand the availability of such data to scientists and policy planners wishing to conduct future climate impact analyses (Trotochaud et al., 2016). Therefore, this proposal was initiated to the objectives of: - to describe the temporal trends and spatial distribution of long-term weather data in the three agro ecological zones, to validate and test the performance of different weather generator tools across different locations, to select the best fit weather generator tools for each parameter.

Materials and methods

Description of the study area

North Shewa is one of the administrative zones in Amhara Regional state, which includes the three agro-ecological zones. The study was conducted in three agro-ecological zones of North Shewa; Shewarobit and Antsokia Gemza, Minjar Shenkora and Merhabete, Basona werena and mehalmeda wereda from low lands, mid-altitude, and high altitudes respectively (Figure 13). Actual observed daily weather data was collected from these weather stations from the National metrology service agency. Long-term climatic data (1990-2020) from the three agro ecologies of North Shewa was collected from national metrology agency and data arrangement was done accordingly. Data quality management like outlier detection and handling of missing data was done. Outliers are values, which are greater than a threshold value. It was filled with interquartile range test on excel sheet and treated as a missing values and filled by normal ratio methods. Based on the type of weather generators a set of parameters may include long-term means of monthly rainfall amounts, maximum temperature, and minimum temperature.

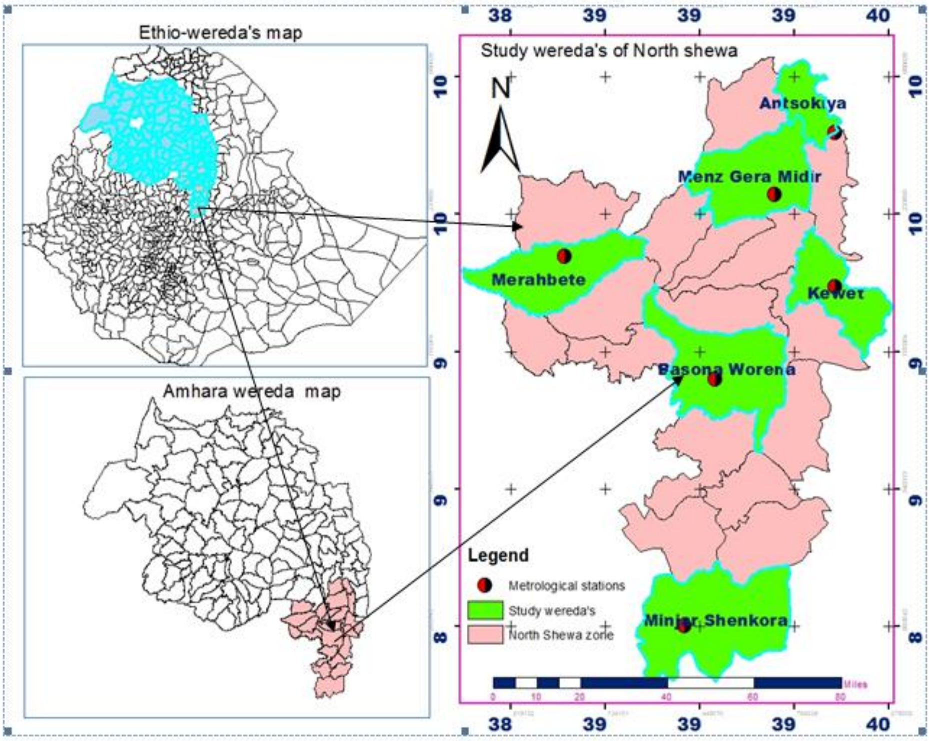


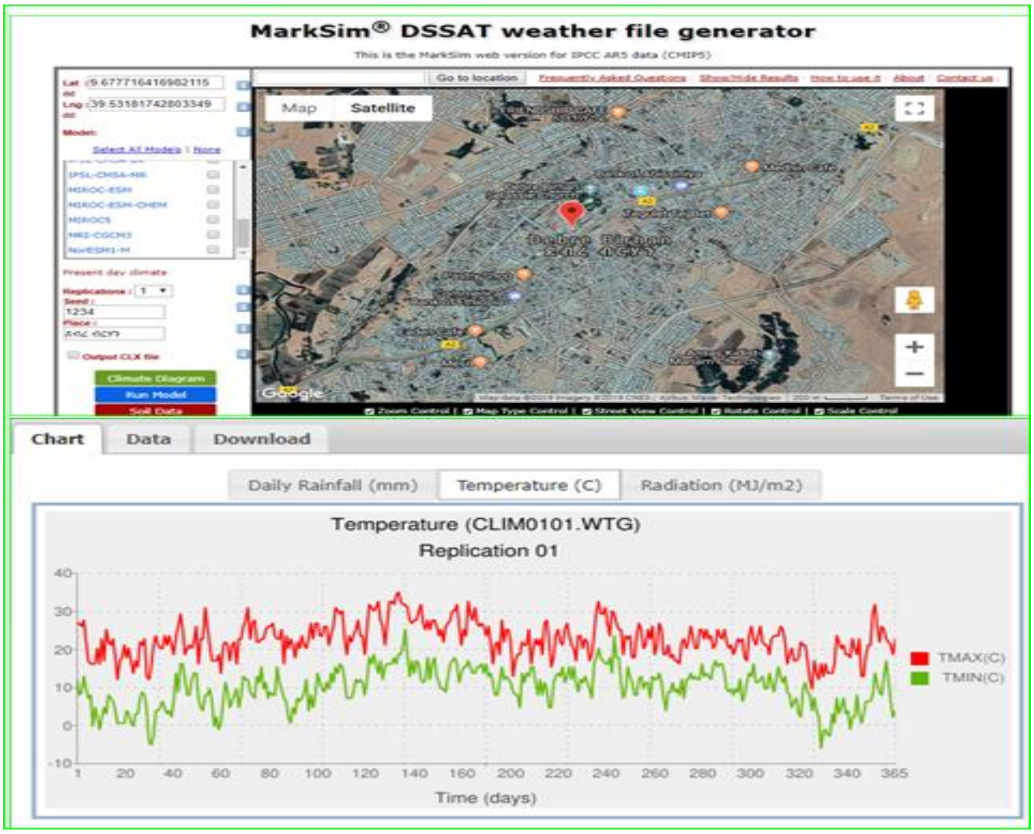
Figure 13. Geographical location of the study areas.

Weather generator's description

Marksim DSSAT weather file generator

It is an easy-to-use online web application (http://gismap.ciat.cgiar.org/MarkSimGCM), and a valid weather simulator model that produces rainfall, temperature, and solar radiation, soil type information for other model applications. It produces either continuous daily data in single year segments or the assembles of more than two years data depending on the replication fields. It follows the procedures of global climate models (GCM) sequence by requesting the geographical location data. MarkSim GCM is a weather generator that works on the principle of a third order Markov chain process (Jones and Thornton, 2000). Marksim DSSAT was downscaled about 17 GCM with a resolution of 18km *18km; among these, four of them are validated in this study (

Table *39*). According to (Dhakal *et al*, 2018), the four models of GCMs; Had-GEM2-ES, MRI-CGCM3, MRIOC5, and CSIRO-Mk3.6.0 were specifically chosen as they had the finest spatial resolution.


MarkSim® DSSAT weather file generator

This is the MarkSim web version for IPCC AR5 data (CMIP5)

Lat dd: 9.677716416982115

Lng dd: 39.53181742803349

Replications : 1

Seed : 1234

Place : ደብረ ብርሃን

Figure 14. The Marksim DSSAT weather files generator web windows

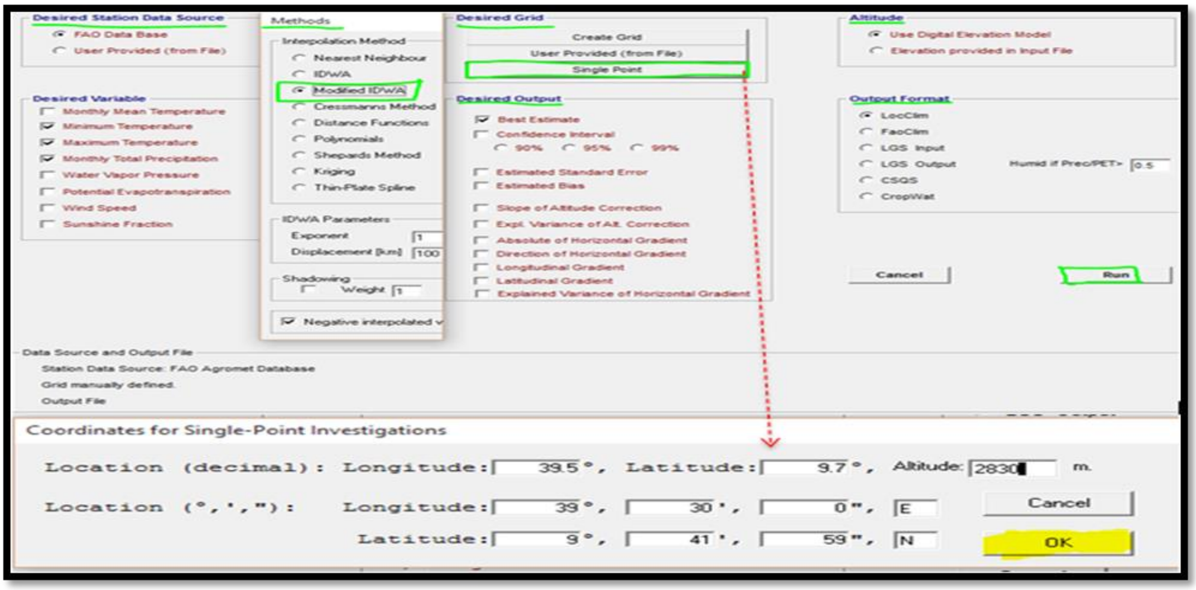
Table 39. The global climatic models tested in this study

No	Model abbreviation	Institution	Resolution
1	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organization and the Queens land Climate Change Centre of Excellence	1.875 x 1.875
2	HadGEM2-ES	Met Office Hadley Centre, UK	1.2414 x 1.875
3	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute	1.406 x 1.4063
4	MRI-CGCM3	Meteorological Research Institute	1.125 x 1.125

New_LocClim V 1.10

It is a new version of LocClim, developed in collaboration with the Deutscher wetterdienst (German weather service) and the Global Precipitation Climatology center (GPCC). The users make it at single point mode and fed the geographical co-ordinates of the points (Figure 15).

It allows all the interpolation methods (Nearest neighbor, IDW, kriging, modified IDW, polynomials methods) to determine the desired variables like, Maximum and Minimum Temperature, Precipitations, Wind speed, Sunshine hours (Gommes *et al*., 2004)



Desired Station Data Source
● FAO Data Base
○ User Provided (from File)

Desired Variable
☐ Monthly Mean Temperature
☑ Minimum Temperature
☑ Maximum Temperature
☑ Monthly Total Precipitation
☐ Water Vapor Pressure
☐ Potential Evapotranspiration
☐ Wind Speed
☐ Sunshine Fraction

Methods
Interpolation Method
○ Nearest Neighbour
○ IDWA
● Modified IDWA
○ Cressmanns Method
○ Distance Functions
○ Polynomials
○ Shepards Method
○ Kriging
○ Thin-Plate Spline

IDWA Parameters
Exponent: 1
Displacement [km]: 100

Shadowing
☐ Weight: 1

☑ Negative interpolated v

Desired Grid
Create Grid
User Provided (from File)
Single Point

Desired Output
☑ Best Estimate
☐ Confidence Interval
○ 90% ○ 95% ○ 99%
☐ Estimated Standard Error
☐ Estimated Bias
☐ Slope of Altitude Correction
☐ Expl. Variance of Alt. Correction
☐ Absolute of Horizontal Gradient
☐ Direction of Horizontal Gradient
☐ Longitudinal Gradient
☐ Latitudinal Gradient
☐ Explained Variance of Horizontal Gradient

Altitude
● Use Digital Elevation Model
○ Elevation provided in Input File

Output Format
● LocClim
○ FaoClim
○ LGS Input
○ LGS Output
○ CSQS
○ CropWat

Humid if Prec/PET> 0.5

Data Source and Output File
Station Data Source: FAO Agromet Database
Grid manually defined.
Output File

Coordinates for Single-Point Investigations
Location (decimal): Longitude: 39.5 °, Latitude: 9.7 °, Altitude: 2830 m.
Location (°,',"): Longitude: 39 °, 30 ', 0 ", E
Latitude: 9 °, 41 ', 59 ", N

(Source: FAO and GPCC)

Figure 15. The New_LocClimV1.1 windows

NASA data source

Climatological data, from 1983 onwards can be obtained from NASA at the following link:

http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov

The NASA Prediction of Worldwide Energy Resource (POWER) gives an estimation of certain climatological parameters, based primarily upon solar radiation derived from satellite observations and meteorological data from assimilation models. In other words, they are not "recorded" values, but are derived from satellite imagery. A detailed description of the methodology, including an accuracy assessment is found at http://power.larc.nasa.gov/documents/Agroclimatology_Methodology.pdf.

ClimaGen weather generators

It is a weather generator based on SIMMETEO, as developed by (Geng *et al*. 1988). It needs an input of name of weather station, Latitude, longitude, altitude, number of years to be generated and gives an output of solar radiation (MJ/m2/day), maximum temperature (ºC), minimum temperature (ºC), total monthly rainfall (mm), number of rainy days, wind speed (m/s), vapor pressure (kPa). It also makes a summary of descriptive statistics.

Spatial and temporal distributions of observed data

Precipitation concentration index (PCI) was determined for each agro-ecological zone by dividing the square of the monthly rainfall amount to the square of the yearly rainfall. The PCI value less than 10 % indicates uniform rainfall distribution (low rainfall concentration),values between 11% and 15% a moderate rainfall concentration; values between 16% and 20% an irregular rainfall distribution, and greater than 20% shows highly irregularity of rainfall distribution (i.e. high rainfall concentration) of rainfall distribution (De Luis et al, 2011). The coefficient of variability was also determined to determine the rainfall pattern and temperature variation in each agro-ecological zone. It is the ratio of standard deviation to the mean values for each parameter. ArcGIS was used to map the distributions of extreme climate trends across the study area by using inverse distance weighted interpolation methods.

Trend analysis of observed data

To determine the trend analysis of observed maximum temperature, minimum temperature and rainfall over the three agro-ecologies, Sen's slope method and Mann-Kendall's trend test (non-parametric method) was used. The Sen's slope estimator was employed after Mann-

Kendal test statistics in order to determine the change and variability of rainfall and temperature trends through time series (Worku *et al.*, 2018). The equation of test statistic is given by -

$$\mathbf{Ts} = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\mathbf{sign(Xj - xi)}$$

Where Ts is the Mann-Kendal's test statistics; x_i and x_j are the sequential data values of the time series in the years j and I (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The variance of S, for the situation where there may be ties;

$$\mathrm{Var\ (Ts)} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)\right]$$

Where, m is the number of tied groups in the data set and tie is the number of data points in the i^{th} tied group. For the values of 'n' larger than 10, Z_{mk} approximates the standard normal distribution (Partal, 2006).

$$\mathrm{Zmk} = \begin{cases} \frac{Ts-1}{\sqrt{var(Ts)}}, & Ts > 1 \\ 0, & \text{if}\ Ts = 0 \\ \frac{Ts+1}{\sqrt{var(Ts)}}, & Ts < 1 \end{cases}$$

In a two-sided test for trend, the null hypothesis Ho should be accepted if $|Z_{mk}| < |Z_{1-a/2}|$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of Z_{mk} from the standard normal table.

Validation criterion

The outputs from each generator compared with the observed climatic data with statistical methods to select the best-fit models. To check the predicted climatic parameters: - a statistical procedure (mean, RMSE, CV, R^2 and Correlation analysis) was employed. Among descriptive statistics of error or deviation between actual value and estimate, error mean is the representative value of the error. The S.D of error indicates the deviation from mean values. The coefficient of determination, R^2 is defined as the squared value of the Pearson correlation coefficient. It ranges from zero to one; values close to 1 indicating a good agreement.

$$R^2 = \left[\frac{\sum(Oi - Oi^{-})(gi - gi^{-})}{(Oi - Oi^{-})^2(gi - gi^{-})^2}\right]^2$$

g_i = generated value, O_i= observed value, $\bar{O_i}$=mean of O_i and $\bar{g_i}$=mean of P_i

RMSE measures the average magnitude of error, calculated as the square root of the average of squared differences between prediction and observation data. A lower RMSE indicates that better performance of the model.

$$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=0}^{n}(gi - oi)^2\right]^{0.5}$$

Where, g_i=model generated value; o_i=observed value; n=number of observations.

$$\mathrm{NRMSE} = \frac{1}{\bar{Oi}} * \sqrt{\frac{\sum(gi - Oi)^2}{N}} * 100$$

NRMSE (C.V) generated value considered as excellent if smaller than 10%, good if between 10 and 20%, fair if between 20 and 30% and poor if larger than 30%.

The index of agreement was proposed to measure the degree to which the observed data are approached by the predicted data (Willmott, 1982). It ranges between 0 and 1, with “0” indicating no agreement and “1” a perfect agreement between the predicted and observed data.

$$d = 1 - \frac{\sum(Pi - Oi)^2}{\sum(/Pi - \bar{Oi}/+/Oi - \bar{Oi}/)\hat{}2}$$

Where, d = Willmott’s index of agreement, pi = predicted value Oi= observed value,

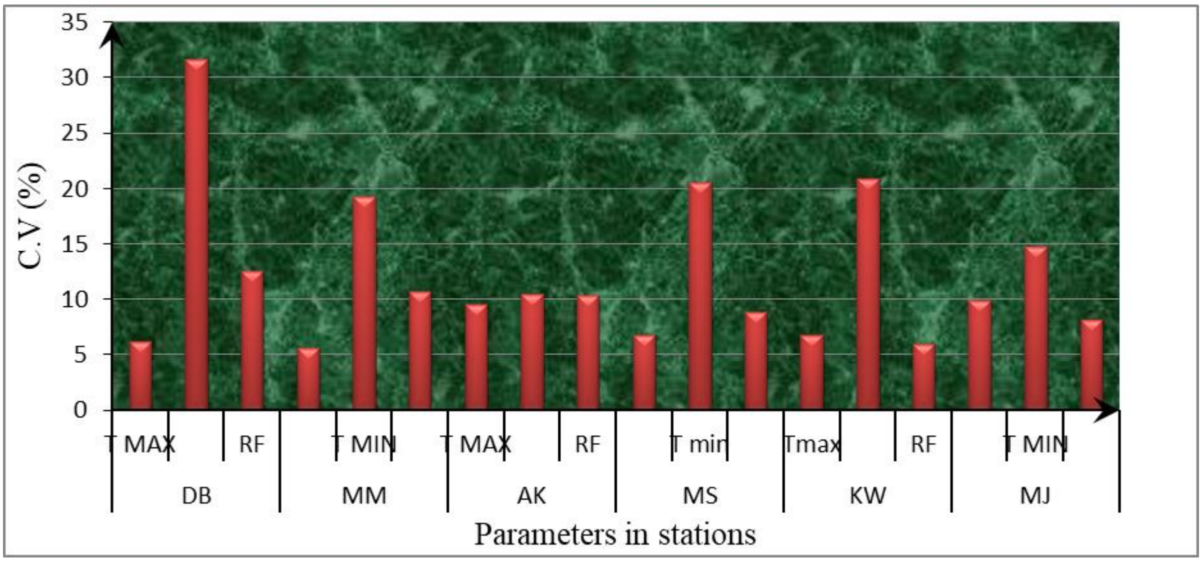
$\bar{Oi}$=mean of Oi

Correlation analysis was done to determine the association between the observed and generated value of among these weather generators.

Results and discussion

Spatial and temporal variation of parameters

The temporal variation for observed monthly rainfall distribution over stations is enough good, having a coefficient of variability of fewer than 10%, indicates that the rainfall amount distributed uniformly over years. This implies well impacts on agricultural activities of the community and hence assures the well-being of the community. The C.V for maximum temperature and rainfall nearly for each stations is in acceptable range, which is 6^0C (Mehal Meda) to 10^0C (Minjar Shenkora) and 7 mm (kewat) to 13 mm (Debre Birhan) respectively. The higher rainfall variability was observed in the low lands areas. Minimum temperature for all stations is highly variable except Alem ketema. In general, the temporal variability of maximum temperature is smaller (C.V<10%), uniform distributions over stations. Whereas, the C.V for minimum temperature over stations ranges from 15 to 33%, indicates that satisfactorily distributions (Figure 16)



DB-Debre birhan, MM-Mehal meda, AK-Alem Ketema, MS-Minjar shenkora, KW-Kewat, MJ-Majete.

Figure 16. The temporal variability of rainfall and temperatures over stations

The C.V nearly in all stations shows that rainfall in North Shewa has high inter-annual variability. The result indicated that annual rainfall and temperature over stations are highly variable. The spatial Variability of Rainfall and minimum temperature is higher, having a C.V of nearly above 30%. However, the C.V for maximum temperature is 15-25%, which indicates that satisfactorily distributions over seasons (Figure 17). This primarily influences all the agricultural activities either positively or negatively. The map of the annual rainfall, maximum temperature, and minimum temperature across the study location were determined by inverse distance weighted interpolation methods. It revealed that the rainfall distributions over high land areas (900-1050mm), mid lands (850-1000mm), and low lands (1000-1100mm). Similarly, the maximum temperature and the minimum temperature ranged from 17 to 39 ^{0}C and 3 to 20 ^{0}C respectively shown (Figure 18) and (Figure 19).

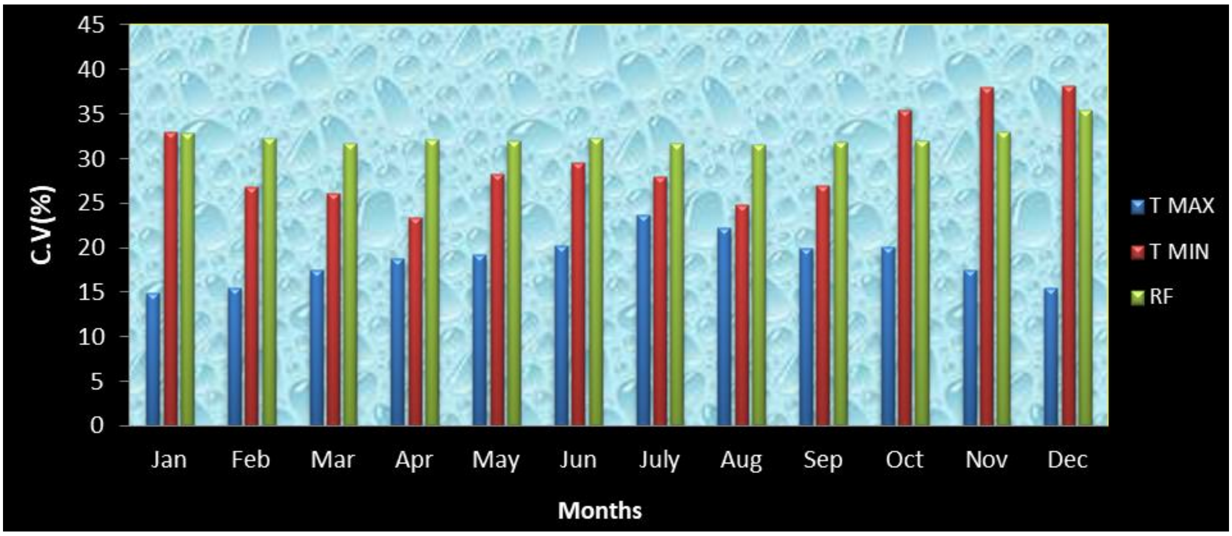


Figure 17. The spatial variation of rainfall and temperatures over seasons

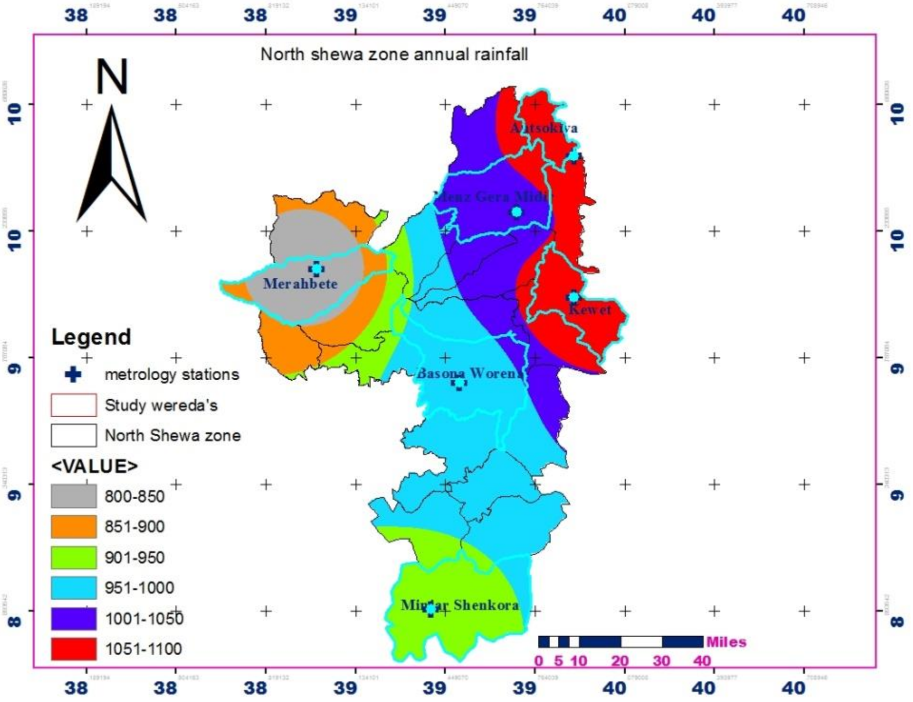


Figure 18. The map of rainfall extremes distribution across locations.

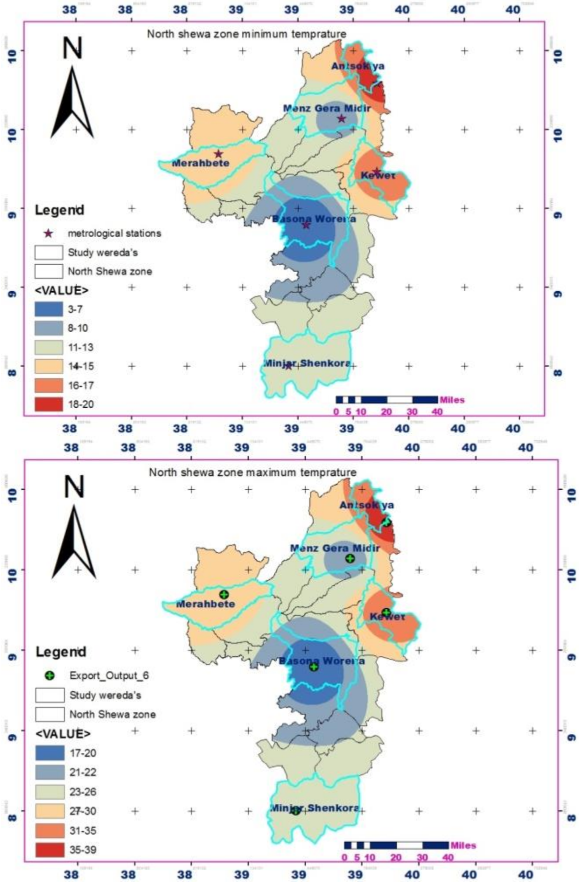


Figure 19. The map of minimum and maximum temperature distribution across locations

As the analysis of PCI, the rainfall distribution shows a bimodal nature from March to May and July to September in Kewat and Majete stations, whereas in others stations it shows uni-modal pattern from July to September. The PCI value across the stations for kiremt season rainfall is ranged from 5 to 15, indicates that there were moderate rainfall distributions (higher rainfall concentration). While, on other months the value of PCI is nearly 0 and 1, indicates the more uniformity of rainfall (no rainfall, or small amount of rainfall concentration) over the three-agro ecological zones of North Shewa (Table 2).

Table 40. The PCI (%) values for each month over stations

Stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DB	Ave	9	12	33	36	32	41	239	316	64	16	4	3
	PCI	0	0	0	0	0	0	9	15	1	0	0	0
MM	Ave	16	23	45	55	40	41	268	252	74	24	7	5
	PCI	0	0	0	0	0	0	10	9	1	0	0	0
AK	Ave	7	19	46	48	55	70	280	308	141	24	10	9
	PCI	0	0	0	0	0	0	8	9	2	0	0	0
MS	Ave	10	29	51	62	32	76	232	233	94	42	15	9
	PCI	0	0	0	0	0	1	7	7	1	0	0	0
KW	Ave	28	48	58	86	81	24	144	182	84	39	14	48
	PCI	0	0	0	1	1	0	3	5	1	0	0	0
MJ	Ave	31	40	72	99	64	25	221	297	104	45	28	23
		0	0	0	1	0	0	4	8	1	0	0	0

DB-Debre Birhan, MM-Mehal Meda, AK-Alem Ketema, MS-Minjar Shenkora, KW-Kewat, MJ-Majete, PCI----precipitation concentration index, Ave-----average.

Trend Analysis of parameters

Seasonal rainfall trends: The Mann–Kendall trend test shows a decreasing trend ($p<0.05$)on monthly and annual rainfall in the three agro ecologies of North Shewa except in Alemketema stations, but the trends were found to be statistically non-significant ($p<0.05$) in both decreasing and no trends.The trend detection framework resulted in the identification of some significant decreasing trends of rainfall especially in January, February, and September (Partal,2006). This could be due to higher variability of rainfall in the areas over years, eratic avaiablity and uneven distribution. This similar with that of (Gebre *et al.*, 2013), the trends were found to be statistically non-significant ($P>0.05$) at most of the stations where they were studied.

Maximum temperature and minimum temperature: There was highly significant ($p<0.01$) increasing trend of maximum tempreture in highlands and mid lands and significantly increasing trends at low lands, which ranges from 0.12 ^{o}C/year at Majete to 0.37 ^{0}C/year at ; and for minimum temprature the increase rate ranged at low lands (Majete) 0.01 ^{o}C and mid lands (Alemketem) 0.2^{0}C respectively. There was a significantly increasing trend of minimum temperature at highland areas and Alem ketema stations. Whereas, at Arerti from mid lands and at low lands there were statistically insignificant increasing trends. Generally, Maximum temperature and Minimum temperature at highlands, mid lands and low lands shows an increasing trend (below**).** This results agreed to (Worku et al., 2018), the long-term minimum and maximum temprature have significant increasing trend over the stations.

Table 41. Trends of Rainfall, maximum and minimum temperature over stations from 1981-2020.

Stations	Rain fall			Maximum Temperature			Minimum Temperature		
	Z_{mk}	Sen's slope	P-value	Z_{mk}	Sen's slope	P-value	Z_{mk}	Sen's slope	P-value
DB	0.35	-0.007	0.79ns	0.24	0.168	**	0.19	0.2	**
MM	0.03	0	0.41ns	0.31	0.199	**	0.2	0.146	**
AR	0.01	0	0.89ns	0.42	0.37	**	0.09	0.131	0.45ns
AK	0.03	0.11	0.42ns	0.28	0.277	**	0.23	0.202	**
KW	0.01	0	0.84ns	0.15	0.184	*	0.03	0.042	0.64ns
MJ	0.03	-2.66	0.367ns	0.1	0.121	*	0.05	0.01	0.26ns

*ZMK is Mann–Kendall trend test, Slope (Sen's slope) is the change in mm per annual; **,* is statistically significant at 0.05 and 0.1 probability level; ns is non-significant trend at 0.1;*

Validation of weather generators

The generated data from the weather generators were compared with the historical records of weather data in the three agro-ecological conditions of North Shewa. The suitability of weather generators is decided by how the RMSE is as much to be smaller and close the estimates to historical values are in a given time series. The minimum RMSE was observed for NewlocClim in most of the stations for maximum and minimum temperature, whereas for rainfall the minimum RMSE observed with NASA and followed by NewlocClim except Minjar Shenkora.

The higher RMSE for minimum and maximum temperature were observed in Climagen. The RMSE for minimum temperature in low lands are relatively smallest than that of the highlands and mid altitude agro ecologies for most of the weather generators. The RMSE of Rain fall for lowlands is larger than mid and high lands agro ecologies in most of the tools. That means, there is greater rainfall variability in the lowland's areas. Lowland agro ecology shows high RMSE for rainfall and low RMSE for temperature in NASA (Figure 20).

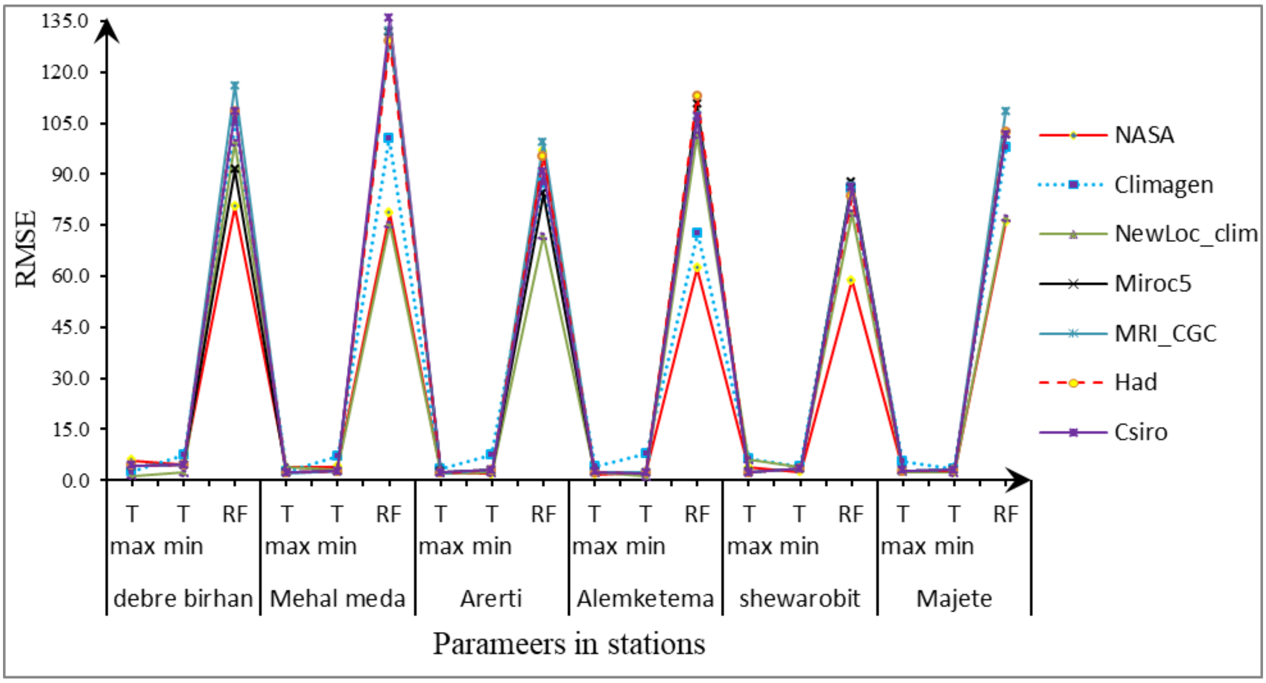


Figure 20. The root mean square error values for each weather generator over stations

The C.V for maximum and minimum temperature in NewlocClim was found to be minimum at all stations except Mehal meda and Kewat stations (Figure 21). However, the C.V values of minimum temperatures for all weather generators tools are higher. The C.V values for rainfall in all station except shewarobit are smaller in NewlocClim, followed by NASA, HadGEM2-ES CSIRO-MK3.6.0. The maximum C.V found in ClimaGen models for both temperature and rain fall. For HadGEM2-ES, CSIRO-MK3.6.0, the variability of minimum temperature decreased tangentially from highlands to lowlands. In regards with C.V, the best-fit tools are NewLocClim for temperature and NASA for rainfall (the variability in temperatures and rainfall is smaller in NewLocClim and NASA). Nextly, Had-GEM2-ES and MIROC-5 best fit for maximum temperature and minimum temperature.

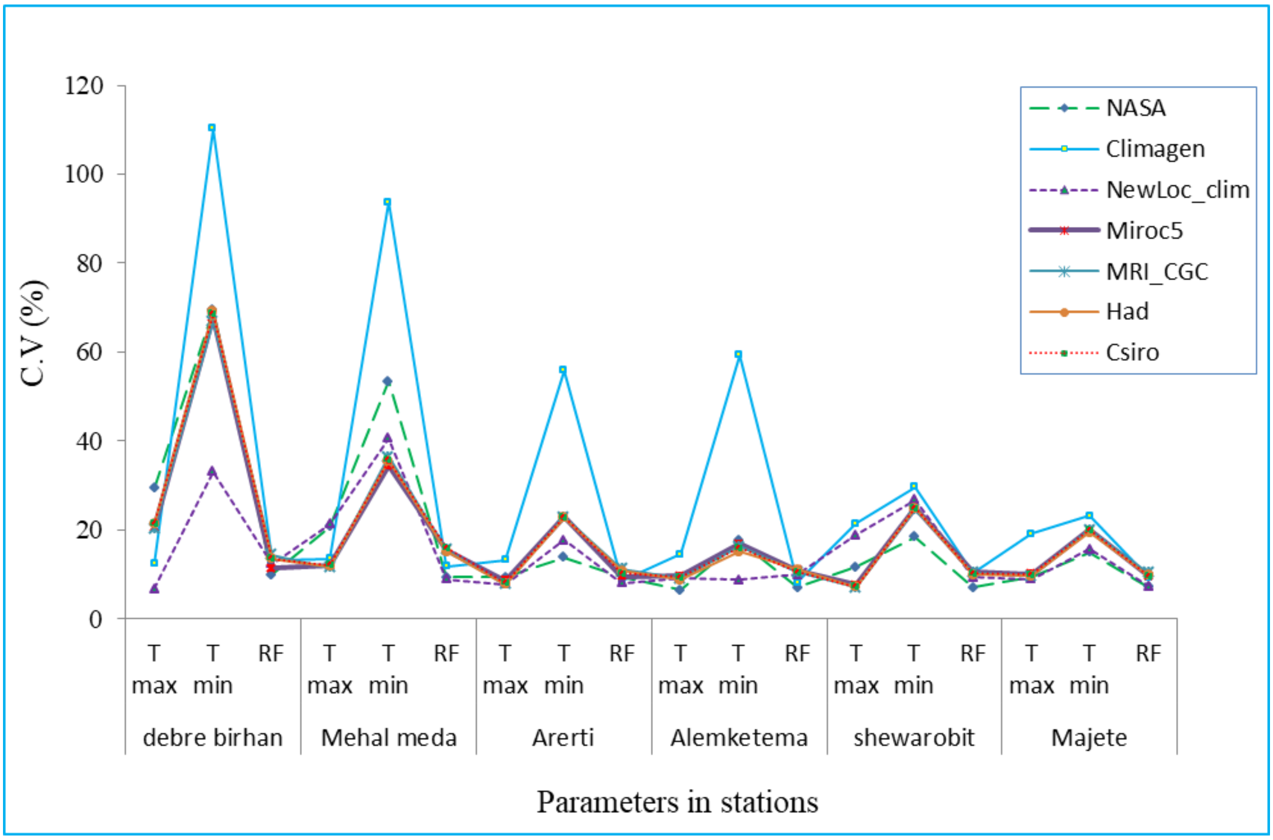


Figure 21. The Coefficient of variations values for each weather generator over stations

Correlation Coefficient is an indicator for the strength of the relationship between observations and estimates. Higher correlation coefficients indicate that the generated data is high or low when observed data is high or low respectively giving evidence about the suitability of the generator tools. The correlation coefficient for maximum temperature and minimum temperature in NASA and NewlocClim was found to be higher (> 80 %) at all stations (Figure 22).

The coefficient of determination R^2 is the squared value of the Pearson correlation coefficient. For the three agro ecologies, NASA and NewLocClim well predicts for maximum tempratures and minimum tempratures better than others do. Similarly, the rainfall distribution over stations well predicted by NASA and NewlocClim. However, ClimaGen poorly predicts both temperature and rainfall for all stations. Therefore, NewLocClim and NASA are alternatively predicts temperature and rainfall. Similar to RMSE, the results of this parameter also agreed tangentially for most of the tools except ClimaGen.

Generally, for most station the correlation coefficient for rainfall, maximum and minimum temperature has good correlation for all tools. From Figure 23, the coefficient of determinations is higher for maximum and minimum temperature in NASA at all stations except Alemketema. Rainfall highly predicted with NewLocClim over stations except Shewarobit, nearly 90% coefficient of determinations.

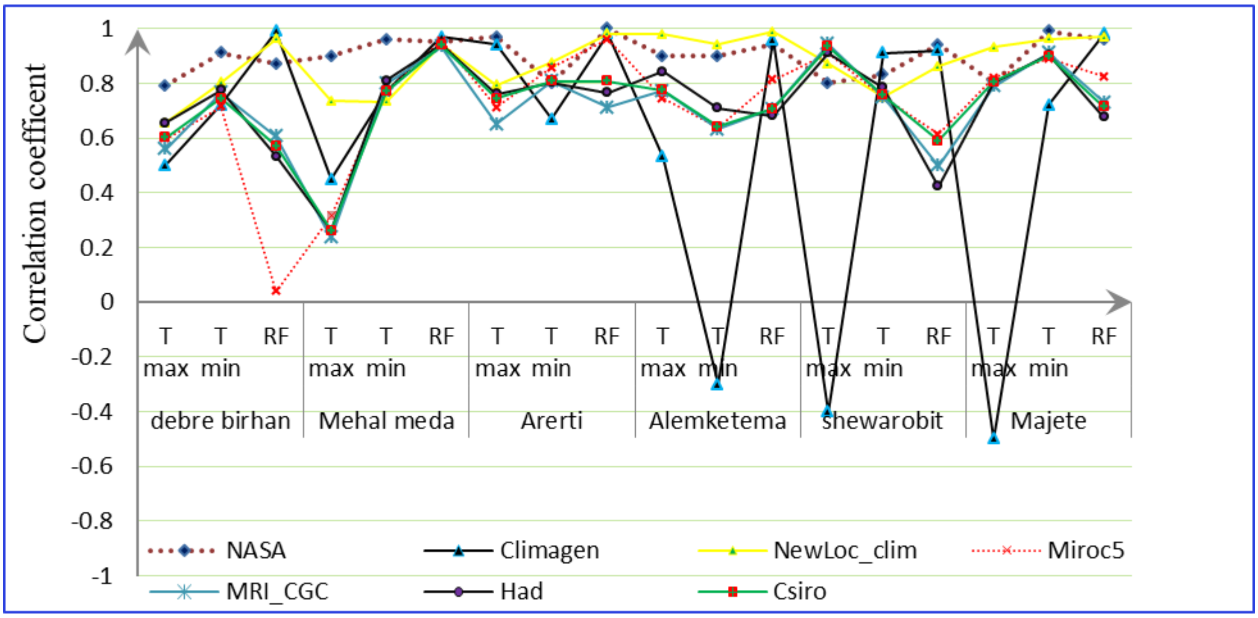


Figure 22. The values correlation coefficient for each weather generator over stations

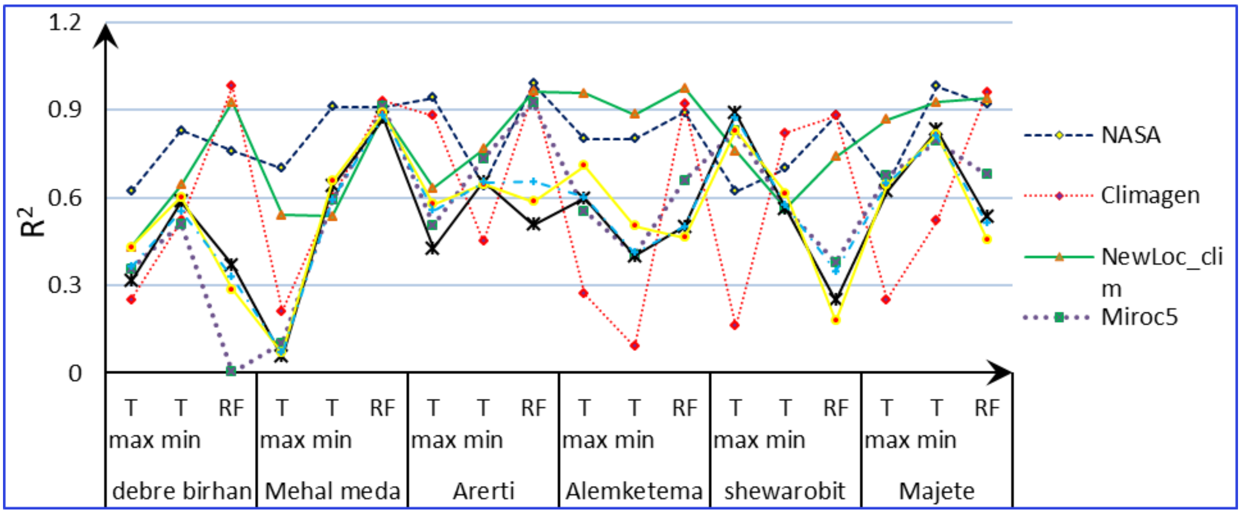


Figure 23. The values coefficient of determinations for each weather generator over stations

The observed and generated rainfall from all-weather generators is in enough agreement for all stations. Unlikely, maximum and minimum temperature have higher index of agreement at high lands and mid lands in NewLocClim, and followed by NASA. However, for low lands the index of agreement for NASA is higher than NewLocClim. Climagen performs poor agreement to the observed maximum and minimum temperature at all stations (Figure 24). According to (Kumar, *et al*, 2008), there was good agreement between observed and generated weather data for monthly period parameters in majority of the weather parameters for study areas. In general, there was enough agreement for rainfall and temperature for NewlocClim and NASA.

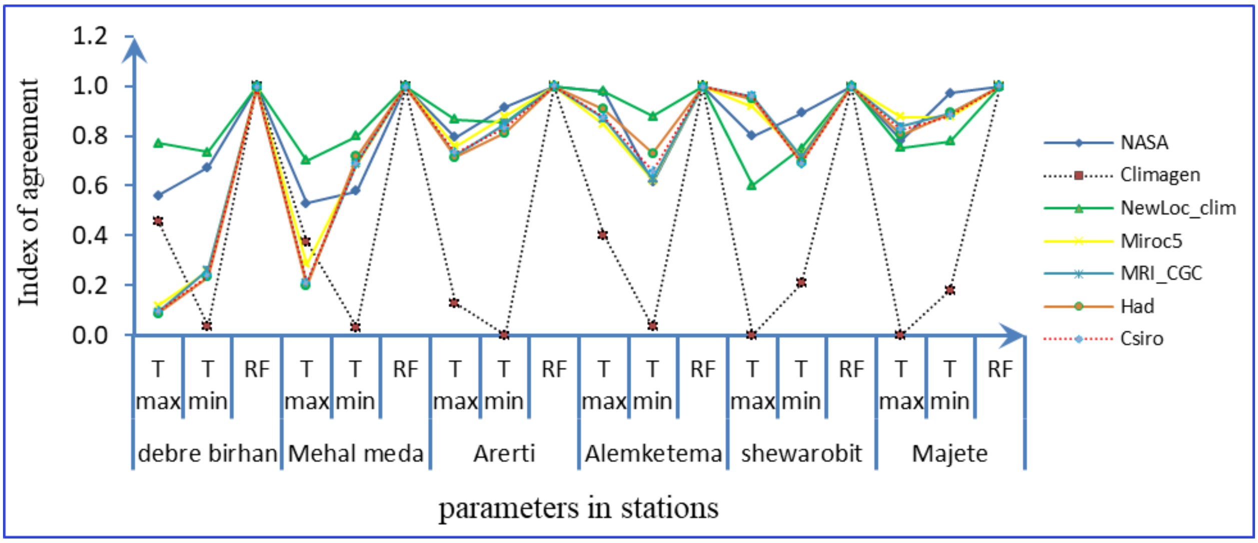


Figure 24 . The willmot index of agreement values for each weather generator over stations.

Conclusion and recommendation

In this research, spatial extensions and temporal trends analysis of rainfall, maximum and minimum temperature, validations of different weather generators tools under various climatic agro ecological zones were done. The study aims to validate different weather generators models in reference with the historical rainfall records with designing Marksim DSSAT weather generators, Climagen, NASA data source, and New LocClim tools as a generator of weather data. The Mann–Kendall trend test shows a decreasing trend of monthly rainfall in the three agro ecologies in some of stations and no trends in some of stations except Alem ketema. This might be due to large variation of rainfall in the area over years. As the analysis of PCI, the rainfall distribution shows a uni-modal nature in all stations except Kewat and Majete. The rainfall event was not having a significant trend. There was variability in maximum temperature, having significant increasing trends in the three agro ecologies, while the variability in minimum temperature at highland areas, but at mid and low lands variation in minimum temperature and have not significant increasing trends in the three agro ecologies. The smallest RMSE was observed in NewlocClim and NASA for rainfall and temperature in most of stations. Similarly, the smallest C.V also was observed in NewlocClim and NASA for rainfall and temperature in most of the stations. The higher value of correlation and index of agreement for rainfall, Tmax and Tmin was observed in NewlocClim and NASA nearly at all stations. Both NASA and NewLocClim are well performed with respect to representing the statistical characteristics of observed rainfall and minimum and maximum temperatures. Since agriculture is directly related to climatic variability; this actual observed increasing temperature and rainfall variability, well-validated weather generators are needed. This works provide an input climatic data for crop simulation models, soil erosion models, and water management system models where no actual weather stations are present. Therefore, from this study for rainfall data generation one may use NASA and NewLocClim. Similarly, for reproducing maximum and minimum temperature over location and time, NASA and NewLocClim are better to reproduce. Furthermore, to get precise results, others similar studies should be conducted with a greater number of metrological stations and others more weather generators tools.

References

Chen, J. and Brissette, F.P., 2014. Comparison of five stochastic weather generators in simulating daily precipitation and temperature for the Loess Plateau of China. International Journal of Climatology, 34(10), pp.3089-3105.

Chinnachodteeranun, R., Hung, N.D., Honda, K., Ines, A.V. and Han, E., 2016. Designing and implementing weather generators as web services. Future Internet, 8(4), p.55.

De Luis, M., Gonzalez-Hidalgo, J.C., Brunetti, M. and Longares, L.A., 2011. Precipitation concentration changes in Spain 1946–2005. Natural Hazards and Earth System Sciences, 11(5), pp.1259-1265.

Dhakal, K., Kakani, V.G. and Linde, E., 2018. Climate change impact on wheat production in the Southern Great Plains of the US using downscaled climate data. Atmospheric and Climate Sciences, 8(2), pp.143-162.

Fenta Mekonnen, D. and Disse, M., 2018. Analyzing the future climate change of Upper Blue Nile River basin using statistical downscaling techniques. Hydrology and Earth System Sciences, 22(4), pp.2391-2408.

Gayatri, S., Sailaja, B., Voleti, S.R. and Subrahmanyam, D., 2014, October. Validation of Climgen model with regional climate data. In Poster presented in the 3rd International Conference on Agriculture and Horticulture (pp. 27-29).

Gebre, H., Kindie, T., Girma, M. and Belay, K., 2013. Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception.

Academia Journal of Agricultural Research, 1(6), pp.088-100.

Geng, S., Auburn, J.S., Brandstetter, E. and Li, B., 1988. A Program to Simulate Meteorological Variables: Documentation for SIMMETEO, Agronomy Progress Rep 204. Department of Agronomy and Range Science, University of California, Davis, California.

Gommes, R., Grieser, J. and Bernardi, M., 2004. FAO agroclimatic databases and mapping tools. Eur Soc Agron Newsl, 22, pp.32-36.

Jones, P.G. and Thornton, P.K., 2000. MarkSim: software to generate daily weather data for Latin America and Africa. Agronomy Journal, 92 (3), pp.445-453.

Mequanint, F., Takele, R. and Shiferaw, A., 2016. Observed and future climate variability and extremes over East Shoa Zone, Ethiopia. J. Climatol. Weather Forecast, 4, pp.1-9.

Partal, T. and Kahya, E., 2006. Trend analysis in Turkish precipitation data. Hydrological Processes: An International Journal, 20 (9), pp.2011-2026.

Trotochaud, J., Flanagan, D.C. and Engel, B.A., 2016. A simple technique for obtaining future climate data inputs for natural resource models. Applied Engineering in Agriculture, 32(3), pp.371-381.

Tingem, M., Rivington, M., Azam-Ali, S. and Colls, J., 2007. Assessment of the ClimGen stochastic weather generator at Cameroon sites. African Journal of Environmental Science and Technology, 1(4), pp.86-92.

Tseng, H.W., Yang, T.C., Kuo, C.M. and Yu, P.S., 2012. Application of multi-site weather generators for investigating wet and dry spell lengths under climate change: a case study in southern Taiwan. Water resources management, 26(15), pp.4311-4326.

Wilks, D.S. and Wilby, R.L., 1999. The weather generation game: a review of stochastic weather models. Progress in physical geography, 23(3), pp.329-357.

Willmott, C.J., 1982. Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society, 63(11), pp.1309-1313.

Worku, T., Khare, D. and Tripathi, S.K., 2019. Spatiotemporal trend analysis of rainfall and temperature, and its implications for crop production. Journal of Water and Climate Change, 10(4), pp.799-817.

Appendices

Table 1. Global climatic models in Marksim DSSAT weather generators

No	Model	Institution	Resolution
1.	BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration	2.81 x 2.81
2	BCC-CSM1-1-M	Beijing Climate Center, China Meteorological Administration	2.81 x 2.81
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organization and the Queens land Climate Change Centre of Excellence	1.88 x 1.88
4	FIO-ESM	The First Institute of Oceanography, SOA, China	2.81 x 2.81
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory	2.0 x 2.5
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	2.0 x 2.5
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	2.0 x 2.5
8	GISS-E2-H	NASA Goddard Institute for Space Studies	2.0 x 2.5
9	GISS-E2-R	NASA Goddard Institute for Space Studies	2.0 x 2.5
10	HadGEM2-ES	Met Office Hadley Centre	1.24 x 1.88
11	IPSL-CM5A-LR	Institute Pierre-Simon Laplace	1.88 x 3.75
12	IPSL-CM5A-MR	Institute Pierre-Simon Laplace	1.26 x 2.5
13	MIROC-ESM	Atmosphere and Ocean Research Institute	2.81 x 2.81
14	MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute	2.81 x 2.81
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute	1.41x 1.41
16	MRI-CGCM3	Meteorological Research Institute	1.13x 1.13
17	NorESM1-M	Norwegian Climate Centre	1.875x2.5

Table 2. The spation temporal variability of rainfall and temperature

Stations	Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Mean	RME	C.V (%)
DB	T max	20	21.1	21.3	21	21.6	22	18.9	18.3	19	19.2	19.4	19.3	20.1	1.2	6.2
	Tmin	4.7	6.4	7.6	8.9	7.9	7.9	8.9	8.7	7	4	3.5	3.7	6.6	2.1	31.6
	RF	8.5	12.3	32.8	35.8	32.2	40.6	239.2	315.5	64.1	16.3	4.1	2.8	804.2	101.1	12.6
MM	T max	18.8	19.2	19.1	18.8	19	19.7	17.6	17	17.1	16.7	17.3	18	18.2	1.0	5.6
	T min	5.7	7.2	7.9	8.4	8.7	8.5	8.4	8.4	8	6.4	5.1	4.9	7.3	1.4	19.3
	RF	16	23	55	45	40	41	268	252	74	24	7	5	850	90.6	10.7
AK	T max	26.1	27.3	27.6	27.6	27.8	27.3	21.9	20.8	22.7	24.8	25.3	25.3	25.4	2.4	9.5
	T min	12.6	13.6	14.2	14.6	15.5	14.8	12.3	11.5	12.4	12.3	11.6	11.9	13.1	1.4	10.4
	RF	7.2	18.5	46.4	47.6	55	70.1	280	308.3	141	23.7	9.5	8.6	1016	104.8	10.3
MS	Tmax	26.7	28.0	29.5	29.4	29.8	29.0	25.4	25.7	26.5	25.9	26.0	24.6	27.2	1.8	6.8

Mean		MJ			KW				
T min	T max	RF	T min	t max	RF	T min	T max	RF	Tmin
8.9	24.3	31	12	25.8	28	9.7	28.7	10.1	8.8
10.6	25.5	39.8	13.1	27.2	48	12.5	30.2	28.7	10.7
12.1	26.4	71.9	14.5	28.8	58	15.4	32.1	51.3	13.1
12.8	26.5	99	15.8	29.5	86	15.2	32.8	61.8	14.1
13.7	27.2	63.7	16.6	31.2	81	17.2	33.7	31.9	16.5
13.6	27.8	25.2	17.9	33	24	17.7	35.6	76.1	14.8
13.2	24.6	221.2	17.1	30.6	144	17.9	33.4	231.9	14.4
12.3	23.6	296.5	16.4	28.9	182	13.6	30.8	233.5	15.2
11.5	23.9	104	15.5	27.3	84	11.7	30.7	94.5	14.3
10.1	24.1	45.1	13.6	26.6	39	11.6	31.3	42.4	12.7
9.2	23.7	28.1	12.2	24.5	14	11.3	29.7	14.6	11.5
8.5	23.2	23.3	11.5	23.5	48	10.9	28.5	9.3	7.9
		1048.6	14.7	28.1	836.0	13.7	31.5	886.1	12.8
		86.1	2.2	2.8	50.2	2.9	2.1	78.7	2.6
		8.2	14.8	10.0	6.0	20.9	6.8	8.9	20.6

C.V			RME			
RF	T min	Tmax	RF	T min	T max	RF
32.9	33.0	14.9	33.1	2.9	3.6	101
32.3	26.8	15.5	55.0	2.8	4.0	170
31.7	26.1	17.5	100.0	3.2	4.6	315
32.1	23.4	18.7	120.4	3.0	5.0	375
32.0	28.3	19.2	97.3	3.9	5.2	304
32.3	29.5	20.2	89.5	4.0	5.6	277
31.7	27.9	23.6	438.2	3.7	5.8	1384
31.6	24.8	22.2	502.3	3.1	5.2	1588
31.8	26.9	19.9	178.6	3.1	4.8	561
32.0	35.5	20.1	61.0	3.6	4.8	191
33.0	38.1	17.6	25.5	3.5	4.2	77
35.4	38.1	15.4	34.3	3.2	3.6	97

Table 3. Validations of weather generators

Tools	Stations	Debre birhan			Mehal meda			Arerti			Alem ketema			Shewarobit			Majete		
	Criterion	Tmax	Tmin	RF	Tmax	Tmin	RF	Tmax	Tmin	RF	Tmax	Tmin	RF	Tmax	Tmin	RF	Tmax	Tmin	RF
NASA	RME	5.9	4.60	80.4	3.8	3.9	78.6	2.4	1.8	96.7	1.73	2.20	62.3	3.7	2.5	58.8	2.7	2.2	75.9
	CV	29.4	4	0	7	4	9.3	9.4	8	9.5	0	5	0	7	4	7.1	9.5	9	7.2
	CORR	0.8	1	0.9	0.9	1.0	1.0	1.0	0.8	1.0	0	0	4	0.8	0.8	0.9	0.8	1.0	1.0
	R^2	0.62	3	6	0	1	1	4	4	9	0	0	9	2	0	8	4	8	2
	d	0.6	0.7	1.0	0.5	0.6	1.0	0.8	0.9	1.0	1.0	0.6	1.0	0.8	0.9	1.0	0.8	1.0	1.0
Climagen	RME	2.5	7.3	2	2.5	6.9	3	3.4	7.3	87.1	3.97	7.60	0	6.3	4.1	85.7	5.4	3.4	98.0
	CV	12.4	110	1	5	8	8	3	8	8.6	6	3	0	5	7	3	1	2	9.4
	COR	0.5	0.7	1.0	0.5	0.8	1.0	0.9	0.7	1.0	0.53	-0.30	0.96	-0.4	0.9	0.9	-0.5	0.7	1.0
	R^2	0.3	0.52	0.98	0.21	0.60	0.93	0.88	0.45	0.96	0.27	0.09	0.92	0.16	0.82	0.88	0.25	0.52	0.96
	d	0.5	0.0	1.0	0.4	0.0	1.0	0.1	0.0	1.0	0.4	0.0	1.0	0.0	0.2	1.0	0.0	0.2	1.0
New-LocClim	RME	1.4	2.2	99.3	3.9	3.0	75.2	2.1	2.3	71.9	2.3	1.1	5	5.9	3.7	78.5	2.5	2.3	77.2
	CV	6.8	33.1	12.3	21.3	40.7	8.9	7.7	17.7	8.1	9.0	8.7	10.0	18.9	26.8	9.4	8.9	15.7	7.4
	COR	0.7	0.8	1.0	0.7	0.7	0.9	0.8	0.9	1.0	1.0	0.9	1.0	0.9	0.7	0.9	0.9	1.0	1.0
	R^2	0.4	0.6	0.9	0.5	0.5	0.9	0.6	0.8	1.0	1.0	0.9	1.0	0.8	0.6	0.7	0.9	0.9	0.9
	d	0.8	0.7	1.0	0.7	0.8	1.0	0.9	0.9	1.0	1.0	0.9	1.0	0.6	0.8	1.0	0.8	0.8	1.0
MIROC-5	RME	4.1	4.5	91.3	2.2	2.5	8	2.3	2.9	84.2	2.46	2.20	111	2.4	3.4	87.7	2.8	2.9	6
	CV	20.4	67.8	11.4	12.0	34.4	15.5	8.6	22.9	9.5	9.70	16.80	10.88	7.7	24.9	10.5	10.1	20.1	9.7
	COR	0.6	0.7	0.0	0.3	0.8	1.0	0.7	0.9	1.0	0.74	0.64	0.81	0.9	0.7	0.6	0.8	0.9	0.8
	R^2	0.36	1	0	0	9	1	1	3	2	5	0	6	3	6	8	7	9	8

CSIRO –MK 3.6.0					HadGEM2-ES					MRI_CGCM3					
d	R^2	COR	CV	RME	d	R^2	COR	CV	RME	d	R^2	COR	CV	RME	d
0.1	0.36	0.6	21.3	4.3	0.1	0.4	0.7	21.3	4.3	0.1	0.31	0.56	20.3	4.1	0.1
0.2	0.55	0.7	68.5	4.5	0.2	0.6	0.8	69.2	4.6	0.3	0.59	0.8	67.0	4.4	0.3
1.0	0.33	0.6	13.5	108	1.0	0.3	0.5	13.5	108.4	1.0	0.37	0.6	14.4	0	1.0
0.2	0.07	0.3	12.0	2.2	0.2	0.1	0.3	11.8	2.2	0.2	0.06	0.2	11.6	2.1	0.3
0.7	0.59	0.8	35.8	2.6	0.7	0.7	0.8	35.6	2.6	0.7	0.64	0.8	36.4	2.7	0.7
1.0	0.88	0.9	16.0	136	1.0	0.9	0.9	15.2	129.0	1.0	0.87	0.9	15.6	3	1.0
0.7	0.55	0.7	8.1	2.2	0.7	0.6	0.8	7.8	2.1	0.7	0.42	0.7	7.8	2.1	0.8
0.8	0.65	0.8	22.9	2.9	0.8	0.6	0.8	22.7	2.9	0.9	0.65	0.8	22.8	2.9	0.9
1.0	0.65	0.8	10.2	90.7	1.0	0.6	0.8	10.7	95.2	1.0	0.51	0.7	11.2	99.4	1.0
0.9	0.60	0.8	9.33	2.37	0.9	0.7	0.8	8.8	2.2	0.9	0.60	0.77	9.05	2.30	0.8
0.7	0.41	0.6	15.9	2.09	0.7	0.5	0.7	15.1	2.0	0.6	0.40	0.63	9	2.14	0.6
1.0	0.50	0.7	10.5	107	1.0	0.5	0.7	11.1	113.0	1.0	0.50	0.71	6	3	1.0
1.0	0.87	0.9	7.2	2.3	0.9	0.8	0.9	7.2	2.3	1.0	0.89	0.9	7.0	2.2	0.9
0.7	0.57	0.8	24.9	3.4	0.7	0.6	0.8	24.9	3.4	0.7	0.56	0.7	24.7	3.4	0.7
1.0	0.35	0.6	10.3	86.0	1.0	0.2	0.4	10.0	83.4	1.0	0.25	0.5	10.4	86.6	1.0
0.8	0.65	0.8	10.0	2.8	0.8	0.6	0.8	9.6	2.7	0.8	0.62	0.8	9.6	2.7	0.9
0.9	0.81	0.9	20.0	2.9	0.9	0.8	0.9	19.5	2.9	0.9	0.83	0.9	20.1	2.9	0.9
1.0	0.51	0.7	9.7	101	1.0	0.5	0.7	9.8	102.5	1.0	0.53	0.7	10.3	4	1.0

Effect of irrigation regimes (frequency and water depth) on yield of onion in Metema, western Amhara, Ethiopia

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Abstract

Farmers did not know how much and when to apply irrigation water for irrigating crops resulted in under or over-irrigation. They apply more water at one time and lost the water through deep percolation beyond the root zone and runoff. The study was conducted in 2017and 2018 at Gondar agricultural research center irrigation station. The objective of the study was to determine irrigation regimes for a better yield of onion. Treatments were a combination of irrigation interval (4, 7, and 10days) with (60%, 80%, 100%, and 120% of Etc. The experimental design was a split-plot design with three replications. Irrigation interval and depth were the main plot and subplot respectively. The combined result revealed that there were interaction effects and main effects on tested parameters at a=0.05. Irrigating every 4days gave the highest Bulb weight (61.18g), Bulb Diameter (52.41 mm), and total yield (22.93th^{-1}) followed by watering every 7days. On the other hand, 7days irrigation interval gave the highest water productivity (4.39 kg/m^{3}) than 4days with 10days irrigation interval. Applying 120%ETc provided the highest value concerning all yield components considered, while the lowest values were obtained from 60%ETc. The highest and lowest water productivity obtained from treatment 80%ETc with 120%ETc respectively. The interaction result revealed that the maximum total yield (27.66t/ha) and bulb weight (72.5g) obtained from 120%ETc with 4days intervals. This is statistically the same with 120%ETc with 7days intervals. Besides, the least amount of total yield (15.36 th^{-1}) and bulb weight (45.47 th$^{-1)}$ were recorded from 60%ETc with 10days intervals. In the area, there is no water scarcity for irrigation. Therefore, in the advantage of the less frequent watering day and minimizing of operational and labor cost, irrigating every 7 days with 120%ETc is more appropriate for the command area and others those have the same ecology and soil type.

Keywords: irrigation interval, Metema, water depth, water productivity, yield

Introduction

Onion is considered as one of the most important vegetable crops produced on small scale farming in Ethiopia. It also occupies an economically important place among vegetables in the country. The area under onion is increasing from time to time mainly due to its high profitability per unit area, ease of production, and the increases in small scale irrigation areas. In different areas of the country, the offseason crop (under irrigation) constitutes much of the area under onion production. Nigussie *et al.,* (2015) described that the range of altitude for onion production is between 500-2400 m.a.s.l. The best growing altitude so far known in Ethiopia is between 700-1800 m.a.s.l.

In Ethiopia, the crop is believed to be more intensively consumed than any other vegetable crops and a lion share of 95% of the vegetables and fruits produced in the country (Belay *et al.,* 2016). In most irrigable lands, the role of horticultural crops particularly Vegetables being cash crop with high nutritional value become important and irreplaceable to contribute the household food security and income. Higher profits can be achieved by increasing the production of a particular vegetable throughout the year when an efficient irrigation system is used. In Ethiopia, it contributes substantially to the national economy apart from overcoming local demand. Onion is among the largest production and highly commercialized vegetable crops in the Amhara region grown under irrigation. Currently, farmers in most irrigable areas of the Amhara region produce a large number of onion bulbs every year (Agumas, Abewa, and Abebe, 2014).

All crops require a certain amount of water during each stage of development mainly their initial stage, crop development stage, mid-growing, and maturity stage, and will transpire water maximum rate when the soil water is at field capacity. But the amount, intensity, duration, frequency, and distribution of rain needed to meet the actual water requirement of the crop to achieve full production potential is rarely realized in nature (Pejic, B. *et al.,* 2008).

Water management of onion is extremely important at all stages of plant development. Also, irrigation strategies with appropriate water restriction during mid and late-season growth stages are recommended in a way a significant amount of irrigation water could be saved without any significant decrease in onion yield and quality. The great challenge faces for the onion producers in achieving a high yield that meets the quality standards and market requirements with less water use (Zayton, 2007).

The interval between irrigations and the amount of water applying to each irrigation depends on how much water is held in the root zone and how fast the crop uses it. This is determined by -soil texture, soil structure/water penetration, depth of effective root zone of the soil, the crop has grown and the stage of development of the crop. Proper irrigation scheduling will improve profitability and water use efficiency by - maximizing crop yield and quality, decreasing water loss through deep percolation and runoff and, optimizing pumping, and other costs.

Different water application schedules on the growth and yield of onion, yield components, and morphological characteristics of the onion crop had significantly affected all the studied parameters, except for the fresh weight of leaves. Therefore to achieve a high production potential of onion, appropriate soil moisture should be maintained during the entire growing season (Pejic, B., et al., 2008).

The production of onion in the Metema district is mainly under irrigation but there were poor agronomic practice and water management skills. Farmers did not know how much and when to apply irrigation water for irrigating crops. Which lead crops under irrigation or over-irrigation. They apply more water at one time and lost the water through deep percolation beyond the root zone and the crop suffocates for some days. Therefore this study was initiated for the objective of determining the optimum irrigation water depth and irrigation interval for a better onion yield.

Materials and methods

The study area

The experiment was conducted in the lowland of western Amhara region **Metema** which is located 13°00′N and 36°15′E, it is one of the zones in the Amhara Region of Ethiopia named as “west Gondarzone administration”. Metema is bordered on the south by Quara, on the west by Sudan, on the north by Mirab Armachiho, on the northeast by Tach Armachiho, on the east by Chilga, and on the southeast by Takusa. Altitude ranges between 550 and 1600 meters above sea level. Rivers include the Atbarah, the GendaWuha, the Guang, and the Shenfa. Guang River is where the irrigation station of Gondar Agricultural Research center is situated.

The experimental site domain is one of the high potential areas for agriculture in the country. It can grow cash crops like sesame, cotton, soya bean, haricot bean, groundnut, and different horticultural crops (fruits: mango, banana, orange, onion, tomato). It has also a potential area for livestock. The soil is deep enough dominantly clay soil and it has a shallow groundwater table and surface water. Irrigation is very infant for the area but it is expanding in a short time. Generally, it is possible to grow three to four times within a year in the area.

The maximum and minimum temperature of the area was 35.88°c and 19.48°c respectively. The metrological information of the Metema district was average reference evapotranspiration of 5.21mm/day using *penman-monteith* and the total and effective rainfall were 885 mm and 636.5mm respectively by USDA S.C. Method.

Table 1. Climatic data for the study area

Month	T. Min [°C]	T. Max [°C]	Humidity %	Wind [km/day]	Sun [hours]	Rad [MJ/m²/day]	Eto [mm/day]	Rain [mm]	Eff rain [mm]
January	18.7	35	45	156	8.5	19.1	5.1	1	1
February	20.2	39	39	156	9.1	21.5	6.06	0	0
March	20.2	40	34	147	8.7	22.3	6.49	0	0
April	17.5	40.2	28	130	8.8	23.1	6.47	1	1
May	18.3	39	69	156	8	21.6	5.78	67	59.8
June	19.8	35.7	84	156	7.3	20.3	4.83	160	119
July	20.2	31.8	93	104	7	19.9	4.15	209	139.1
August	20.1	31.7	93	86	5.1	17.2	3.64	211	139.8
September	20.2	31.7	65	104	7.1	20	4.49	187	131
October	20.1	34.5	41	138	8.8	21.3	5.44	45	41.8
November	19.8	35.9	40	138	9.4	20.6	5.32	4	4
December	18.7	36	44	112	9.2	19.5	4.71	0	0
Average	19.5	35.9	56	132	8.1	20.5	5.21	885*	6.36.5*

Source: FAO-newLocclim; *total

Methodology

The experiment was performed in the 2017 and 2018 irrigation seasons from January 2017 to May 2017 at Metema irrigation station specifically Mender 6, 7, and 8. The experimental design was a split-plot with three replications in two factors. The first factor was irrigation interval consisted of three levels (i.e., four days, seven days, and ten days) and the second factor has consisted of four irrigation water depths (120%ETc, 80%ETc, 100%ETc, and 120%ETc). Generally, the experiment had twelve (12) treatment combinations. The spacing between blocks and plots was 1.5meter and 1meter respectively. The plot size was 3 meters by 3 meters. Crop spacing was 40*20*10, double row (i.e., 40 cm between ridge, 20 cm between rows, and 10 cm between plants). Fertilizer has been applied as the recommendation of EIAR (2007) which was 92kg/ha nitrogen. Data analysis was performed using SAS software window 9.0, and also multiple All-Pair wise Comparisons Test were done using LSD comparison method at 0.05 significant levels.

Water productivity in agriculture and landscape irrigation may be generically defined as the ratio between the actual crop yields achieved (Ya) and the water use, expressed in kg/m3 (Pereira, 2012).

Therefor water productivity was determined by the equation (Pereira, 2012)

$$WP = \frac{Ya}{TWU} \text{ --- } (1)$$

Where, Ya is bulb yield (kg/ha) and TWU is total water used (m^3)

Table 2. The crop has four stages and its kc values (Science, 2015)

Growth stages	Growth length	Crop coefficient (kc)
Initial stage	15	0.6
Developmental stage	25	0.6
Mid stage	40	1.1
Late stage	30	0.9

Materials used

During the experiment execution materials were used as; a Siphon tube which was used to deliver water from the tanker to the plot field, and this was also used as the water measurement by calibrating flow rates. The weighing balance was also used as a weighing of harvested bulb samples and soil samples which were collected by plastic bags. Besides tape meter and caliper were important for measuring the experimental area and plot dimensions, plant height, and diameter of bulbs.

Results

Determination of irrigation regimes for better yield of onion in Matema district tested for its interaction effect and main effects. The result revealed that there were interaction effects and main effects on tested parameters at a 0.05 level of significant difference. Analysis of variance table (3) showed that there was a highly significant difference in total yield, bulb weight, bulb diameter, and water productivity among irrigation intervals. Moreover, irrigation water depths affected highly significantly total yield, bulb weight, bulb diameter, and also significantly affect water productivity. On the other interaction between irrigation interval and water, depth affected total yield and bulb weight significantly. However, there were no differences in bulb diameter and water productivity among treatment interactions.

Table 3. Analysis of variance (ANOVA) for total yield, bulb weight, bulb diameter, and water productivity.

Source	DF	Total Yield	Bulb weight	Bulb diameter	Water productivity
REP	4	38.15*	156.59*	9.89*	1.24*
Interval(IN)	2	240.60**	718.86**	67.61**	10.07**
REP*IN(Error)	8	31.15	165.92	19.01	1.1
Water depth(D)	3	238.26**	1146.04**	114.1**	2.12*
IN*D	6	22.76*	90.15*	6.33	0.58
Error (pooled)	0	8.47	34.49	4.58	0.35

*significant, **highly significant, DF= degree of freedom, REP= replications

Table 4 showed that irrigating onion every 4 days gave the highest Bulb weight (61.18g), Bulb Diameter(52.41 mm), and Total yield(22.93 th^{-1}), followed by a 7days irrigation interval with the Bulb weight (59.33g) Bulb Diameter (51.97mm), and Total yield (22.3th^{-1}). 7days irrigation interval gave the highest water productivity (4.29 *kg/m*^{3}) and water productivity (4.39 *kg/m*^{3}). However, there was no statistical difference between 4days with 7days irrigation intervals. 10-day irrigation interval provided the lowest value for all variables.

On the other hand application of 120%ETc, provided the highest result on bulb weight (64.61 g), bulb diameter (54.09 mm), and total yield (24.07 th^{-1}). The lowest values for bulb weight, bulb diameter, and total yield obtained from treatment 60% ETc. The highest and lowest water productivity was obtained from treatment 80% ETc with 120% ETc respectively.

Table 4. Effects of irrigation interval and depth on the mean of bulb weight (gram), bulb diameter (mm), total yield (t h^{-1}), and water productivity (kg/m^3)

Irrigation Interval	*Bulb weight*	Bulb diameter	Total yield	Water productivity
4days	61.18^a	52.41^a	22.93^a	4.29^a
7days	59.33^{ab}	51.97^{ab}	22.30^a	4.39^a
10days	50.89^b	49.33^b	17.16^b	3.23^b
LSD*(0.05)*	8.58	2.90	3.72	0.7
depth				
120%ETc	64.61^a	54.09^a	24.07^a	3.53^b
100%ETc	61.97^a	51.66^b	22.83^a	3.93^{ab}
80%ETc	55.31^b	51.23^b	20.48^b	4.27^a
60%ETc	46.65^c	47.97^b	15.81^c	4.15^a
LSD*(0.05)*	3.97	1.45	1.97	0.40
CV*(%)*	10.28	4.18	14.0	14.95

Values with the same letters have no significant difference

According to table 5, the interaction result revealed that the maximum total yield (27.66t/ha) and bulb weight (72.5g) obtained from 120%ETc with 4days intervals. Which is statistically the same with 120%ETc with 7days intervals. Also, the least amount of total yield (15.36 th-1) and bulb weight (45.47 th-1) were recorded from 60%ETc with 10days intervals.

Table 5. Interaction effects on bulb weight (gram) and total yield (th^{-1})

Water Depth	Bulb Weight			Total Yield		
	Irrigation interval- days					
	4	7	10	4	7	10
120%ETc	72.50^{a}	66.27^{ab}	55.05^{de}	27.66^{a}	25.84^{ab}	18.71^{d}
100%ETc	68.38^{ab}	63.80^{bc}	53.73^{de}	25.66^{ab}	24.17^{bc}	18.65^{d}
80%ETc	58.05^{cd}	58.55^{cd}	49.32^{ef}	22.24^{c}	23.28^{bc}	15.91^{d}
60%ETc	45.80^{f}	48.68^{ef}	45.47^{f}	16.17^{d}	15.9^{d}	15.36^{d}
Cv*(%)*		10.78			14.00	
Lsd*(<0.05)*		6.88			3.41	

ETc= crop evapotranspiration*; values with the same letters have no significant difference*

Discussion

Yield, individual bulb weight, and individual bulb diameter are the important criterion to be considered when a plan to produce an onion bulb. Before planting and growing the crop under irrigation, irrigation interval and water depth should be decided.

Yield

Irrigation interval and water depth interaction result displayed in table 5, which showed interactions effect on yield of onion crop. The result revealed that the maximum bulb yield was recorded from 120%ETc with 4day irrigation intervals (**27.66**t ha^{-1}**)** followed by 120%ETc with 7day irrigation intervals (**25.84**t ha^{-1}). Increasing the Application of water from 60%, 80%, 100% to 120%ETc will increase the total bulb yield. This is in line with (Kumar, Imtiyaz, Kumar, & Singh, 2007) who reported that irrigating onion from 60%ETc, 80%ETc, 100%ETc to 120%ETc increased onion yield. The same result was also obtained by Tsegaye *et al.*, (2016), who reported that increasing irrigation water from 25%ETc to 50%ETc, 75%ETc, and 100%ETc increase marketable yield from **15.48 to27.59**tha^{-1}. Patel and Rajput, (2013) also found that irrigation from 60%, 80% deficit to full irrigation had increase yield from 39.2 to 44.4tha^{-1}. In the same trend Enchalew *et al.*, (2016) found that an increase in water depth from 50 to 60, 70, 80, 90 to 100%ETc has been increased in marketable(**10.9**t ha^{-1}) and total bulb yield(**15.69**t ha^{-1}).

Bulb weight

Irrigating onion at increasing of 4 to 7 and 10-day irrigation interval (main plot) has been decreased bulb weight from 72.5 to 66.27 and 55.05g. Beyond the 7day interval, bulb weight had significantly affected by water stress. On the other hand, increasing of application of water from 60%ETc, 80%ETc, 100%ETc, and 120%ETc water depth (subplot) will increase the bulb weight. The application of water below 100%ETc of crop water requirement significantly decreases the individual weight of the bulb. A similar result on bulb size was observed by Kumar et al. (2007). The maximum bulb weight **(72.5g)** lied on the interaction of 4-day and 120%ETc, which is statistically identical with 4day with 100%ETc (**68.38g)** and 7 days with 120%ETc (**66.27**g).

Water productivity

Increasing water depth from 80%ETc to 100%ETc and 120%ETc would decrease water productivity from 4.27 to 3.93 and 3.53 kg/m3. Independent of water depth, irrigating every 7 days (4.39kgm^3) is optimal for the water productivity of the onion. than 4days (4.29kg/m^3) and 10days (3.23kg/m^3).

Conclusion and recommendation

Production of onion under irrigation in Metema district and the same ecology, application of water every 4-day irrigation interval with 120%ETC water depth followed by 7day with 120%ETc is appropriated. Moreover, there is no yield and quality penalty among them. Independence of water depth irrigating every 7 days is best in terms of water productivity but it is in contrast on the point of water depth that will prefer 80%ETc. however, in the area, there is no water scarcity for irrigation.

Therefore, in the advantage of the less frequent watering day and minimizing of operational and labor cost, irrigating every 7 days with 120%ETc water depth with a net amount of seasonal water of **664**mm will more appropriate for the command area and others those have the same ecology and soil type.

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References

Agumas, B., Abewa, A., & Abebe, D. (2014). *Response of Irrigated Onion (Allium cepa L .) to Nitrogen and Phosphorus Fertilizers at Ribb and Koga Irrigation Schemes in Amhara Region , North western*. *4*(5), 95–100.

Belay, S., Mideksa, D., Gebrezgiabher, S., & Seifu, W. (2016). *Yield Components of Adama Red Onion (Allium cepa L .) Cultivar as Affected by Intra-row Spacing Under Irrigation in Fiche Condition*. *3*(6), 75–79. https://doi.org/10.11648/j.plant.20150306.13

Enchalew, B., Sl, G., Rabo, M., Hindaye, B., Kedir, M., Musa, Y., & Shafi, A. (2016). *Irrigation & Drainage Systems Engineering Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepal .) under Drip Irrigation*. *5*(3), 5–8. https://doi.org/10.4172/2168-9768.1000172

Kumar, S., Imtiyaz, M., Kumar, A., & Singh, R. (2007). *Response of onion (Allium cepa L .) to different levels of irrigation water*. *89*, 161–166. https://doi.org/10.1016/j.agwat.2007.01.003

Nigussie, A., Kuma, Y., Adisu, A., Alemu, T., & Desalegn, K. (2015). *Onion Production for Income Generation in Small Scale Irrigation Users Agro- pastoral Households of Ethiopia*. *2*(3). https://doi.org/10.4172/2376-0354.1000145

Patel, N., & Rajput, T. B. S. (2013). *Effect of deficit irrigation on crop growth , yield and quality of onion in subsurface drip irrigation*. *7*(July).

Pejic, B., Gvozdanovic-Varga, J., Vasic, M., Maksimovic, L., Milic, S. (2008). *effect of different water application schedules on the growth and yield of onion (allium cepa l .) at golinga irrigation scheme in the tolon district of*.

Pereira, L. S., Cordery, I., & Iacovides, I. (2012). Improved indicators of water use performance and productivity for sustainable water conservation and saving. *Agricultural Water Management*, *108*, 39–51. https://doi.org/10.1016/j.agwat.2011.08.022

Science, I. (2015). *Determination of water requirement , single and dual crop coefficients of black cumin (Nigella sativa L .) in a semi-arid climate*. (October). https://doi.org/10.1007/s00271-013-0412-2

Tsegaye, B., Bizuayehu, T., Woldemichael, A., & Mohammed, A. (2016). *Yield and Yield*

Components of Onion (Allium cepa L .) as Affected by Irrigation Scheduling and Nitrogen Fertilization at Hawassa Area Districts in Southern Ethiopia. *2*(2), 15–20.

Zayton, A. M. (2007). *Effect Of Soil-Water Stress On Onion Yield*. *24*(January), 141–160.

III. Soil and Water Conservation

Evaluation of conservation agriculture for soil loss, runoff, soil property and agronomic response in Yilmana Densa, Ethiopia

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Abstract

In Ethiopian highlands including the study area, the livelihoods of an increasing human population are dependent on tillage-based soil management for intensive crop production. This farming practice combined with the dynamic climate change leads to soil degradation. This degradation eventually leads to loss of soil and water, crop productivity, and deterioration of vital soil physicochemical properties. Moreover, farmers have to face challenges such as the consumption of much time, labor, energy, agrochemicals, and other production inputs required by intensive cropping. The objective of this study was to evaluate the effects of conservation agriculture (CA) on runoff, soil loss, soil properties and crop yield. To achieve the objective, five treatments as no-tillage combined with mulching and intercropping (NT + M + In), no-tillage combined with mulching and rotation (NT + M + R), conventional tillage combined with mulching and rotation (CT + M + R), potato production as farmers practice and conventional tillage (CT) were evaluated in simple plot design. The over-year effect of treatments on runoff and soil loss was compared using analysis of variance at a 95% level of confidence. The result verified that the significant difference among treatments in reducing runoff and soil loss is mainly due to minimum soil disturbance for the case of treatments combined with no-tillage and due to ridges for the case of potato plots as compared to local practices. There is also significant runoff reduction due to mulching as compared to farmers' practices. These practices (NT + M + R, potato, NT + M + In, and CT + M + R) have a significant effect on soil and water conservation with a runoff reduced by 73, 62, 56 and 38 % and soil loss reduced by 78, 68, 63, 27 % respectively as compared to the local practices or CT. Based on the result of the study no-tillage, ridges and mulching maximize the water and soil conservation effect of CA and should be recommended as important elements and be implemented widely. Consequently, these elements help to stabilize crop yields against weather extremes since often, CA increases average yields in the long term

Keywords: conservation agriculture, mulching, ridge

Introduction

The growth of human population and climate change cause the world's agricultural systems need to produce more food through intensified farming (Page et al., 2020; Struik and Kuyper, 2017). This agricultural practice leads to declining in the quality of basic natural resources particularly soil and water, which eventually lead to loss of crop productivity and environmental risk such as on-site and off-site effects on land and also on water bodies, (Blum, 2013; Kopittke et al., 2019; Issaka and Ashraf, 2017). Moreover, farmers have to face high costs for energy, labor, agrochemicals, and other production inputs required by intensive cropping.

This needs to adopt more sustainable and cost-effective agricultural practices by considering the relationship between natural resources and community lifestyle (Gomiero, 2016). Most of the above challenges could be tackled through conservation agriculture (CA) for all farmers and rural communities that depend on the agri-environment in the area such as Ethiopian highlands including Yilmana Densa (González-Sánchez et al., 2016). Araya et al. (2011) stated that CA aims to improve soil quality and crop yield whilst reducing runoff and soil erosion. Rusinamhodzi et al. (2011) also mentioned that CA includes important elements such as reduced tillage, permanent soil cover and crop rotations to optimise food supply through improving soil fertility and reducing soil loss and runoff. Due to mulching CA provides a protective blanket of leaves, stems and stalks. Consequently, it enhances soil productivity by improving its physicochemical properties through soil and water conservation and improving soil OM, the population of micro-organisms (which take over the function of traditional tillage such as loosening of the soil and mixing the soil components), humus formation (Fuhrer and Chervet, 2015; Shokati and Ahangar, 2014; Amini and Asoodar, 2015; Khursheed et al., 2019).

Moreover, CA saves energy such as fuel for machines and calories for humans and animals and time required for cultivation. For instance, Wijewardene (1979) found that no-tillage required 52 MJ of energy and 2.3 hours of labour per hectare whereas conventional tillage needed 235 MJ and 5.4 hours to cultivate the same area of land. Therefore, it is very crucial to test and amend alternatives to existing technologies for their effectiveness on soil and water conservation and ease of use by the farmers, i.e., to improve soil productivity in representative areas of the Amhara region.

Materials and methods

The study was conducted during 2016-2020 cropping seasons at Adet agricultural research center on the station and during 2018-2020 at Debre Mawi watershed in Yilmana Densa district of Amhara region which is one of the soil erosion-prone areas of the region. For this experiment, five treatments with a simple plot design were set. Although crop rotations were not used as a treatment, we used maize and faba bean crops as a rotation which has also the benefit to control pests and diseases by breaking their cycles. Besides, faba bean is a legume crop that can fertilize the soil when used for crop rotation. To achieve soil cover, 30% of the crop stand (residue) was retained after harvest.

From the total treatments implemented in the simple plot design, the first treatment was potato planting as a farmers' practice where the ridge and early land cover are expected as functioning as soil and water conservation practice as compared to faba bean and maize prlanting as a farmers' practice; the other four treatments were no-tillage (NT) combined with 30% stubble retention or mulching (M) and intercropping(In), NT combined with M and rotation (R), conventional tillage (CT) combined with M and R, and farmers practice (CT) as mentioned in Table 1. During this experiment, the management of land in CA included no tillage leaving crop stubbles in the field and zero grazing. Other agronomic practices and fertilizations were the same for all plots, and the crop rotation was cereal by legume (pulse crops), i. e., maize and fababea except for the potato plot. Potato has different fertilizer and agronomic practices requirements.

Table 42. Experimental design and treatments description

Treatment		Description
T_1:	Potato	Conventional tillage
T_2:	NT + M + In	No tillage + Mulching (30%) + Intercropping
T_3:	NT + M + R	No tillage + Mulching (30%) + Rotation
T_4:	CT + M + R	Conventional tillage + Mulching (30%) + Rotation
T_5:	CT	Farmers' practice (conventional tillage)

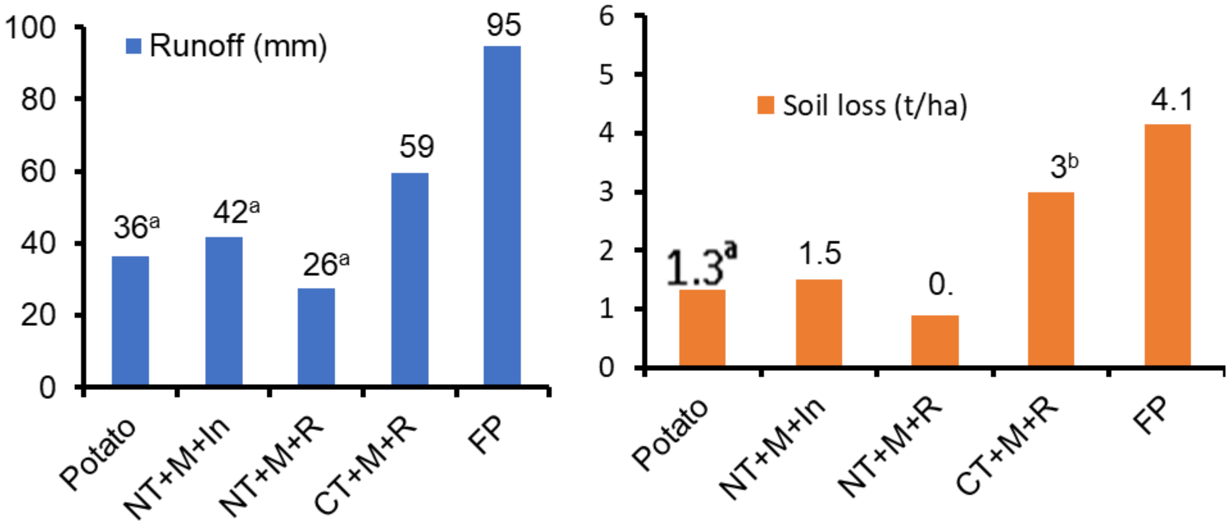
*Plot size: **10** m x 10 m (Adet on station); 5 m x 22 m at Debre Mawi

*Design: simple plot design

Regarding data collection, runoff and sediment were harvested using rectangular tanks which were installed at the end of each experimental plot; these data were recorded in every 24 hours of the day; then sediment data were oven-dried. Besides, crop agronomic data particularly grain yield (i.e., very important component of crop performance) and soil samples at 0-20cm soil depth (for pH, organic matter, bulk density and soil moisture analysis) were collected. Finally, the effects of treatments were compared, using analysis of variance and graphical presentation.

Results and discussion

The CA practices and conventional potato production were implemented for five and three cropping seasons at Adet on station and Debre Mawi watershed respectively. Except for the fixed potato plot, the other four plots were planted with maize and faba bean test crops in rotation. Runoff and soil loss showed responses to some treatments implemented during these years. It is confirmed that the first three treatments (Figure 1, 2) particularly treatments with no-tillage and potato plots are effective to reduce runoff and soil loss significantly as compared to farmers' practice. The conventional tillage combined with mulching and rotation is also better in runoff reduction than farmers’ practice due to the mulching effect (Figure 1). Such effectiveness of CA on runoff and soil loss reduction is supported by different studies such as Ghosh et al. (2015) and Araya et al. (2011). This effect is primarily due to no-tillage that leaves the soil undisturbed (Khursheed et al., 2019; Seitz et al., 2019). It is also confirmed that mulching reduces runoff and soil loss by enhancing infiltration of rainfall with an efficient mulch application found to be 0.25–0.50 kg/m^2 (Adekalu, et al., 2007; Mannering and Meyer, 1963; Kavian, et al., 2020; Wang et al., 2021).



** CV (%): 38.6; LSD (5%): 26.9*

** CV (%): 46.4; LSD (5%): 1.3*

Figure 25. Effect of CA practices on 2016 to 2020 average runoff and soil loss at Adet on station

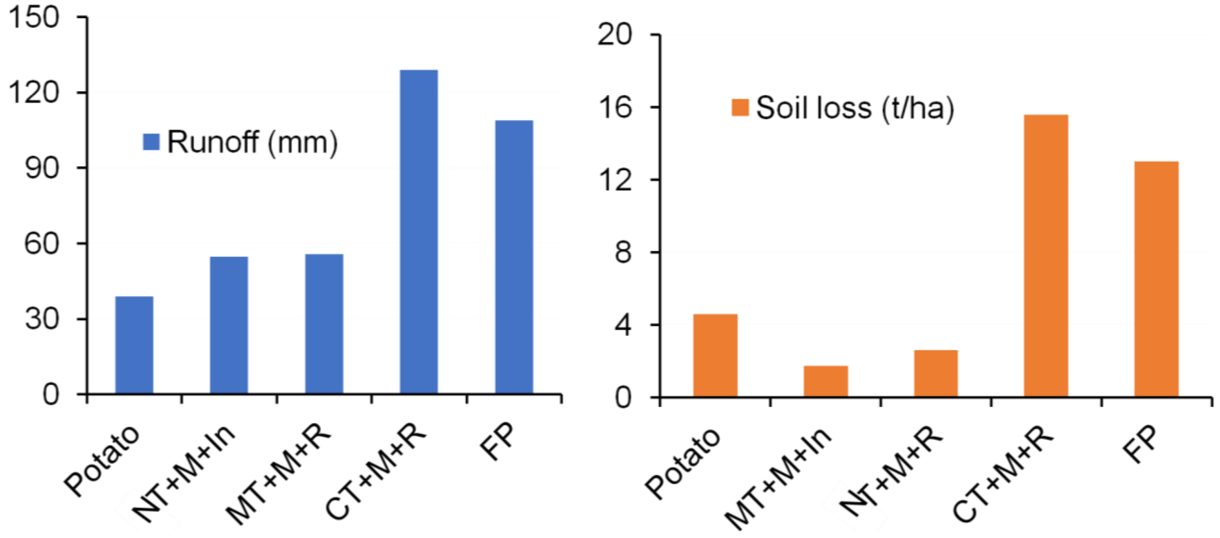


Figure 26. Effect of CA practices on 2018 to 2020 average runoff and soil loss at Debre Mawi watershed

Unlike runoff and soil loss, a significant difference was not observed in crop yield in this a short-term study. However, NT+M+R and CT+M+R show some maize and faba bean yield advantages as compared to farmers' practices. As compared to local practices, NT+M+R improves maize yield by 1.4 and 0.3 t/ha at Adet and Debre Mawi respectively (Figure 3-4 A) and faba bean yield by 0.6 ton/ha both at Adet and Debre Mawi (Figure 3-4 B). Whereas CT+M+R improves maize yield by 2 and 0.7 ton/ha at Adet and Debre Mawi respectively (Figure 3-4 A), and faba bean yield by 0.6 and 0.1 ton/ha at Adet and Debre Mawi (Figure 3-4 B). In this study, the farmer's practice was better than one of the CA practices (i.e., NT+M+IN) in maize and faba bean yield except in maize yield at Adet.

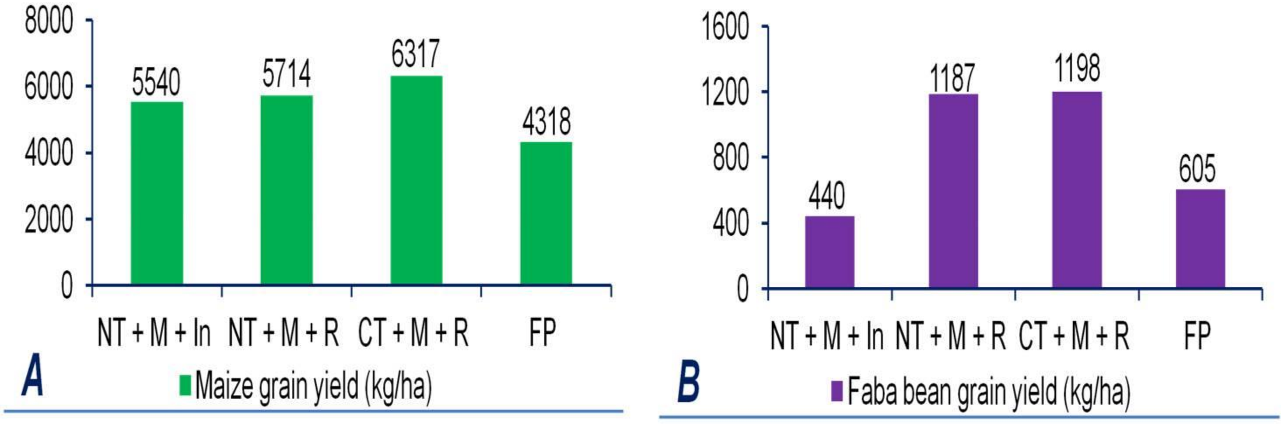


Figure 27. Average grain yield at Adet; A: Maize grain yield in kg/ha during 2017 and 2019; B: Faba bean during 2018 and 2020

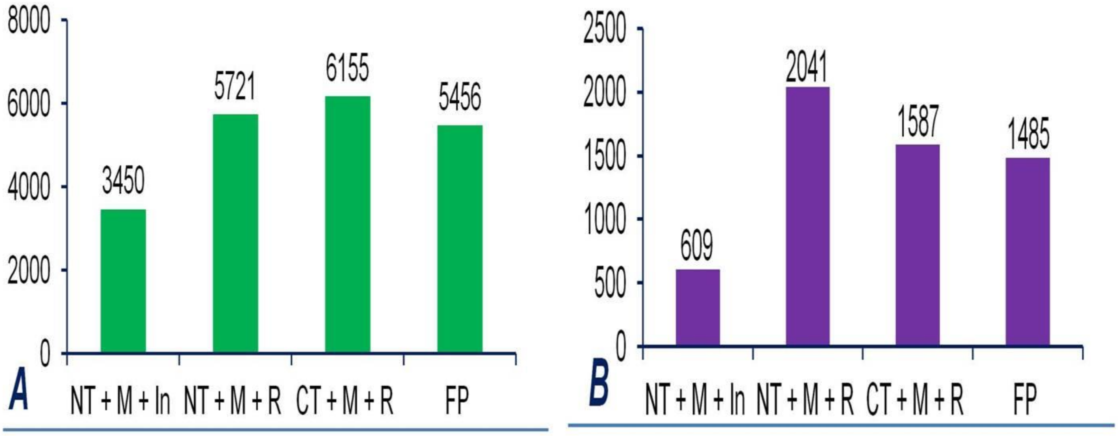


Figure 28. Average grain yield at Debre Mawi; A: Maize grain yield in kg/ha in 2019; B: Faba bean during 2018 and 2020

Similar to crop yield there was no significant difference in soil parameters including pH, organic matter (OM) and bulk density (Table 2).

Table 43. Soil chemical and physical properties (2018-2020 average values)

Treatment	**pH (Adet)**	**%OM (Adet)**	**Bulk density, g cm^{-3} (Adet)**
Potato	5.2	2.5	1.19
NT + M + In	5.5	3.0	1.30
NT + M + R	5.5	2.8	1.35
CT + M + R	5.4	2.6	1.27
FP	5.4	2.4	1.25
Treatment	pH (Debre Mawi)	%OM (Debre Mawi)	Bulk density, g cm^{-3} (Debre Mawi)
Potato	5.5	2.0	1.31
NT + M + In	5.5	2.0	1.27
NT + M + R	5.6	2.2	1.20
CT + M + R	5.6	2.0	1.27
CT	5.7	2.4	1.31

Conclusion and recommendation

This study confirms that conservation agriculture especially with an element of no-tillage is effective land management practice for a short period to reduce runoff and soil loss, in water-induced soil erosion-prone areas such as in Yilmana Densa district and other similar regions of the world. Rearding potato conventional farming treatment, the reasearch confirmed that in soil erosion-prone areas where potato, maize and faba bean are major crops, potato conventional production is preferable instead of maize ana faba bean conventional production to minimize runoff and soil loss. .Therefore these practices are recommended to be used by smallholder farmers to enhance soil and water conservation where soil erosion by water is severe. However, a long-term observation is important to determine the effect of other CA practices on soil properties and grain yield.

References

Adekalu, K. O., Olorunfemi, I. A. and J.A.Osunbitan,J. A. 2007. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. *Bioresource Technology*, 98, 4, pp. 912-917.

Amini, S. and Asoodar, M. A. 2015. Investigation the effect of conservation tillage on soil organic matter (SOM) and soil organic carbon (SOC) (the review). *New York science journal*, 8(3): 16-24.

Araya, T., Cornelis, W. M., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D., Sayre, K. D., Haile, M. and Deckers, J. 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use and Management, September 2011, 27, 404–414, doi: 10.1111/j.1475-2743.2011.00347.x.

Blum, W. E. H. 2013. Soil and land resources for agricultural production: General trends and future scenarios-A worldwide perspective. *International Soil and Water Conservation Research*, Vol.1, No.3, pp.1-14.

Fuhrer, J and Chervet, A. 2015. No-tillage: long-term benefits for yield stability in a more variable climate? *Procedia environmental sciences*, 29: 194 – 195.

Ghosh, B. N., Dogra, P., Sharma, N. K., Bhattacharyya, R. and Mishra, P. K. 2015. Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas. International *SoilandWater Conservation Research*, 3(2015)112–118.

Gomiero, T. 2016. Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. *Sustainability*, 8, 281; doi:10.3390/su8030281.

González-Sánchez, E. J., Kassam, A. Basch, G. Streit, B., Holgado-Cabrera, A. and Triviño-Tarradas, P. 2016. Conservation Agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe. *AIMS Agriculture and Food*, 1(4): 387-408, DOI: 10.3934/agrfood.2016.4.387.

Issaka, S. and Ashraf, M. A. 2017. Impact of soil erosion and degradation on water quality: a review. *Geology, Ecology, and Landscapes,* 1:1, 1-11, DOI:10.1080/24749508.2017.1301053.

Kavian, A., Kalehhouei, M., Gholami,L., Jafarian, Z., Mohammadi, M. and Rodrigo-Comino, J. 2020. The Use of Straw Mulches to Mitigate Soil Erosion under Di_erent Antecedent Soil Moistures. *Water* **2020**, 12, 2518; doi:10.3390/w12092518.

Khursheed, S., Simmons, C., Wani, S. A., Tahir Ali, T., Raina, S. K and Najar, G. R. 2019. Conservation tillage: impacts on soil physical conditions–an overview. *Adv Plants Agric Res.* 2019;9(2):342–346.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna. B. A. and Lombi, E. 2019. Soil and the intensification of agriculture for global food security. *Environment International*, 132 (2019) 10507.

Mannering, J. V. and Meyer, L.D. 1963. The Effects of Various Rates of Surface Mulch on Infiltration and Erosion. *Soil science society America journal*, 27, 1, 84-86.

Page, K. L., Dang, Y. P. and Dalal, R. C. 2020. The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Front. Sustain. Food Syst. 4:31.doi: 10.3389/fsufs.2020.00031.*

Rusinamhodzi, L., Corbeels, M., van Wijk, M. T., Rufino, M. C., Nyamangara, J. and Giller, K. E. 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy Sust. Developm*. DOI 10.1007/s13593-011-0040-2.

Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., van der Heijden, M. G. A. and Scholten, T. 2019. Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development* (2019) 39: 4. https://doi.org/10.1007/s13593-018-0545-z.

Shokati, B. and Ahangar, A. G. 2014. Effect of conservation tillage on soil fertility factors: A review. *International journal of biosciences*, 4(11):149-156.

Struik, P. C. and Kuyper, T. W. 2017. Sustainable intensification in agriculture: the richer shade of green. A review. Agron. *Sustain. Dev*., (2017) 37: 39. DOI 10.1007/s13593-017-0445-7.

Wang, B., Niu, J., Berndtsson, R., Zhang, L., Chen,X., Li, X. and Zhu, Z. 2021. Efficient organic mulch thickness for soil and water conservation in urban areas. www.nature.com/scientificreports.

Wijewardene, R. 1979. Systems and energy in tropical small holder farming. In Proc. Appropriate tillage workshop (pp. 73-86). Zaria, Nigeria: IAR.

Comparative evaluation of conservation agriculture and other management practices to improve the productivity of Vertisols in the Amhara region

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Abstract

The vast potential of Vertisols in the study area is underutilized due to excess soil water content. Conservation agriculture integrated with Vertisols drainage have a pronounced positive role to improve crop yield under high rainfall areas. This study aimed to evaluate the effects of conservation agriculture (CA) and Vertisols drainage on the productivity of sorghum and sesame. The study was conducted in Metema experimental station and it has three replications with six treatments of a permanent raised bed with minimum tillage (PRB+MT), permanent raised bed with minimum tillage and mulch (PRB+MT+M), broad bed furrow (BBF), flatbed with minimum tillage and mulch (Flat+MT+M), flatbed with minimum tillage (Flat+MT) and control. Melkam and Abassina varieties were used for sorghum and sesame respectively while the recommended agronomic practices were applied equally to all treatments. The results showed that the highest sorghum and sesame grain yields were obtained from plots treated with PRB+MT+M and BBF respectively. These excess soil water drainage techniques were able to improve the yield of sesame by 46.20 % and sorghum in the range of 20-39.74 %. On the other hand, the lowest grain yield and relatively highest soil moisture (43.87%) were observed at the plots treated with farmers' practices and flatbeds. Whereas, the soil moisture contents were significantly different between treatments, while the lowest mean soil moisture content (38.69 %) was obtained at BBF. Therefore, Vertisols-dominated fields should be treated with PRB with minimum soil disturbance and BBF to enhance sorghum and sesame production, respectively. Indeed, soil nutrients were not improved significantly within three years of experiments. Hence, to identify the most efficient Vertisols management technique that helps to improve soil quality long-term Vertisols management is required.

Keywords: Drainage; Sesame; Soil Moisture; Sorghum; Waterlogging

Introduction

Vertisols have crucial importance for improving and sustaining food production in Ethiopia (Wubie, 2015). The advantages of Vertisols are their good chemical fertility and occurrence in extensive flatland making it easy for reclamation and mechanical cultivation. However, they are not easy to cultivate due to their poor internal drainage and waterlogging during the wet season and are hard to cultivate during the dry season (Debele & Deressa, 2016; Rutherford, 2008; Wubie, 2015). In Ethiopia, the tremendous potential of Vertisols for crop production is severely constrained because of excessive soil water leading to yield reduction (Gebrehiwot, 2018). The problem of Vertisols is believed to be emanated from the intensity of seedbed preparation and the grazing practices in wet conditions. These practices are supposed to cause compaction and pan formation that hinder hydrological conductivity and create perched water on the surface which usually leads to waterlogging.

Likewise, the study area mostly situated as a flatland with the vast potential of Vertisols is underutilized because of excess soil water and conventional tillage. The above-mentioned challenges could be tackled through conservation agriculture (CA). CA includes minimum soil disturbance, permanent soil cover, and crop rotation to increase productivity by improving soil quality (Busari *et al*., 2015; Rusinamhodzi et al., 2011). In the study area, sorghum, cotton, and sesame have been produced for a long time conventionally with limited farm inputs. To maximize crop production there have been Vertisol management practices and technologies developed by research institutions in Ethiopia. Of the technologies so far released for the extension system, the popular BBF, camber bed maker, raised bed system and some other known traditional methods are some to mention.

The research conducted by Latham, Ahn, and Elliott (1987) showed that preparing broad beds and furrows (BBF) and raised beds (RB) with shallow ditches in between them on Vertisol, increased the grain and straw yields of the crops dramatically. However, there are few success stories in the adoption of Vertisol management technologies by small-scale farmers due to the lack of compatibility of the technologies with the farmers' socio-economic conditions (Debele & Deressa, 2016). Therefore, it is high time to test and amend alternatives to existing various technologies and other experiences from around the world for their effectiveness and ease of use by the farmers.

Hence, the amendments of excess soil water drainage techniques and CA with stable retention are required to improve Vertisols' productivity. CA reduces the energy (fuel for machines and calories for humans and animals) and time required. There is also greater production of biomass in a system with cover crops and zero or reduced tillage compared to conventional tillage. In this way, organic matter can be built up in the soil, which has a great influence on the activity and the population of the micro-organisms. It is believed that such kinds of research should receive high priority because of the vast underutilized potential of Vertisols for crop production. Therefore, the objective of this study is to evaluate the effectiveness of CA and drainage techniques on the productivity of major crops in the northwestern lowlands.

Materials and methods

The study was conducted at Metema experimental station in the northwestern lowlands of the Amhara region in Ethiopia, which is geographically located between 12º 17' 31" to 13º 5' 40" N latitude and 36º 0' 15" to 36º 46' 30" E longitude (Figure 1). The experiment was conducted in 2017, 2018 and 2019 cropping seasons with sorghum-sesame-sorghum rotation. The test crop varieties were Melkam for sorghum and Abasina for sesame. The recommended fertilization for sorghum (100 NPS kg/ha and 150 kg/ha urea) and sesame (65 kg/ha urea) were applied. The experiment, which has six treatments, was laid out in a randomized complete block design (RCBD) with three replications and a 5m length by 4m width plot size. The spacings between plots and blocks were 1.5m and 1.8m respectively.

The spacing between plants and rows for sorghum was 15 and 75cm respectively whereas, the spacing between plants and rows for sesame were 10 and 40cm respectively. Different drainage techniques and flatbeds with stable retention and minimum soil disturbance were compared with local practice. Among the drainage methods, a permanently raised bed (PRB) and broad bed furrow (BBF) were used to drain excess water. Approximately 30 % of crop residue was left at harvest on permanently raised beds and flatbeds with minimum soil disturbance.

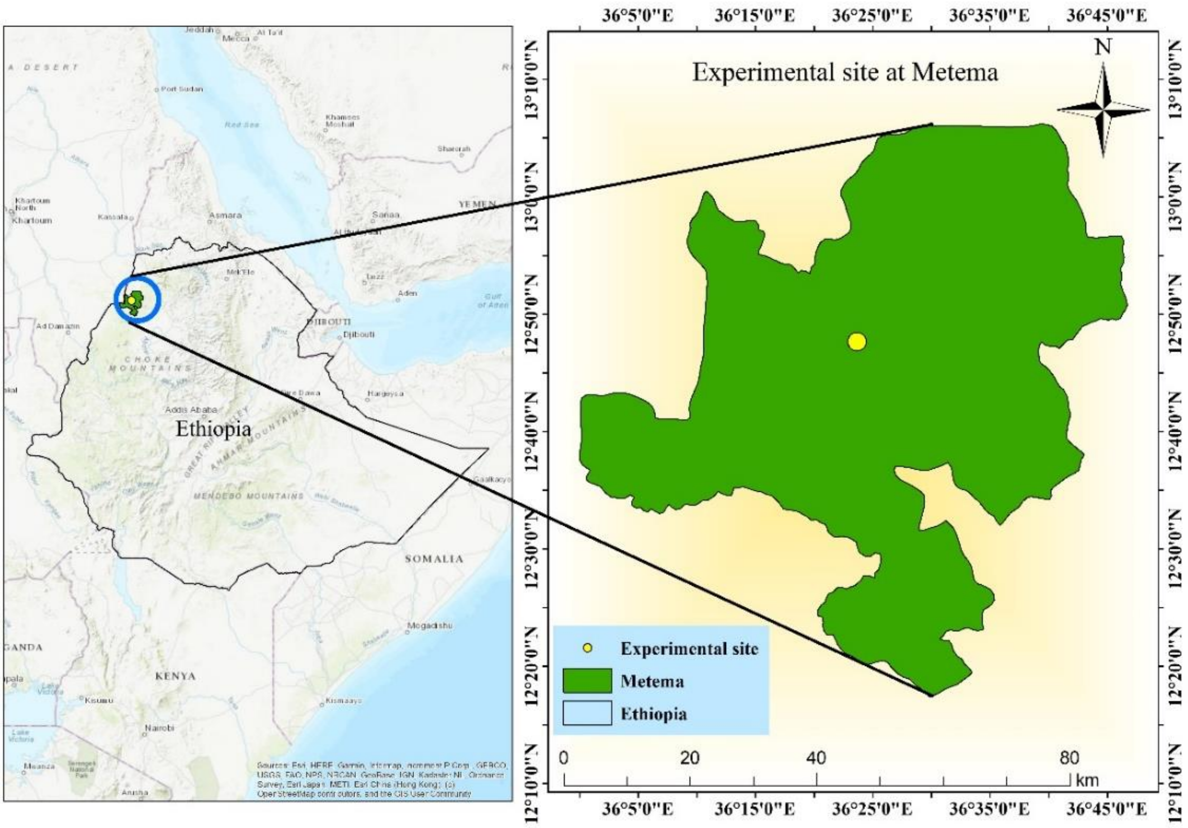

Figure 1. Location of the study area

Soil samples were collected from a depth of 0-20 cm to determine the physicochemical properties of the soil. Whereas, the soil moisture data were collected within two weeks intervals throughout the growing season. Soil moisture content was determined using the gravimetric method by measuring initial weight and oven-dried weight at 105^0C for 24 hours and is defined as the ratio of the mass of water-held soil to the dried soil (Klute, *et al*., 1986). Finally, the biological and soil data were analyzed using SAS software and an excel spreadsheet while the means were compared using mean separation by LSD.

Result and discussion

The results in (Figure 2) showed that the soil moisture contents were significantly different among treatments where the lowest soil moisture result was obtained at BBF as compared to the other treatments. It could be because of the timely and orderly removal of excess water using BBF to improve the growing conditions of the crop. Excess water drainage helps to minimize the soil water content in the root zones of the plant and thereby crop yield is enhanced significantly. Similarly, Debele and Deressa (2016), reported as BBF performed best in both excess rain and dry spells. It may be due to the provision of effective drainage during excess rains and it serves as in-situ moisture conservation during dry spells (Ertiban *et* *al*., 2017; Verma *et al*., 2017). Whereas, the highest soil water contents were recorded from local practice and flatbeds without stable retention that was supposed to cause compaction and excess soil water under high rainfall conditions.

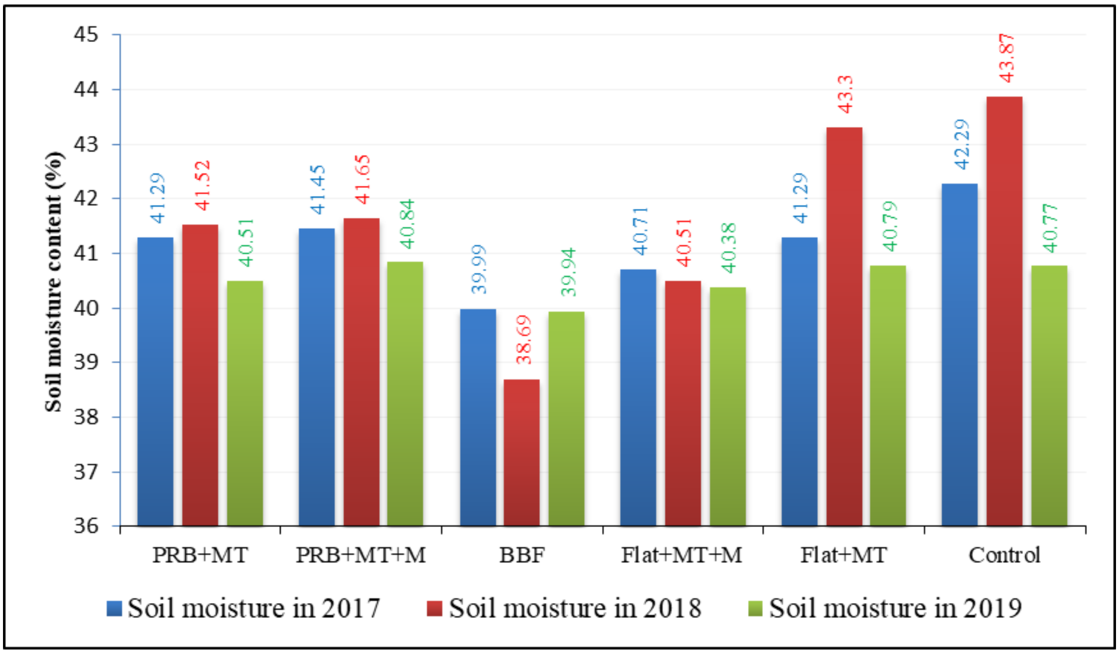

Figure 2. The mean growing season soil water contents for the experimental years

In this research, the soil's physical and chemical properties were not significantly varied among treatments except bulk density and organic carbon in the 2018 and 2019 experimental years respectively. The results of organic carbon and bulk density were numerically improved compared with the results of the initial year (2017). Generally, in this study, the treatment variation on soil nutrients was not consistent across the experimental years. Several scholars argued that nutrients and crop yield improvement could be enhanced by long-term Vertisols management using CA practices (Pathak *et al*., 2011). This may require longer-term and more data monitoring to identify the effectiveness of CA on soil quality improvement.

Table 1. Soil physical and chemical properties

Years	Treatments	pH (H2O)	Available P /ppm	O.C %	CEC (cmol/kg)	Ex. K (cmol (+)/kg)	Bulk density (g/cm^3)
2017	Initial	6.940	2.830	1.200	79.850	0.400	1.32
	PRB+MT	7.040	6.716	1.799	62.188	0.342	1.23
	PRB+MT+M	6.980	5.264	1.717	65.741	0.383	1.26
	BBF	6.750	8.168	1.759	65.398	0.356	1.25
	Flat+MT+M	7.240	5.324	1.636	62.916	0.342	1.32
	Flat +MT	7.040	5.506	1.718	63.044	0.315	1.34
	control	6.700	6.111	1.677	61.118	0.342	1.33
2018	PRB+MT	7.170	3.254	1.294	78.873	0.571	1.12^{b}
	PRB+MT+M	7.133	2.868	1.363	78.338	0.516	1.16^{ab}
	BBF	7.127	3.132	1.475	78.317	0.526	1.17^{ab}
	Flat+MT+M	7.303	3.254	1.349	81.313	0.621	1.19^{ab}
	Flat +MT	6.943	1.649	1.363	77.732	0.511	1.26^{a}
	control	6.860	3.030	1.391	80.828	0.516	1.29^{a}
2019	PRB+MT	6.740	2.347	1.373^{ab}	72.060	0.437	1.03
	PRB+MT+M	6.823	3.417	1.280^{bc}	71.067	0.453	1.02
	BBF	6.820	1.953	1.223^{c}	70.463	0.440	1.14
	Flat+MT+M	6.880	1.593	1.250^{c}	69.937	0.443	1.07
	Flat +MT	7.073	2.010	1.213^{c}	68.787	0.400	1.03
	control	7.097	1.650	1.393^{a}	70.157	0.387	1.10

The CA practice, i.e., the combination of the permanent raised bed, minimum tillage and stable retention, PRB+MT+M resulted in the significantly highest sorghum grain yield similarly in 2017 and 2019 (Table 2). Sorghum grain yield was improved by 20 to 39.74% as a result of CA compared with conventional practice in 2017 and 2019 respectively. This yield improvement could be related to timely removals of excess water, minimum soil disturbance and crop residue retention. Whereas, the reasons that caused the lowest grain yield obtained from the local practice, were supposed to be compaction and excess soil water resulting in restricted air and water movements in the root zones of Vertisols (Abera, Beshir, & Liben, 2020; Liben et al., 2018).

Table 2. Yield and yield components of sorghum for 2017 and 2019 experimental years

Treatments	Plant Height (cm)		Head length (cm)		Biomass (ton/ha)		Grain yield (ton/ha)	
	2017	2019	2017	2019	2017	2019	2017	2019
PRB+MT	183.33^{a}	190.66	31.90^{a}	27.03	24.19^{a}	23.70^{a}	5.42^{ab}	4.51^{ab}
PRB+MT+M	184.10^{a}	192.33	29.67^{ab}	26.73	27.13^{a}	23.90^{a}	5.62^{a}	5.29^{a}
BBF	173.70^{a}	190.67	30.40^{ab}	26.97	26.69^{a}	20.13^{b}	5.06^{bc}	4.23^{bc}
Flat+MT+M	177.73^{a}	191.33	28.47^{bc}	25.77	24.27^{a}	23.40^{ab}	4.88^{c}	5.13^{ab}
Flat +MT	161.90^{b}	192.66	27.40^{cd}	27.43	19.63^{b}	23.43^{ab}	4.76^{c}	4.91^{abc}
control	172.73^{ab}	196.33	26.90^{d}	28.00	18.38^{b}	22.77^{ab}	3.95^{d}	4.16^{c}
CV (%)	3.59	2.9	4.39	6.70	8.52	8.41	9.84	10.86
LSD(0.05)	11.46	10.16	2.35	3.29	3.55	3.5	0.44	0.93

** Note: PRB+MT is a permanent raised bed with minimum tillage, PRB+MT+M is a permanent raised bed with minimum tillage and mulch, BBF is broad bed furrow, Flat+MT+M is flatbed with minimum tillage and mulch, Flat+MT is flatbed with minimum tillage, BM is biomass, GY is grain yield.*

Sorghum provides optimum grain yield under deep, fertile, and well-drained soils and is relatively drought tolerant than soil with excess water. In drainage problematic soils, it is obvious that soil water status stays above field capacity after effective rainfall (Ertiban *et al*., 2017). The plant parameter result showed that the highest plant height and head length were obtained in 2017 from CA treatments compared with the flat and control beds. Similarly, the biomass yield in the two experimental years was significantly different between treatments while the highest biomass (27.13 t/ha) was recorded in PRB+MT+M. The results showed that the yield parameters are attributed to grain yield as explained in (Table 2). Generally, the highest grain yield of sorghum in CA plots was supported by the results of plant height, head length and biomass (Table 2).

Figure 2. Field performances of sorghum at different growing stages

Table 3 revealed that the grain yield, biomass, bearing zone height, and the number of branches of sesame were significantly higher because of BBF than sesame yields produced by other treatments. The results confirmed that excess water drainage through BBF improved sesame productivity by 46.20% compared with local practice while the recommended agronomic practices and variety were the same for all treatments. Similarly, Sarkar *et al.* (2016) found that 51.67-58.24% sesame yield losses were observed due to 36 hours of waterlogging and suggested removing the standing water from the field as early as possible to avoid drastic yield loss from excess soil water. Aslam et al. (2015), also reported as maximum grain yield was obtained from beds (843 kg ha^{-1}) followed by ridge planting (811 kg ha^{-1}) than the conventional method (349 kg ha^{-1}). Whereas, Agegnehu and Sinebo (2012), found that BBF and ridge and furrow (RF) increased the chickpea yield by an average of 45% over the flatbed.

Table 3. Yield and yield-related components of sesame (2018)

Treatments	Bearing zone height (cm)	Number of branches	Biomass (ton ha^{-1})	GY (kg ha^{-1})
PRB+MT	65.53^{ab}	4.23^{bc}	5.63^{ab}	1044.31^{b}
PRB+MT+M	64.07^{abc}	4.27^{b}	5.7^{ab}	1014.35^{b}
BBF	71.87^{a}	4.97^{a}	6.59^{a}	1138.52^{a}
Flat +MT + M	52.20^{d}	$4.17b^{cd}$	5.48^{ab}	823.73^{c}
Flat +MT	55.13^{cd}	3.87^{d}	4.81^{bc}	825.35^{c}
Control	$56.80b^{cd}$	3.90^{cd}	3.35^{c}	778.77^{c}
CV (%)	8.25	4.46	17.98	7.95
LSD (0.05)	9.14	0.35	1.72	84.38

Meanwhile, the lowest sesame grain yield was obtained from local practices and flatbeds compared with other treatments that may be related to excess soil water content. Sesame is considered a drought-tolerant oil crop and is typically susceptible to harmful effects of waterlogging that is detrimental to crop survival and grain yield (Dossa *et al*., 2019; Sarkar *et al*., 2016; Terefe et al., 2012). A few hours of waterlogging (lasting over 36 hours) are detrimental to crop growth, yield, and survival (Dossa *et al*., 2019). According to Sharaby and Butovchenko (2019), the ideal soil for sesame cultivation is characterized by good drainage, is well-ventilated, and is highly fertile to maximize crop yield.

Figure 3. Field performance of sesame at different growth stages

Generally, most plant parameters and grain yields for sorghum and sesame were significantly highest from PRB+MT+M and BBF respectively. PRB+MT+M and BBF allow the water to drain away from the plant root zone and help to reduce the adverse effects of excess soil water. That is why the highest grain yield was obtained at the lowest soil moisture content resulting in timely removals of excess water from the root zone. The results of this study showed that excess soil water drainage has a positive impact on yield and yield-related parameters of sorghum and sesame. However, the soil's physical and chemical properties were not significantly improved. Hence, a long-term study of conservation agriculture is needed to identify the effectiveness of the technologies on soil quality improvement.

Conclusion

The study aimed to evaluate the effectiveness of various drainage techniques integrated with conservation agriculture. It was conducted for the last three years (2017-2019) as a rotation of sorghum-sesame-sorghum. The results of this study showed that sorghum production was significantly varied between treatments while the highest yield was obtained from PRB+MT+M. Based on the results of two experimental years the grain yield of sorghum was improved by 20 to 39.74% compared with local practice. On the other hand, sesame production was enhanced by 46.20 % as a result of surface water drainage using BBF technology while the recommended agronomic practices and variety were the same for all treatments. Meanwhile, the highest grain yield (1138.52 kg ha^{-1}) and the lowest mean value of soil moisture (38.69 %) were obtained at BBF than other treatments. Whereas, the lowest grain yield (778.77 kg ha^{-1}) and relatively highest soil moisture (43.87%) were observed at the farmers' practice. The negative relationship between grain yield and soil moisture confirmed that surface drainage has a significant positive impact on crop production enhancement under high rainfall conditions. However, the soil properties were not improved significantly among treatments which may be due to the short duration. Generally, to enhance sorghum and sesame production preparation of raised beds with minimum soil disturbance and broad bed furrow should be considered accordingly. Furthermore, to identify the most efficient Vertisols management technique that helps to improve soil quality, long-term Vertisols management is required.

References

Abera, D., Beshir, B., & Liben, F. M. (2020). The Role of Conservation Agriculture for Soil Quality Improvement: A Review. *Ethiopian Journal of Agricultural Sciences, 30*(4), 197-222.

Agegnehu, G., & Sinebo, W. (2012). Drainage, sowing date and variety effects on chickpea grown on a Vertisol in Ethiopia. *Archives of Agronomy and Soil Science, 58*(1), 101-113.

Aslam, M., Nasrullah, H., Akhtar, M., Ali, B., Akram, M., Nawaz, H., & Javeed, H. (2015). Role of different planting techniques in improving the water logging tolerance and productivity of sesame (Sesamum indicum L.). *Bangladesh Journal of Scientific and Industrial Research, 50*(3), 193-198.

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research, 3*(2), 119-129.

Debele, T., & Deressa, H. (2016). Integrated Management of Vertisols for Crop Production in Ethiopia: A Review. *Journal of Biology, Agriculture and Healthcare. ISSN*, 2224-3208.

Dossa, K., You, J., Wang, L., Zhang, Y., Li, D., Zhou, R., . . . Jiang, S. (2019). Transcriptomic profiling of sesame during waterlogging and recovery. *Scientific data, 6*(1), 1-5.

Ertiban W , Muuz G , Sisay A, & Melkie D. (2017). Dry and Wet Spells and Ridging Tied-ridging of Vertisol Effect on SorghumYield and Soil Moisture Variability, North Gondar, Ethiopia. *Nile Water Science & Engineering, 10*(2).

Gebrehiwot, K. A. (2018). A review on waterlogging, salinization and drainage in Ethiopian irrigated agriculture. *Sustainable Water Resources Management, 4*(1), 55-62.

Klute, A., Page, A. L., Miller, R. H., & Keeney, D. R. (1986). *Methods of Soil Analysis: Physical and mineralogical methods*: American Society of Agronomy.

Latham, M., Ahn, P. M., & Elliott, C. R. (1987). *Management of vertisols under semi-arid conditions.* Paper presented at the Regional Seminar on the Management of Vertisols under Semi-Arid Conditions in Africa and Southwest Asia 1986: Nairobi, Kenya).

Liben, F., Tadesse, B., Tola, Y., Wortmann, C., Kim, H., & Mupangwa, W. (2018). Conservation agriculture effects on crop productivity and soil properties in Ethiopia. *Agronomy Journal, 110*(2), 758-767.

Pathak, P., Wani, S. P., & Sudi, R. R. (2011). Long-term effects of management systems on crop yield and soil physical properties of semi-arid tropics of Vertisols. *Agricultural Sciences, 2*(04), 435.

Rusinamhodzi, L., Corbeels, M., Van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for sustainable development, 31*(4), 657-673.

Rutherford, A. S. (2008). *Broad bed maker technology package innovations in Ethiopian farming systems: An ex post impact assessment*: ILRI (aka ILCA and ILRAD).

Sarkar, P., Khatun, A., & Singha, A. (2016). Effect of duration of water-logging on crop stand and yield of sesame. *International Journal of Innovation and Applied Studies, 14*(1), 1.

Sharaby, N., & Butovchenko, A. (2019). *Cultivation technology of sesame seeds and its production in the world and in Egypt.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

Terefe, G., Wakjira, A., Berhe, M., & Tadesse, H. (2012). Sesame production manual. *Ethiopia: Ethiopian Institute of Agricultural Research Embassy of the Kingdom of the Netherlands*.

Verma, P. Parmanand and Tamrakar S K. 2017. Effect of broad bed furrow method for rainfed soybean cultivation at Balodabazar district of Chhattisgarh. *International Journal of Agricultural Engineering, 10*(2), 297-301.

Wubie, A. A. (2015). Review on vertisol management for the improvement of crop productivity in Ethiopia. *Journal of Biology, Agriculture and Healthcare, 5*(12), 92-103.

Erosion spatial distribution mapping and sediment yield estimation using RUSLE and Arc GIS of Ayigebire watershed, North Shewa zone of Amhara region, Ethiopia

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Abstract

Soil erosion is the removal of the soil particle from its place of origin through the process of detachment, transport and deposition. Ethiopia is losing 1.5 billion tons of topsoil with an average rate of 22.3 tons ha^{-1} $yr^{-1.}$ *The loss of soil is affecting the economy by shortening the life of constructed dams and reservoirs through sedimentation. The Godebe soil dam, which was built by the Amhara water works construction organization in Menz Gera woreda for irrigation purposes, has a sedimentation issue. Therefore, the purpose of this study was to identify the catchment's "hotspot" area and to estimate the watershed's annual sediment yield as well as the rate at which soil is lost each year. To accomplish those goals, this study used both primary (soil sample) and secondary data (rainfall and satellite data for RUSLE parameter generation). The outcome shows that the watershed's average annual soil loss is 47 tons* ha^{-1} yr^{-1} *with a range of 0 to 288 tons* ha^{-1} yr^{-1}. *The land along the main drainage line is identified as an erosion hot spot area of the watershed which contributes about 76.6 % of soil loss from the total area. Additionally, it was determined that the watershed's sediment delivery ratio was 0.48. With this ratio, the Godebe soil dam received an annual average discharge of 10653.51 tons (8710m3) of sediment. Around 74575 tons (60969 m3) of sediment were transported and stored throughout the past seven years, beginning on the day the dam became operational for water harvesting. As a result of this finding, it is advised that the high sediment-producing areas along the river and the over cultivated land close to the inlet and side bank of the dam deserve considerable attention.*

Keywords: dams, delivery-ratio, Godebe, erosion, sediment yield, topsoil, yield

Introduction

Erosion is the removal of soil particles from their place of origin through the involvement of detachment, transport and deposition process of soil particles and aggregate (Kumar, et al. 2015). It is a universally recognized threat to human well-being. Erosion affects the productivity of the land by removing the uppermost fertile layer of the soil (Suresh 2012). The Ethiopian highland seriously affected by water erosion for a long time ago. While now a day its impact reaches a peak level along with more land cultivated to meet the need of the highly growing population (Hurni 1985). Ethiopia loses 1.5 billion tons of fertile topsoil from its highland area which can add 1-1.5 million tons of grain to the county's product (Taddese 2001). Specifically, (Desalegn, et al. 2018) reported that the soil loss of the central highland of the country ranges from 0-291 ton ha^{-1} yr^{-1} with an average of 22.3 ton ha^{-1} yr^{-1}. In the Ethiopian highland, the sediment mobilization from cultivated land causes serious land degradation (Guzman, et al. 2013). As it is difficult to quantify and mapping of soil loss in a traditional way most researchers commonly use the USLE (Wischmeier and Smith 1978), and RUSLE (Renard and Freimund 1994) empirical erosion models as predictive tools for hotspot area identification of the watershed.

Sedimentation is the process of settling down of the particles carried out by water while sediment yield is the total amount of eroded material delivered to the specific point under consideration (Suresh 2012). This is mainly dependent on soil loss rate and transportation mechanism (Kumar, et al. 2015). The fragmented soil particle and other materials transported by water, wind, and ice are deposited when the transporting agent dissipates its energy of transportation and when the slope becomes flat. The total eroded soil was not delivered to the dam. Some of the eroded soil is deposited on different parts of the catchment area and the other is directly delivered to the dam. The scholars develop the sediment transport efficiency which is called the sediment delivery ratio. It is defined as the amount of sediment detached and transported directly to the catchment outlet compared to the total amount of soil that is detached over the area of the catchment above the common outlet. The sediment delivery ratio is directly related to the catchment area (Vanoni 2006). Direct estimation of sediment yield is difficult due to its complexity (Kumar, et al. 2015). As the scholars reported (Vanoni 2006) sediment yield can be estimated using the correlation of sediment delivery ratio which has a direct relation with the watershed area and total soil loss of the watershed.

The delivery of sediment from its place of origin can have on-site and off-site effects. The sediment accumulation affects the reservoir's lifetime and water-holding capacity. In Ethiopia, many dams are constructed for domestic and irrigation purposes. On the other hand, the catchment area of the dam is also cultivated including a steep slope. This causes siltation is the main problem of the dam constructed in Ethiopia. Ayigebir watershed is ecologically not conserved. Most parts of it are covered by cultivated land without enough soil and water conservation practices. Due to this the soil depth, soil fertility and productivity have decreased from year to year even though a high amount of artificial fertilizer has been applied. There is an indicator on the land for the availability of sheet and rill erosion which are not easily detectable by farmers.

The study was conducted at the Ayigebire watershed which is one of the most erosion-susceptible watersheds in Menz Gera woreda. Most parts of the study watershed is covered by cultivated land which does have not enough soil and water conservation measure. Because of this reason, there are lots of erosion indicators such as sheet, rill and gully erosion. At the outlet of the study area, there is a soil dam that covers 12.67 ha from 484.9 ha of the watershed area which is called the Godebe soil dam. The dam was constructed by Amhara water works construction enterprise from 2010-2014. For four years and based on the information gained from Menz Gera Midir woreda agricultural office. The dam is installed for irrigation purposes for around 378 households on 68 ha of land. This dam faces severe siltation problems due to the high amount of soil erosion brought from the upper reaches of the watershed. So identification of erosion hot spot areas and estimation of yearly sediment yields of the watershed is essential to sustain the design life of the reservoir and for protection of the watershed, from severe erosion.

In this regard, this research aimed to locate areas of the watershed that produce the most sediment per year delivered to the dam and to quantify the amount of soil loss using the RUSLE model and Arc GIS software.

Materials and methods

Description of the study area

The study was conducted at the Ayigebire watershed which is located in the southern parts of the Amhara region of Ethiopia. The watershed is 152 km far away from Debre Birhan city which is the capital city of the north Shewa zone. The elevation of the study area varies from 3160-3437 meters above mean sea level and is located between 39^0 42' 40''to 39^0 45' 32''longitudes and 10^0 20'18" to 10^0 21' 14''latitudes geographical coordinate.

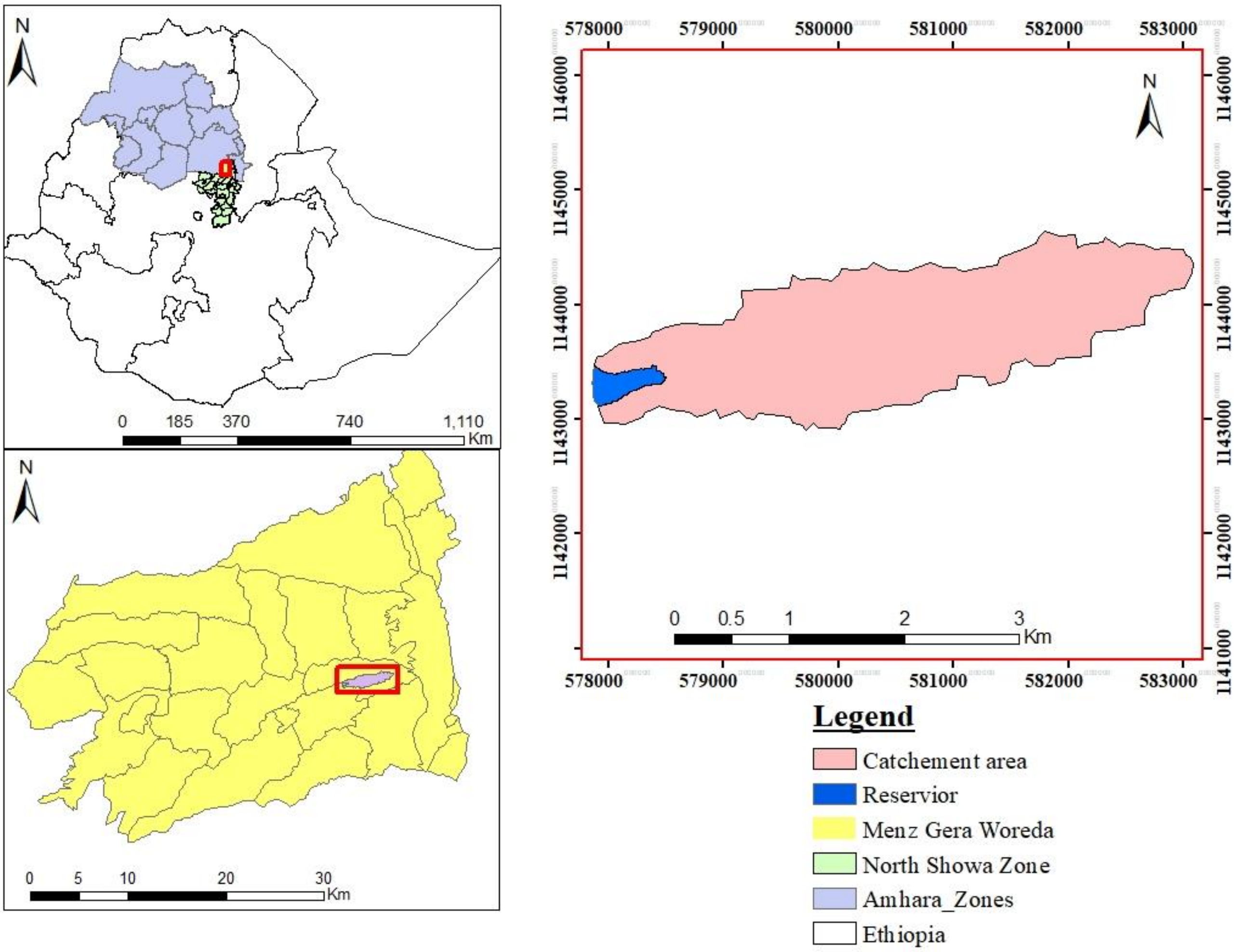

Figure 1: Location map of the study area

The region receives 923.2 mm of rain on average yearly. According to the rainfall statistics, the watershed has a bimodal rainfall distribution between the two crop seasons in 2016 and 2019 (Belg and main season). The main season was seen between July 2016 and August 2019, whereas the maximum rainfall record for the Belg season was observed between April 2016 and March 2019. The watershed's minimum and maximum average annual temperatures are 7.51 °C and 18.9 °C, respectively.

The watershed covers a 484.9 ha area. The dam (water body) covers 2.6% of the watershed with 79.8% cultivated land, 13.83% grassland, 2.14% bare land, 1.29% forest land and 0.23% bush land. The forest and bush lands are mainly covered with Eucalyptus globules and Asta (*Erica arborea* L. (Ericaceae) respectively.

About 38.4 percent of the watershed area has 10-20 % slope class followed by 19.2% and 17.5 % area coverage of the watershed exhibits 20-30 and 5-10 percent of slop class respectively. On the other hand, 30-50, 0-5 and >50 percent slop classes have 13.1, 6.9 and 4.9 percent of the area coverage of the watershed respectively.

Barley, Fababean, lentil and potato are the main crops produced within the watershed. Cultivation activity is mainly held in the main season (summer) and sometimes in the Belg season within the wurchi agro-ecology zones of the watershed which are located in the northeast parts of the watershed. In Belg season barley is the only crop produced in the watershed. Plowing frequency in the watershed varies depending on crop type; usually, it is three times for barley and two times for fababean and potato, but there is no plowing for lentil production before sowing. The main objective of plowing is to minimize weed population and improve soil aeration. About 55.5%, 26.7% and 17.8% portion of the watershed are dominated by Loamy, silt and Sandy soil textural class respectively.

Cattle, sheep, goat, donkey, hoarse and chicken are the main domestic animals reared in the study area. Crop residue, hay and natural grazing are the main sources of animal feed there.

Data collection and analysis

The secondary data (rainfall data and satellite images) were collected from different governmental and non-governmental organizations. On the other hand, a soil sample was collected for soil erodibility analysis; and consecutive field observations were carried out with the help of GPS to gather and generate information regarding the ground truth for image classification and accuracy assessment. Data analysis and processing were done by digitizing, classifying, calculating, and overlaying the necessary information of each thematic layer using GIS software. The conceptual framework followed during the life cycle of this study was illustrated in the chart (Fig. 2)

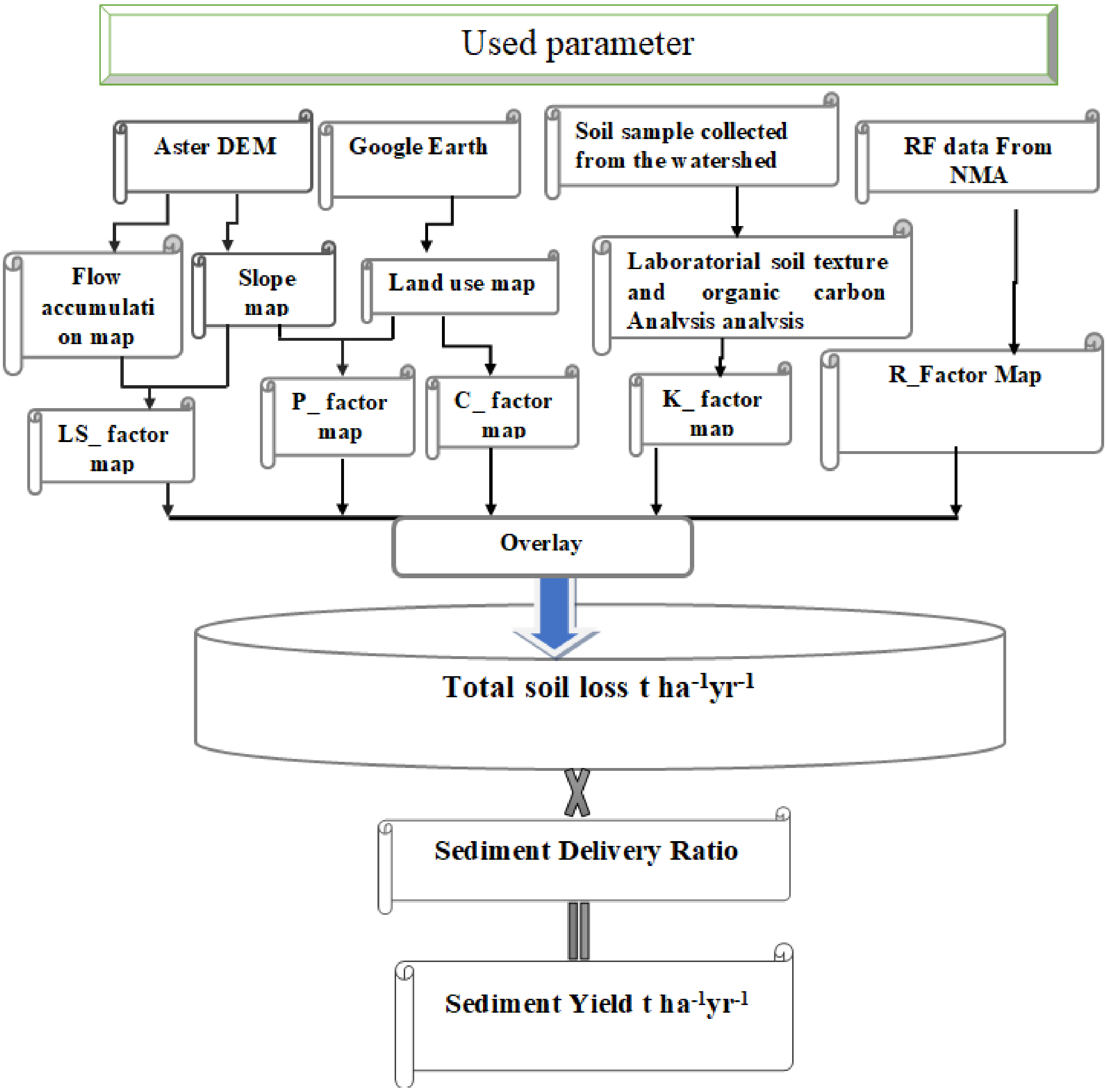

Figure 2: Conceptual framework chart of the study

Generation of RUSLE factors

The annual soil loss was calculated by overlying all six RUSLE factors in a raster format using a raster calculator in GIS software.

$$A = R * K * ls * C * P \quad (1)$$

Where, A = mean annual soil loss (tone ha^{-1} year^{-1}), R is rainfall erosivity factor, K is soil erodibility factor, ls is slope length and steepness factor, C is land use land cover factor, P is land management factor

Rainfall erosivity (R) Factor

The daily recorded rainfall data on the nearby station (7 km from the watershed) which were obtained from the east Amhara metrological information center were used to generate the rainfall erosivity factor (R-value). The daily rainfall data were summarized to get mean annual rainfall and then the rainfall erosivity factor was calculated using the formula adapted for Ethiopia (Hurni 1985).

$$R = -8.21+0.562*P \qquad (2)$$

Where R is the rainfall erosivity factor and P is the mean annual rainfall.

Soil erodibility (K) factor

Soil erodibility is more sensitive to soil texture and organic matter content because of its ability to govern the permeability, infiltration rate and structural stability of the soil (Suresh 2012). Based on land use and slope variability the watershed was divided into several strata. From all strata, 120 soil samples were collected. All sampling points were geo-referenced using handheld GPS. These representatives collected soil samples were delivered to the soil laboratory for soil texture (sand, silt, and clay) and organic carbon (OC) analysis. Depending on the soil texture and OC content of the soil K factor was calculated using the following equation (Williams 1975).

$$K_{USLE} = K_W = f_{csand} * f_{ci-si} * f_{orgc} * f_{hisand} \qquad (3)$$

Where: f_{csand} is a factor that lowers the K indicator in soils with high coarse sand content and higher for soils with little sand, f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios, f_{orgc} reduces K values in soils with high organic carbon content, while f_{hisand} lowers K values for soils with extremely high sand content:

Finally, a k-factor map of 20m resolution was developed using ordinary kriging interpolation

Slope length and steepness (ls) factor

The ls factor shows the effect of topography on erosion, which is proportional to the length and steepness of the slope. To get the ls factor ASTER DEM having a 20-meter resolution was processed in Arc Map to generate flow accumulation and slope gradient. Finally, the factor was computed using a raster calculator in Arc Map using the equation derived from Griffin, et al. (1988).

LS=POW [(flow accumulation) *cell size/22.1, 0.6] *pow [sin (slope)*0.01745/0.09, 1.3 (4)

Land use land cover (C) factor

The C factor is directly related to the land use land cover class of the study area. The land use map has been generated manually from Google earth. To avoid incorrect land use classification accuracy assessment was done by maximum likelihood algorism using recorded GPS points as a reference on each land use class in addition to a detailed field survey and the researcher gained 91.6% of the land use was accurately classified.

Finally, corresponding C-values were developed in a raster format having 20m resolution after assigned cover factor values for each land use class proposed by (Hurni 1985).

Management practice (P) factor

The p-factor was assigned using major land use and slope interaction adopted by(Wischmeier and Smith 1978).

Estimation of sediment delivery ratio

The sediment delivery ratio is the efficiency measurement of sediment transport of the watershed. All the detached soils are not transported to the outlet of the watershed; some of them are deposited near the eroding source. The sediment delivery ratio accounts for the amount of sediment delivered to the outlet compared to the total amount of soil that is detached throughout the watershed. In this research, the sediment delivery ratio and the total amount of sediment that was transported and reached from eroding sources to the reservoir were estimated using the relationship developed by (Mockus 1964).

$$S_{DR}=0.5656*Aw^{-0.11} \quad (5)$$

$$S_Y= S_{DR}*A \quad (6)$$

Where: $S_{DR=}$ sediment delivery ratio

Aw=Area of the watershed (km^2)

S_Y = Sediment Yield (t/ha/yr.)

A= soil loss (t/ha/yr.) obtained by the RUSLE model

Estimation of the total sediment in the dam

To estimate the volume of sediment stored in the dam converting the gained mass of the sediment into volume units by determining the bulk density of the sediment is the first step. But practically taking soil samples for bulk density analysis from the sediment stored within the dam is difficult. To overcome these challenge different scholars, develop different bulk density estimation methods of sediment stored within the dam based on the proportion of soil separates derived to the dam from their place of origin and their duration within the dam. Scholars state that the bulk densities of the deposits vary with the proportion of soil separates and type of reservoir operation (exposed or submerged sediment deposits) and the consolidation period (Rijn 2013). Based on data from reservoirs they derive an expression for the initial (at t=0) bulk density as:

$$\rho_{bulk}=p_{clay}\rho_{clay}+p_{silt}\rho_{silt}+p_{sand}\rho_{sand} \quad (7)$$

Where: p=percentages of clay, silt and sand in sediment deposits; but the values of ρclay, ρsilt, and ρsand are given in (Table 1.)

Table 1. The initial density of soil texture adopted from (Rijin, 2013)

Reservoir type	Initial(t=0)			Compacted after time t		
	ρ_{clay} (kg/m^3)	ρ_{silt} (kg/m^3)	ρ_{sand} (kg/m^3)	$\rho_{clay,initial;K}$ (kg/m^3)	$\rho_{silt,initial;K}$ (kg/m^3)	$\rho_{sand,initial;K}$ (kg/m^3)
Always submerged	415	1120	1550	480 K=255	1040 K=90	1550 K=0

After generating the initial bulk density of the sediment its bulk density after T years of compaction due to later deposits was also estimated using the following formula (Rijn 2013).

$$\rho_{bulk}=\rho_{initial}+K\log(T). \quad (8)$$

Where, ρ initial= initial bulk density, K= coefficient, T= time (years)

Standing from a yearly and cumulated bulk density of the sediment stored in the dam total sediment yield in metric tons was converted to the volume of soil in m^3 units. Finally, the volume of the dam occupied by sediment was evaluated.

Results and discussion

Result of RUSLE factors

Rainfall erosivity (R) Factor

The watershed's erosivity factor was found to be 483.3 MJ.ha^{-1}h^{-1}y^{-1}. Due to the similarity in the watershed's rainfall pattern, the erosivity factor is the same for all grids. The erosivity map of the watershed is illustrated in the (Figure 3).

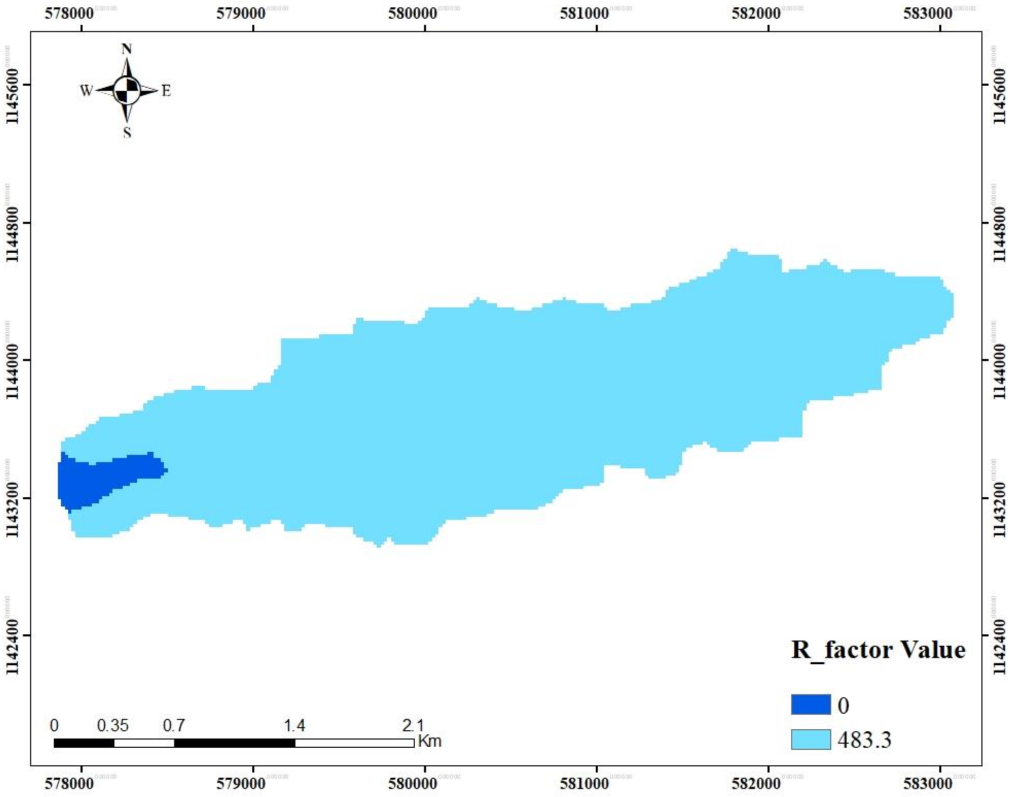

Figure 3: Rainfall erosivity factor map of the study watershed

Soil erodibility (K) factor

The soil of the study watershed has an organic carbon value between 0.6 and 3.1. The North-East side of the watershed produced the highest amount of soil organic carbon. The Guassa community protected area borders this side of the watershed; this might be the reason that this area of the watershed has soil with a loamy texture and high levels of organic carbon. The southwest side of the watershed, on the other hand, had a lower organic matter level. Compared to the North-East side of the watershed, this side is primarily used for agriculture and has sand-textured soil as its predominant soil type. The soil erodibility factor values for the watershed were developed after the spatial overlaying of the texture and organic carbon map of the watershed, and they were found to range from 0.123-0.190 according to equation 3. Although it has a clay texture soil, the northwest and southwest regions of the watershed have the highest soil erodibility due to their low organic carbon contents. In contrast, the watershed's western and eastern edges, where a dominating loam soil texture and a loam textured soil with high organic carbon content, had the lowest soil erodibility values.

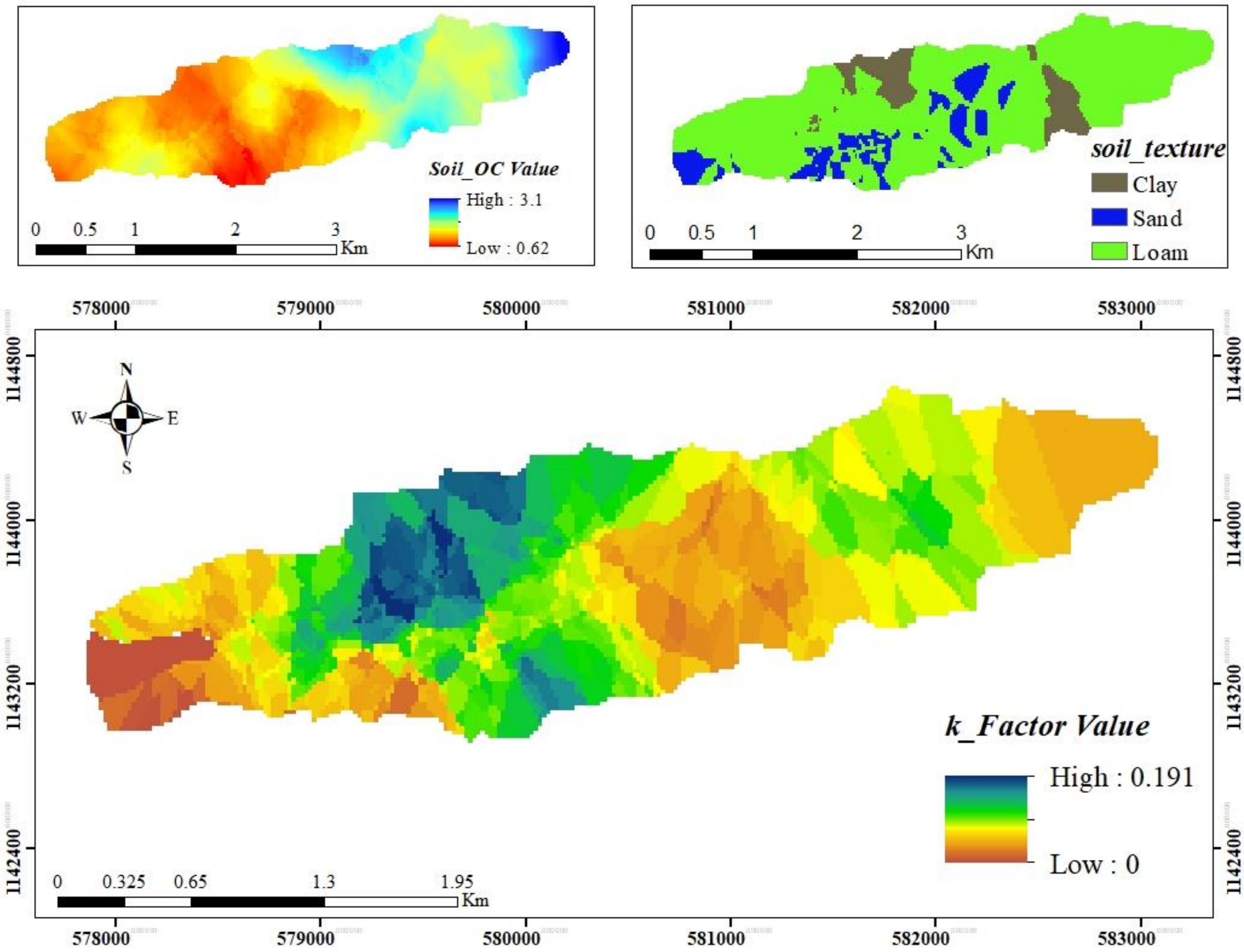

Figure 4: soil erodebility Factor Map

Slope gradient and length (ls) factor

Based on the equation 5, the ls factor of the watershed has a value ranging from 0- 29.5 was generated using watershed slope steepness and flow accumulation. The result shows that ls factor has mainly affected the western part of the watershed along the drainage line.

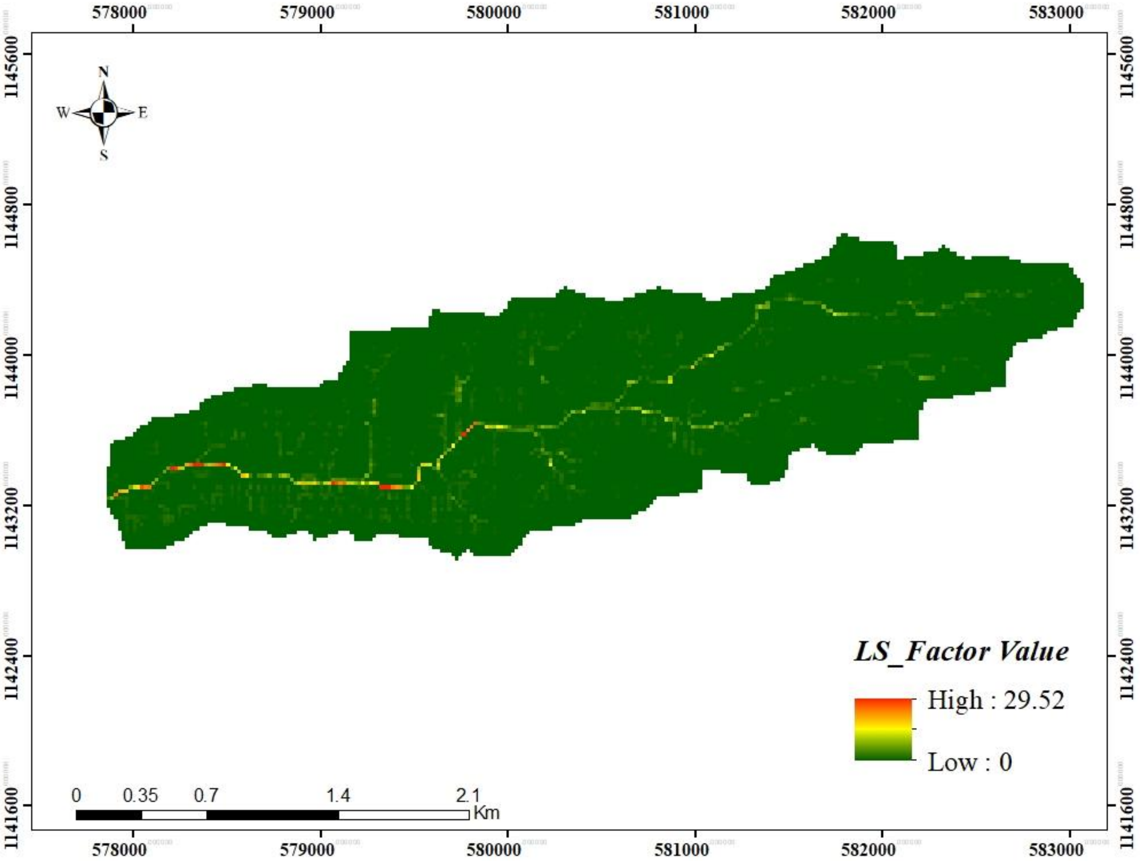

Figure 5: Slope steepness and length (ls) factor map

Land use land cover (C) factor

The study area was classified into six land use type using Google earth manually with the strong ground survey and the crop management factor assigned for each land type is presented in (Table 2).

Table 2: C-factor value of the watershed adopted from Hurni (1985)

Land use type	Area-ha	Coverage (%)	Corresponding C value
Cultivated land	386.97	79.8	0.15
Grassland	67.06	13.83	0.03
Reservoir	12.67	2.61	0
Bare land	10.38	2.14	0.05
Forest land	6.25	1.29	0.01
Bushland	1.55	0.32	0.01
Total area	484.9	100	

Based on the assigned crop cover factor value the C-factor map was generated to make it suitable for the final overlay.

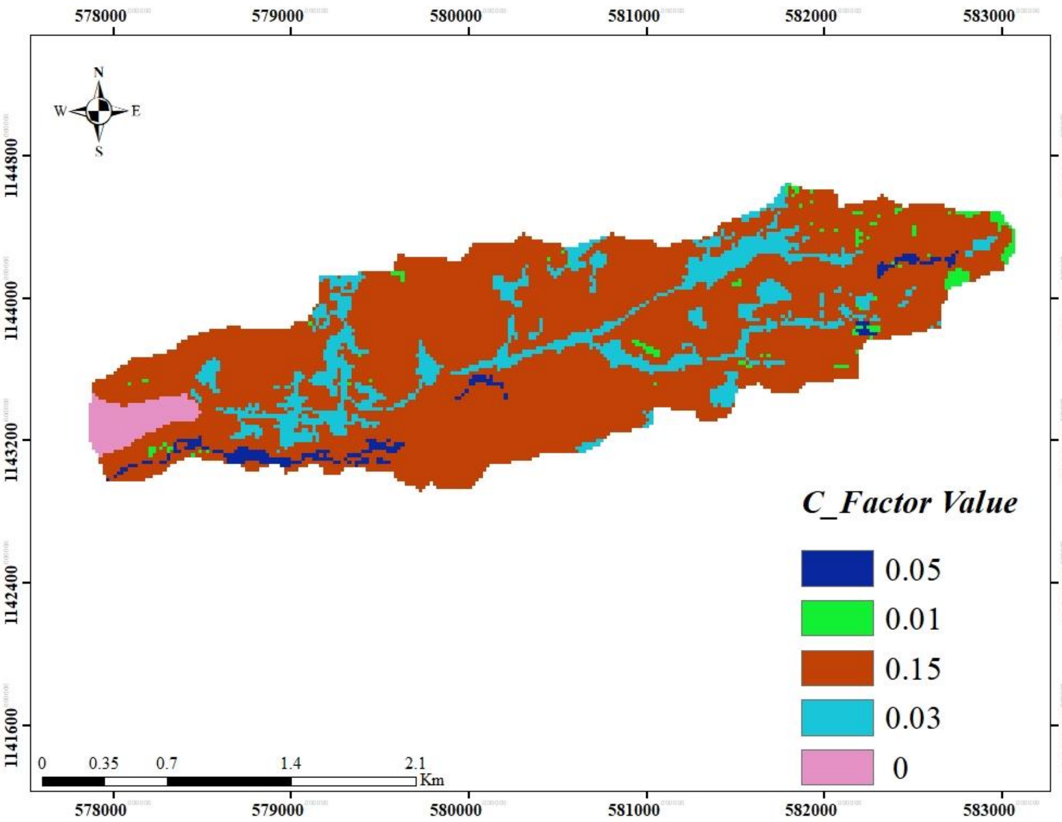

Figure 6: Land use land cover (C) factor map

Management practice (P) factor

The watershed was stratified into six land uses and slope classes. Next to slope and land use classification P-factor values of 0.1,0.1,0.14,0.19,0.25,0.33 were assigned for cultivated land use type with slope class of 0-5,5-10,10-20,20-30,30-50 and >50 respectively. On the other hand bush, grass, forest and bare land uses were not considered individually but grouped into other land uses and P-value 1 was assigned to all slope classes.

Table 3: P-factor value of the watershed adopted from Wischmeier and Smith (1978)

Land use type	Slope (%)	Corresponding P-value
Reservoir	0	0
cultivated land	0-5	0.1
cultivated land	5-10	0.12
cultivated land	10-20	0.14
cultivated land	20-30	0.19
cultivated land	30-50	0.25
cultivated land	>50	0.33
other land use	All	1

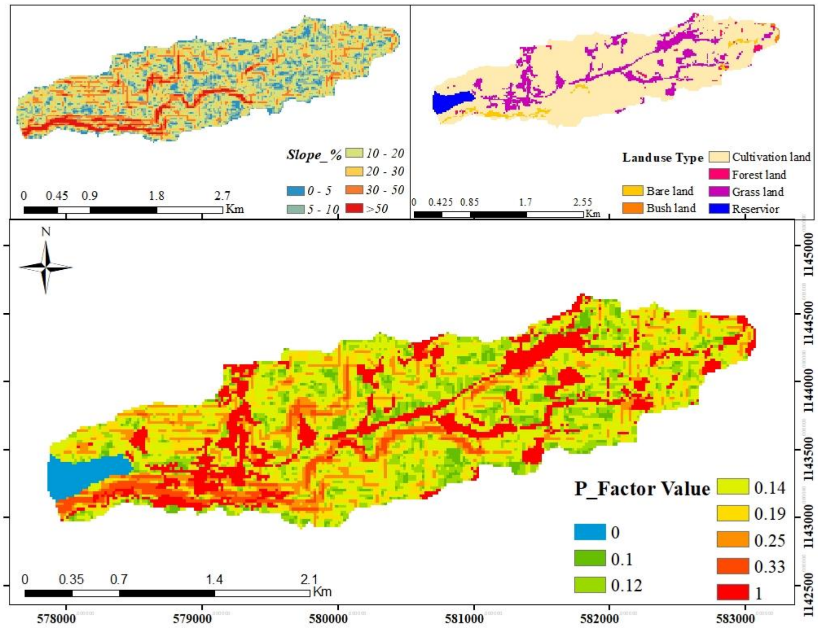

Figure 7: Management practice (P) factor map

Estimated soil loss from the watershed

The spatial distribution of annual soil loss of the study watershed was significantly varied and ranges from 0–288 tons ha^{-1}yr^{-1} according to the equation. It was 0 on the water body (dam) and 288 tons ha^{-1} yr^{-1} on the land along with the main river. The average annual soil loss of the watershed was found to be 47 tons ha^{-1} yr^{-1}. This result is in line with the soil loss rate reported by other scholars (Gelagay 2016) is 47.4 tons ha^{-1} yr^{-1} in the case of the Koga watershed in the upper Blue Nile of Ethiopia similar to the finding of (Tesfaye and Tibebe 2018), i.e., about 62.98 tons ha^{-1} yr^{-1} at Gilgel Gibe-1 catchment, southwest Ethiopia but out of the range of the finding of (Yesuph and Dagnew 2019) 37 tons ha^{-1} yr^{-1} at Bashillo catchment of Blue Nile basin in Ethiopia. On the other hand, the result of this research showed that the watershed is two times more vulnerable than the finding of (Desalegn, et al. 2018) which is 22.3 tons ha^{-1} yr^{-1} at Andit Tid watershed in the central high land of Ethiopia. In contrast to the finding of this research, (Brhane and Mekonen 2009) and (Tiruneh and Ayalew 2015) reported 9.63 and 4.81 tons ha^{-1} yr^{-1} soil loss at the Medego watershed in northern Ethiopia and Enfraz watershed in highland Ethiopia respectively. The annual soil loss of the watershed is 22194.81 tons yr^{-1}.

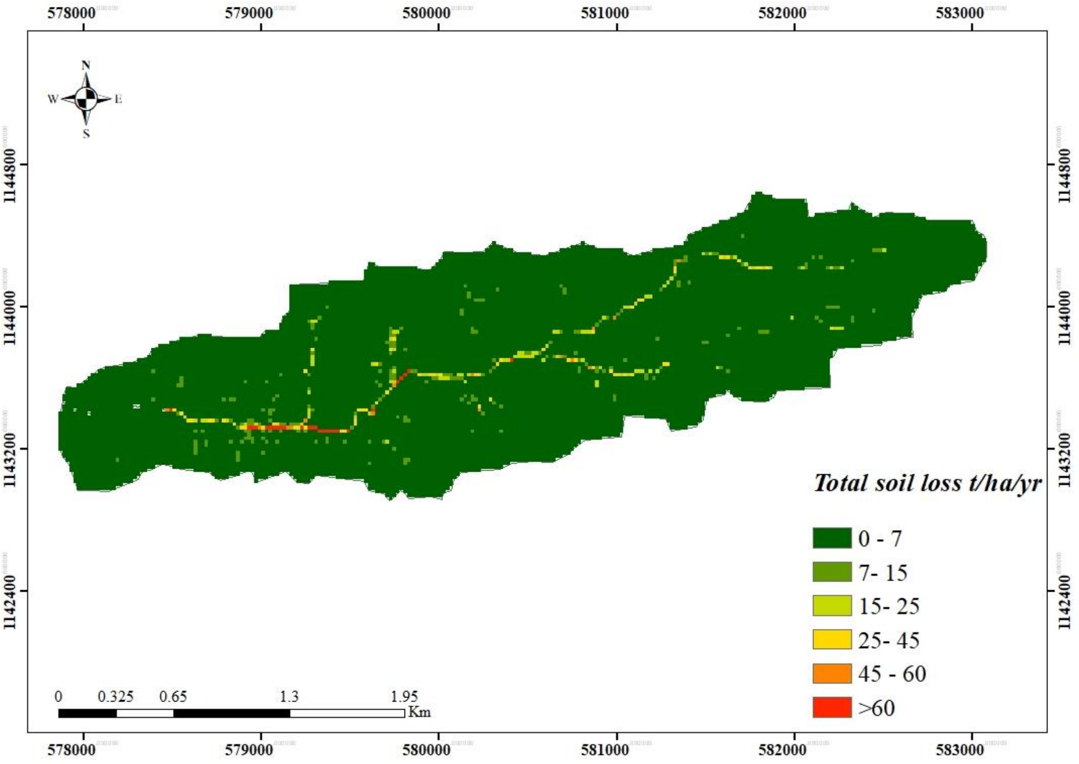

Figure 8: Management Factor Map

Spatial distribution of soil erosion

The land along the drainage line is identified as an erosion hot spot area of the watershed which contributes about 76.6 % of soil loss from the total area, even though 58.8% of the soil loss arises from the lower parts of the watershed along the main drainage line which is fall under a very sever soil erosion class as adopted from(Gelagay and Minale 2016). This is due to the nature of the dominant sand texture class with a low organic carbon content that is responsible to make the soil well-structured and makes resistance to erosion.

Table 4: Soil loss Summary of the watershed

Soil loss rage t $ha^{-1}yr^{-1}$	Average soil loss	soil erosion severity Class	Area (ha)	Area in %	total soil loss	% of soil loss t ha-1yr-1
0-7	3.5	Low	466.6	96.4	1633.1	1.2
7-15	11	Moderate	9.48	2	104.28	3.7
15-25	20	High	3.84	0.8	76.8	6.8
25-45	35	Very high	2.6	0.5	91	11.8
45-60	52.5	Sever	0.6	0.1	31.5	17.8
>60	173.8	Very sever	1.08	0.2	187.704	58.8

Estimated sediment delivery ratio

The sediment delivery ratio of the Godebe watershed is 0.48. This shows that almost half (48%) of the eroded soil reaches the dam and 52% of the eroded materials are re-deposited within the watershed. The result strongly disagrees with the finding (Gelagay 2016) in the Koga watershed. This result may be due to the small drainage area (484.9 ha) of the watershed, and the homogeneity of the watershed to land use, topography, and soil (Vanoni 2006). For example, 79% of the watershed is covered by cultivated land use, 89.8% of the watershed exhibits a 0-5% slope, and also the watershed exhibits a short distance to the main drainage line having a slope of (4%). With this, the sediment delivery ratio which is the amount of sediment delivered and reached the dam was found to be 22.56 tons ha^{-1} yr^{-1} based on equation 6. This result strongly agrees with the finding of (Setegn, et al. 2010), i.e., 24.6 tons ha^{-1} yr^{-1} sediment yield in northern Ethiopia. On the other hand, the result strongly disagrees with the finding of (Haregeweyn, et al. 2008) which was 9.89 tons $ha^{-1}yr^{-1}$ and determined using 11 reservoirs in the northern part of Ethiopia.

Estimated sediment yield

Every year, the Godebe soil dam receives an average of 10653.51 tons (8710 m^3) of sediment. Approximately 74575 tons (60969 m^3) of sediment have been supplied and stored during the past seven years, beginning on the day the dam became operational for water harvesting.

Conclusion and Recommendation

In this study, the RUSLE model was applied for annual soil loss rate estimation. Based on the model the annual soil loss rate of the watershed was found to be 47 tons $ha^{-1}yr^{-1}$. On the other hand, the sediment delivery ratio was also found to be 0.48. With this sediment delivery ratio, 10653.51 tones (8710 m^3) of sediment were delivered and stored in the dam yearly and 74575 tones (60969 m^3) of sediment was delivered and stored within the last seven years. That information leads to the conclusion that the watershed is highly vulnerable to erosion. Consequentially, the sediment delivery ratio and sediment yield delivered to the dam are also high. This implies that the watershed is highly degraded and short life expectancy of the reservoir due to this high siltation.

Based on our finding, in order to minimize the rate of soil erosion and the amount of sediment yield delivered to the dam we recommend that (1) soil erosion hotspot area along with the main drainage line as observed on the map should be given a serious attention for the immediate and appropriate soil and water conservation measure implementation; (2) 79.8 % of the watershed is covered with cultivated land on which soil is easily disturbed, detached and transported by rainfall runoff, ploughing and cultivation, hence attention should be given to implement any activities that minimize soil disturbance and implementation of soil and water conservation measure that can capture the transported sediment; (3) awareness about proper land management for the farmers who are done their cultivation and ploughing activities very closes to the reservoir should be delivered; and (4) the overall construction of the reservoir that was done by Amhara water works construction enterprise is without any feasibility study document (irrigation design document, catchment area, socioeconomic feasibility study document) has been reserving in the woreda agricultural office who has been administer the Godebe soil dam. The construction enterprise should conduct detailed feasibility studies and management document to the office that make fellowship and administer the dam.

References

Brhane, Gebreyesus, and Kirubel Mekonen, 2009. Estimating soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego watershed, Northern Ethiopia. Journal of American Science 5(1):58-69.

Desalegn, Ayele, Abrham Tezera Gessesse, and Fikrey Tesfay, 2018. Developing GIS-based soil erosion map using RUSLE of Andit Tid Watershed, Central Highlands of Ethiopia. Journal of Scientific Research and Reports:1-13.

Gelagay, Habtamu Sewnet, and Amare Sewnet Minale, 2016. Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia. International Soil and Water Conservation Research 4(2):126-136.

Gelagay, HS, 2016. RUSLE and SDR model based sediment yield assessment in a GIS and remote sensing environment; a case study of Koga watershed, Upper Blue Nile Basin, Ethiopia. Hydrology: Current Research 7:239.

Griffin, ML, Beasley DB, Fletcher JJ and Foster GR,1988. Estimating soil loss on topographically non-uniform field and farm units. Journal of Soil and Water Conservation 43(4):326-331.

Guzman, CD, Tilahun SA, Zegeye AD, and Steenhuis TS, 2013. Suspended sediment concentration–discharge relationships in the (sub-) humid Ethiopian highlands. Hydrology and Earth System Sciences 17(3):1067-1077.

Haregeweyn, Nigussie, et al., 2008. Sediment yield variability in Northern Ethiopia: A quantitative analysis of its controlling factors. Catena 75(1):65-76.

Hurni, Hans, 985.Erosion-productivity-conservation systems in Ethiopia.

Kumar, P Sundara, TV Praveen, and M Anjaneya Prasad. 2015 Simulation of sediment yield over un-gauged stations using MUSLE and fuzzy model. Aquatic Procedia 4:1291-1298.

Mockus, Victor, 1964. National engineering handbook. US Soil Conservation Service: Washington, DC, USA 4.

Renard, Kenneth G, and Jeremy R Freimund, 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of hydrology 157(1-4):287-306.

Rijn, LC van, 2013. Sedimentation of Sand and Mud in Reservoirs in Rivers.

Setegn, Shimelis G, et al. 2010. Modeling of Sediment Yield From Anjeni-Gauged Watershed, Ethiopia Using SWAT Model 1. JAWRA Journal of the American Water Resources Association 46(3):514-526.

Suresh, R, 2012. Soil and water conservation engineering: Standard Publishers Distributors.

Taddese, Girma, 2001. Land degradation: a challenge to Ethiopia. Environmental management 27(6):815-824.

Tesfaye, Gizaw, and Degifie Tibebe, 2018. Soil erosion modeling using GIS based RUSEL model in Gilgel Gibe-1 catchment, South West Ethiopia. International Journal of Environmental Sciences & Natural Resources 15(5):141-148.

Tiruneh, Gizachew, and Mersha Ayalew, 2015.Soil loss estimation using geographic information system in enfraz watershed for soil conservation planning in highlands of Ethiopia. International Journal of Agricultural Research, Innovation and Technology 5(2):21-30.

Vanoni, Vito A, 2006. Sedimentation engineering, 2006. American Society of Civil Engineers.

Williams, Jimmy R, 1975. Sediment-yield prediction with universal equation using runoff energy factor.

Wischmeier, Walter H, and Dwight David Smith, 1978. Predicting rainfall erosion losses-a guide to conservation planning. Predicting rainfall erosion losses-a guide to conservation planning.

Yesuph, Asnake Yimam, and Amare Bantider Dagnew, 2019. Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, Ethiopia. Environmental Systems Research 8(1):1-21.