**AMHARA REGIONAL AGRICULTURAL RESEARCH INSTITUTE (ARARI)**

# Proceedings of the 12th Annual Regional Conferences on Soil and Water Management Research, 13–16, May 2019, Bahir Dar, Ethiopia


**Editors**

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***Tadele Amare[1*], Zerfu Bazie[1], Erkihun Alemu[1], Amlaku Alemayehu[1], Abere Tenagne[1], Bitewlgn Kerebih[1], Yasin Taye[2], Assefa Derebe[1] and Tesfaye Feyissa[3]***

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## Abstract

*(Solanum tuberosum L.)*

**Keywords:** Farta, Laigaint, Soil fertility, Tuber yield, Yilmana Densa

## Introduction

Potato (*Solanum tuberosum L.*) is one of the dominant crops globally that ranks fourth in terms of volume of production and its area coverage (FAOSTAT, 2007). It ranks first among root and tuber crops in Ethiopia (CSA, 2016). Potato is characterized as a cheap and nutritive food security crop. Because of its high yield with good nutritive values per unit area and per unit of time than other major cereal crops (Kanter and Elkin, 2019; Beals, 2019), it is considered as a food and nutrition security crop. Potato is one of the strategic crops to the United Nation's Millennium Development Goals of achieving food security and poverty eradication and 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 the price of potatoes mainly depends on local demand and supply than the global market. A short production cycle and early maturing habits are additional benefits of potato to intensification than many other crops.

Ethiopia has an immense potential to boost the productivity of potato (*Solanum tuberosum L.*) especially in the highlands (Woldegiorgis *et al.*, 2012; Haverkot *et al.*, 2012). About 70% of the cultivated land of Ethiopia is suitable for potato production (FAOSTAT, 2008) but only 2% of the potential has been used (Hirpa *et al.*, 2012). About 40% of potato producers are concentrated in the northwestern parts of Ethiopia: South Gonder, North Gonder, East Gojam, West Gojam, and Agew Awi administrative zones, the Amhara National Regional State of Ethiopia (Hirpa *et al*., 2012) that could be related to agroecological suitability. These areas are characterized by a high density of demography with less food and nutrition security that needs improving and promoting high yielding crops and potato is highly recommended under such situations (De Jong, 2016). The Ethiopian Agricultural research system placed its national potato research coordination at Adet Agricultural Research Center (West Gojjam) to use the existing potential of the region through research interventions and promotion. The current state of potato productivity in Ethiopia is less than 10 t ha$^{-1}$ (Deresseh et al., 2016; Hassen *et al*., 2015, Haverkort *et al*., 2012, Hirpa *et al*., 2015) and its total annual production is only about 0.5 million tons.

On the other hand, Haverkot et al., (2012) reported the highest yield report of potato (64 t ha$^{-1}$) around Shashemene in Ethiopia that indicates high variability of productivity in the country governed by different biotic and non-biotic factors. Ethiopia soil has been depleted because of negative input to out-put balances of the nutrients (low soil fertility) that could contribute to the high variability and low crop productivity including potato (Amare, *et al*., 2018, Amare *et al.*, 2013, Hirpa *et al*., 2012; Kebede and Ketema, 2017; Muleta and Aga, 2019). Among plant nutrients, nitrogen and phosphorus are so far the most yield-limiting nutrients (Amare *et al*., 2018) while Muleta and Aga (2019) reviewed that nitrogen is the most yield-limiting nutrient of potato. However, finding and updating on the biological and economical response of potato to nitrogen and phosphorus is a critical gap in northwestern Ethiopia. Therefore, this research was conducted to get the biological and financial optimum rates of nitrogen and phosphorus potato production in Northwestern Ethiopia.

## Materials and Methods

### *Study sites*

Yilmana Densa town is located at about 42 km from Bahir Dar on the way to Addis Ababa through Mota and represents potato growing areas of west Gojjam, Agew Awi, and East Gojjam zones. The district is characterized by highland and midlands. It has a unimodal rainfall with a mean of 1240 mm $yr^{-1}$. June, July, and August receive the largest shares of the annual rainfall. It has 9.3$^{O}$C and 25.7$^{O}$C, minimum and maximum temperatures respectively. The local geology is volcanic basalt and Cenozoic pyroclastic fall deposits (Zewde, 2009). Potato and food barley are the most important crops in the highlands of the district. The district is one of the highly populated districts of the region that led to very small farmland per capita. Farta and Lai Gaint are parts of the south Gondar Admiration zone of the Amhara National Regional State with similar rainfall patterns to Yilmana Densa. Potato and food barley are also the dominant cultivated crops in these districts. The farming system of the study sites is subsistence and crop-livestock mixed type. Potato productivity in Ethiopia and annual production of potato at the global level is displayed in Figure 1 and 2, respectively.

### *Treatment setup*

The experiment was conducted for three years in the rainy season with three sites per location per year (3 for Yilmana Densa and 3 for Farta & Laigaint). A factorial experiment with four levels of nitrogen (46, 92, 138, 194 kg N $ha^{-1}$) combined with three levels of phosphorus (46, 69, 92 $P_2O_5$ kg $ha^{-1}$) was used for the study. One treatment with no nutrient input (control) was also included as a pilot to assess the current state of potato production without fertilizer application as there are potato growers without fertilizer. Treatments were replicated three times and arranged in a randomized complete block design (RCBD). Nitrogen was applied by three splitting: one third at planting, one-third three weeks after germination, and the final one-third at flowering while the whole dose of phosphorus was applied at planting. Urea (46% N) and TSP (46% $P_2O_5$) were sources of fertilizers for nitrogen and phosphorus respectively. Gudene is an improved potato variety developed by the Ethiopian research system and a well-known recommended variety in the study areas and hence used for the study. The distance between plants and rows was 0.3m and 0.75m respectively. The gross size of each plot was $13.5m^2$ (3m*4.5m) while the data was collected from the central 4 rows with a plot size of $9m^2$ (3m*3m). Earthing up was uniformly done at the ages of 3 weeks after germination. Redomil at the rate of 3 kg $ha^{-1}$ was applied uniformly for the control of late blight disease.

*Soil sampling and analysis*

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

*Data analysis*

The effect of independent variables (nitrogen, phosphorus, and their interaction) on the dependent variable (potato tuber yield) was statistically tested. The analysis was made for each site and year and combined as well. Analysis of variance (ANOVA) was carried out to assess the difference between treatments. Upon the existence of significant difference for ANOVA, ($p < 0.05$), further analysis of mean separation was carried out using Duncan's Multiple Range Test (DMRT). Graphical analyses were also employed to evaluate response curves over different doses of nitrogen and phosphorus nutrients. The partial budget analyses were done based on (CIMMYT, 1988). The cost of NPS and urea was 1284.05 and 1158.58 Birr per 100 kg; respectively. The farm gate price of potato (Birr 100 $kg^{-1}$) was 487 at Yilmana Densa and 450 Birr at Laigaint and Farta.

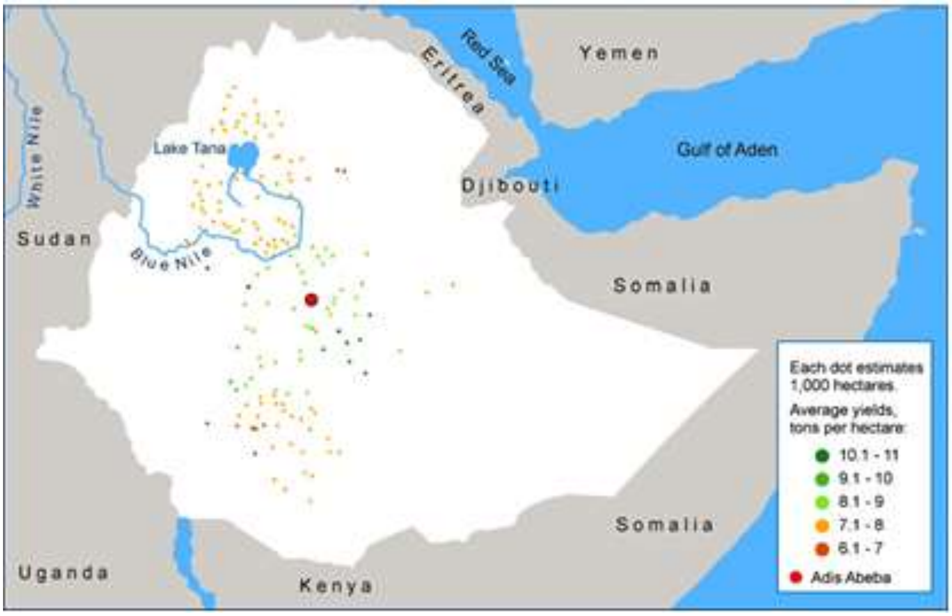


**Figure 1**. Potato productivity in Ethiopia: earch. ). Accessed on 8/1/2019

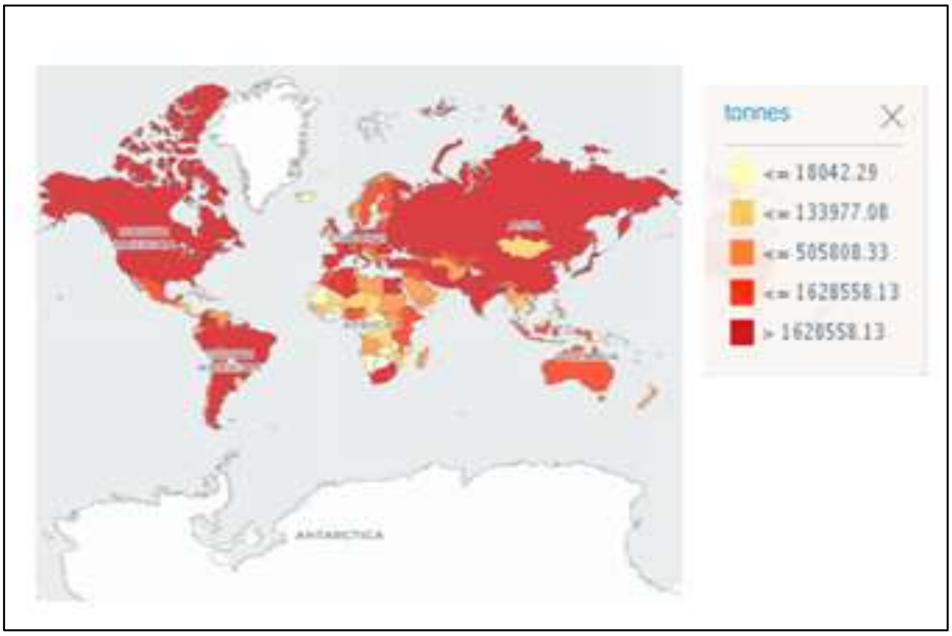


**Figure 2**. Annual production of potato at the global level. http://www.fao.org/faostat/en/#data/QC/visualize (average potato yield from 1994-2017). Accessed on 28/10/2020

## Results and Discussion

### *Soil properties of the study sites*

The pH of the soil (pH of water) was above five that ranged from 5 to 5.3 for the case of Yilmana Densa while for the South Gonder it was ranged from 5.1 to 5.4 both sites are moderately acidic (FAO, 1984). Soil acidity is not a critical yield-limiting factor for the study sites especially in the upper parts of the landscapes as Andosol is dominating in that parts of the districts with pH higher than our report here. Moreover, potato is tolerant of acid soils compared to other sensitive crops and hence pH was not a limiting factor for our research. The soil organic carbon (SOC) contents of the study sites ranged from 0.96 to 1.75% for Yimana Densa and 1.14 to 2.01% for south Gondar. Accordingly, the soils of Yilmana Densa were below the critical limits and south Gondar ranges from below to critical levels (Loveland and Webb, 2003; Murphy, 2014). Generally, soils of the study areas were low in SOC that limits nutrients supplies including N and P (Murphy, 2014). Therefore, for optimum production of potato nutrients must be supplied in the forms of synthetic fertilizer, organic fertilizer, or in the form of synthetic integrated with organic fertilizers. The exchangeable potassium of the soil was ranged from 0.69 to 0.88 cent mol $kg^{-1}$ of the soil for Yilmana Densa while for South Gondar it ranged from 0.46 to 0.62 cent mol $kg^{-1}$ of the soil. The result of soil analysis on soil potassium was above the critical limits for all the study sites (IPI, 2016), indicating that potassium is not a priority fertilizer for the production of annual crops including potato with its current state as supported with the finding of other annual crops (Amare *et al*., 2018). The available phosphorus of Yilmana Densa was in a range of 9 to 10 ppm that is below the critical levels (Huygens and Saveyn, 2018) while for south Gondar it was highly variable (ranged from 10 to 20 ppm).

### *Yield response*

The response of potato to the application of nutrients (NP) was higher as shown in Figure 3. The response to nitrogen was higher than phosphorus (Figure 3, Tables 1 and 2). Figure 3 showed that there was an increase in the yield of potato for the application of nitrogen even at the rates of 194 kg N $ha^{-1}$for all sites and for all seasons (Figure 3: A and B). The yield gap between the rates of nitrogen was higher and uniformly increased for nitrogen than phosphorus. However, the yield response to the applied phosphorus was not as strong as the response to nitrogen (Figure 3: C and D). The higher yield gap for the application of phosphorus was observed between the control (no fertilizer) and the treatments with phosphorus (Figure 3: C and D) compared to the response to nitrogen (Figure 3: A and B). For the applied phosphorus the yield was increased with a low slope coefficient.

The Analysis of variance (ANOVA) results of the research showed a significant yield difference ($p < 5\%$) for all sites and years to nitrogen (Table 1 and 2). The maximum tuber yield (40 t $ha^{-1}$) of potato was found in Yilmana Densa at a site called Chinkulit in the 2018/2019 cropping season using 194 kg of N $ha^{-1}$compared to 11 t $ha^{-1}$ of tuber yield from control for the same location in the same year (data is not shown here). The average maximum yield of potato for the three years in Yilmana Densa for nitrogen was 29.2 t $ha^{-1}$ by applying 194 kg of N $ha^{-1}$ compared to 8.8 t $ha^{-1}$tuber yields from treatments without nutrient (Table 1). While the maximum potato tuber yield (297.5 t $ha^{-1}$) in south Gondar was recorded at a site called Tsegur Kidanimiret, in Farta district by applying 194 kg N $ha^{-1}$compared to 11.6 t $ha^{-1}$of potato tuber yield without nutrient input from the same site in the same season (2018/19), (data not shown). The three-year average tuber yield of potato in south Gondar was ranged from 7.54 t $ha^{-1}$ to 22.08 t $ha^{-1}$without nutrient input and applying 194 kg N $ha^{-1}$; respectively (Table 2).

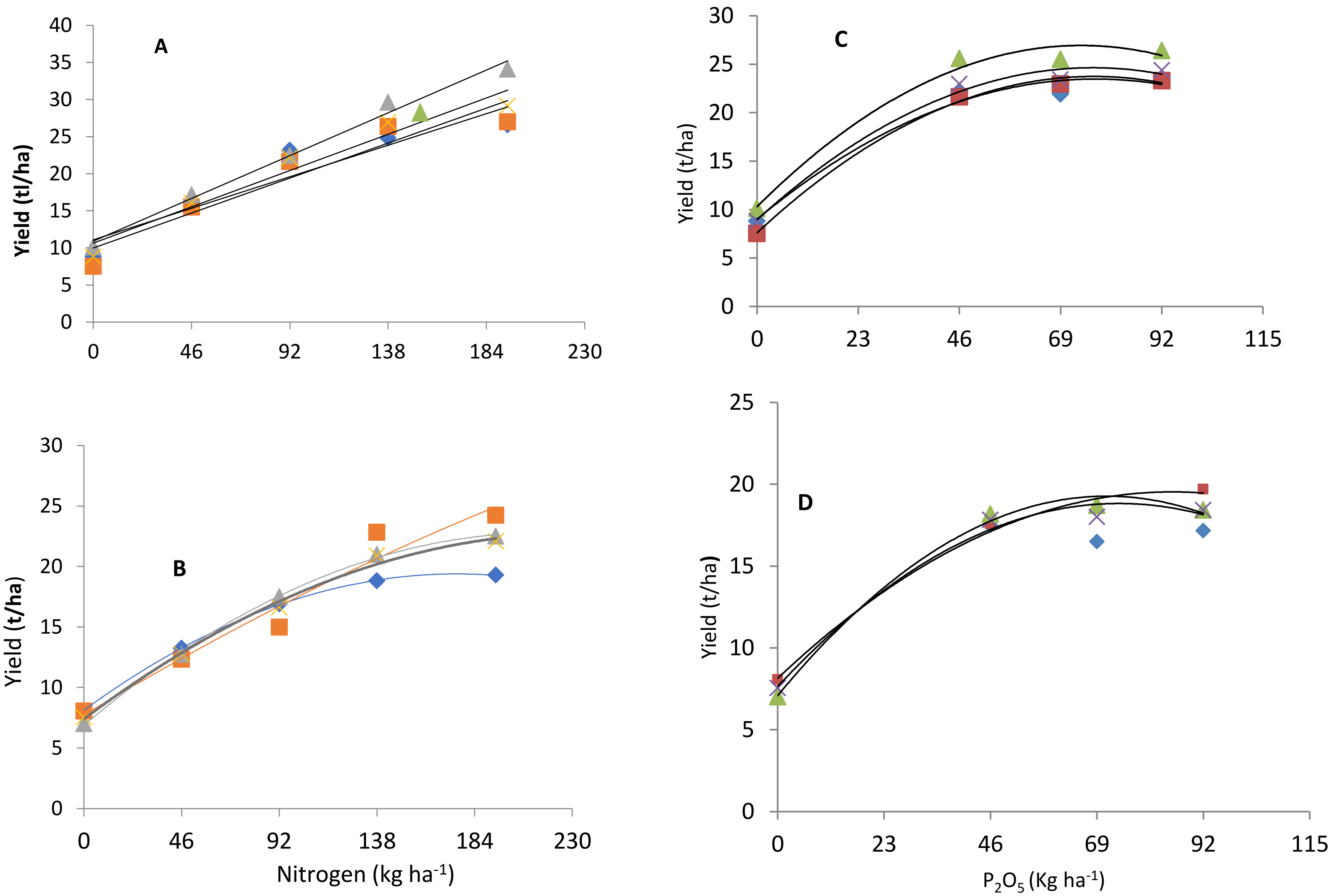


**Figure 3**. Response of potato to N (A Yilmana Densa and B South Gondar) & P (C Yilmana Densa and D south Gondar). Where: is year one is year two is year three and is the mean

**Table 1**. Potato response to applied NP at Yilmana Densa (tuber yield t ha$^{-1}$) over the years

| Nitrogen (kg/ha) | Year 1 | Year 2 | Year 3 | Mean |
|---|---|---|---|---|
| 46 | 15.48 | 15.52 | 17.18 | 16.06 |
| 92 | 23.16 | 21.64 | 22.46 | 22.21 |
| 138 | 24.81 | 26.37 | 29.61 | 26.93 |
| 194 | 26.61 | 27.01 | 34.11 | 29.16 |
| LSD (0.05) | 2.97 | 2.3 | 3.18 | 1.7 |
| Phosphorus ($P_2O_5$ Kgha$^{-1}$) | | | | |
| 46 | 22.17 | 21.63 | 25.61 | 22.98 |
| 69 | 21.94 | 22.97 | 25.51 | 23.41 |
| 92 | 23.43 | 23.31 | 26.41 | 24.38 |
| LSD (0.05) | NS | NS | NS | NS |
| CV (%) | 24.4 | 18.8 | 22.8 | 23 |
| N*P | NS | NS | NS | NS |
| Control (0N and 0P) | - | 7.53 | 10.13 | 8.83 |

Table 2. Potato response to applied NP at South Gondar (tuber yield t ha$^{-1}$) over the years

| Nitrogen (Kg ha$^{-1}$) | Year 1 | Year 2 | Year 3 | Mean |
|---|---|---|---|---|
| 46 | 13.23 | 12.33 | 12.74 | 12.76 |
| 92 | 16.91 | 14.99 | 17.50 | 16.61 |
| 138 | 18.81 | 22.82 | 21.00 | 20.89 |
| 194 | 19.28 | 24.23 | 22.51 | 22.08 |
| LSD (0.05) | 4.30 | 2.55 | 3.11 | 1.97 |
| $P_2O_5$ (Kgha$^{-1}$) | | | | |
| 46 | 17.50 | 17.59 | 18.17 | 17.82 |
| 69 | 16.50 | 18.49 | 18.71 | 18.01 |
| 92 | 17.17 | 19.70 | 18.43 | 18.43 |
| LSD (0.05) | NS | NS | NS | NS |
| CV(%) | 36.3 | 20.9 | 33 | 31 |
| N*P | NS | NS | NS | NS |
| Control (0N and 0P) | - | 8.06 | 7.01 | 7.54 |

The response of tuber yield to phosphorus was much less than to the responses for nitrogen for all the sites; resulting in a non-significant yield difference between phosphorus rates (Table 1 and 2). The smallest rates of phosphorus (46 kg $P_2O_5$ ha$^{-1}$) resulted in comparable tuber yield of potato as that of the maximum rates (69 and 92 kg $P_2O_5$ ha$^{-1}$) for all the sites and more specifically to south Gondar.

Our finding on nitrogen was in line with the findings of Esmael (2017) and Getie *et al.*, (2015) who recommended 110 kg N ha$^{-1}$ for the major potato producing areas of Ethiopia although their recommendation was much lower than our finding. However, Esmael (2017) recommendation of phosphorus for the production of potato for the major producing areas of the country (90 kg $P_2O_5$ $ha^{-1}$) disagreed with our findings. He recommenced a higher rate that was two times our findings. The findings of Nyiraneza *et al*. (2017) in Canada showed no response to phosphorus application under different soils with different levels of soil phosphorus. They reported the recommended amount of N was 150 kg $ha^{-1}$. Similarly, Setu and Mitiku (2018) reported no response of potato to phosphorus in western Ethiopia. Alemayehu and Jember (2018) under the Koga irrigation scheme reached conclusions of different rates of phosphorus recommendations for different sites and varieties. They recommended 102 kg $P_2O_5$ $ha^{-1}$for variety Belete under low phosphorus conditions and for Gudene 69 kg $P_2O_5$ $ha^{-1}$. For areas with sufficient phosphorus, they recommended 69 kg $P_2O_5$ $ha^{-1}$ for Belete and 52 $P_2O_5$ $ha^{-1}$ for Gudene. However, our main difference with their finding was the growing season that is our experiment was in the main season while their experiment was entirely dependent on irrigation. Besides, the authors (Alemayehu and Jember, 2018) reached conclusions with only two sites experiment for a single irrigation season while our data was sufficient to capture the three rainy seasons. They claimed more than 30 ppm of available phosphorus (Olsen p) at Koga that might be less likely under the p limited farming systems of Koga and from our experiences. On the other hand, the recommendations by Hassen *et al*., (2015) was somewhat in line with our finding with phosphorus they recommended 69 kg $P_2O_5ha^{-1}$ while their recommendation to nitrogen was much lower than our finding as they recommended 80.80 kg N ha-1for the potato growing areas of northwestern Amhara Region (South Gondar and Gojjam areas). The recommendation of nitrogen made by Ayichew *et al.*, (2009) to the Vertisols of Debre Birhan area (138 kg N $ha^{-1}$) was in line with our findings to all sites of our study. They recommended 20 kg $P_2O_5$ $ha^{-1}$; lower than by half to our findings. Despite the arguments and suggestions of Fixen and Bruulsema (2014) as well as Follain *et al*., (2009) about higher requirements of phosphorus compared to other crops depending on the nature of the root system of potato, our result showed p satisfaction at lower P rates. The application of high rates of phosphorus without any significant biological yield could not only economically unjustifiable but also has an environmental risk (Ruark *et al*., 2014).

In Thailand, for the commercial production of potatoes, the rate of nitrogen and phosphorus ($P_2O_5$) reaches 187.5 Kg $ha^{-1}$ and 187.5 Kg $ha^{-1}$, respectively (Kittipadakul *et al*., 2016) that implies the elasticity of potato response especially to phosphorus is very high. Khakbazan *et al*. (2019) also used the rates of nitrogen and phosphorus (138-151 N and 69-75 kg $P_2O_5$ $ha^{-1}$) similar to our findings and recommendations. The finding showed that the yield of potato at Yilmana Densa could be improved by more than threefold (greater than 300%) and at south Gondar by more than two and a half folds (greater than 250%) through nutrient applications (N) and its implication on food and nutritional security is tremendous as the study represents 40% of the potato producers of the country (Hirpa *et al*., 2012). There is a growing demand for potatoes for local consumption. One of the strategies to boost the production and productivity of potatoes in the potato farming systems of Ethiopia is through nutrient management (Hirpa *et al.*, 2012; Kebede and Ketema, 2017; Muleta and Aga, 2019).

***Partial budget analysis***

The partial budget analysis was employed to identify the economical optimum rates of NP fertilizer for the production of potatoes. Farm gate prices for potatoes were 4.87 and 4.50 Birr $kg^{-1}$ of potato for Yilmana Dens and south Gondar; respectively. The cost of fertilizer was 1284.05 and 1158.58 for NPS and Urea; respectively. The significant difference in the biological yield was reflected in the economical responses of the partial budget analysis. Some of the treatments with $N/P_2O_5$ kg $ha^{-1}$ (46/69, 46/92, 92/69, 194/46 at Yilmana Densa and 46/69, 46/92, 92/92, 138/69, 138/92, and 194/46 at south Gondar) were dominated and discarded from the analysis.

Accordingly, the highest marginal rate of return (70.9 Birr/Birr) for Yilmana Densa was found at the rates of 138 kg N $ha^{-1}$ and 46 Kg $P_2O_5$ $ha^{-1}$ (Table 3). For south Gondar, the maximum marginal rate of return (24.3 Birr/Birr) was found with treatments 138 kg N $ha^{-1}$ and 46 Kg $P_2O_5$ $ha^{-1}$ (Table 4). The optimum rate of NP fertilizers for potato production with this research disagreed with the one recommended by Yassin (2017). With the yield data of this research, the economic optimum rate could be continuously updated with the situation of farm gate price of potato and the cost of fertilizer. Based on the findings of this research, for Yilmana Densa and similar areas 138 kg N ha-1 and 46 Kg P2O5 $ha^{-1}$ is recommended as the first option and 138 kg N $ha^{-1}$ and 69 Kg P2O5 $ha^{-1}$ as the second option while for south Gondar 138 kg N $ha^{-1}$ and 46 Kg P2O5 $ha^{-1}$ is profitable rate. Of course, the economic situations of farmers limit to use of the optimal amounts of fertilizer recommended by research (Gebru et al., 2017; Muleta and Aga, 2019). Alemayehu et al. (2020) found a very good marginal rate of return using 13.5 t

$ha^{-1}$ combined with 245.1 kg NPS $ha^{-1}$. Their finding is not in line with our finding as they recommend high rates of phosphorus than nitrogen. Moreover, it is hard to apply 13.5 t $ha^{-1}$ s.

**Table 3**. Partial budget analysis for Yilmana Densa

| Treatment | NPS (Kgha$^{-1}$) | Urea (kgha$^{-1}$) | Cost of NPS (Birr) | Cost of Urea (Birr) | TC (Birr) | Yield (ton) | TR (Birr) | MC (Birr | MR (Birr) | MRR (Birr/Birr) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0/0 | 0 | 0 | 0 | 0 | 0 | 8.83 | 43002.1 | - | - | - |
| 46/46 | 121.0 | 50 | 1553.7 | 579.3 | 2133.0 | 16.84 | 82010.8 | 2133.0 | 36875.7 | 17.3 |
| 92/46 | 121.0 | 150 | 1553.7 | 1737.9 | 3291.6 | 22.34 | 108795.8 | 1158.6 | 25626.4 | 22.1 |
| 92/92 | 242.0 | 100 | 3107.4 | 1158.6 | 4266.0 | 23.15 | 112740.5 | 974.4 | 2970.3 | 3.0 |
| 138/46 | 121.0 | 250 | 1553.7 | 2896.5 | 4450.2 | 25.87 | 125986.9 | 184.2 | 13062.2 | 70.9 |
| 138/69 | 181.6 | 225 | 2331.8 | 2606.8 | 4938.6 | 27.04 | 131684.8 | 488.5 | 5209.4 | 10.7 |
| 138/92 | 242.0 | 200 | 3107.4 | 2317.2 | 5424.6 | 27.87 | 135726.9 | 485.9 | 3556.2 | 7.3 |
| 194/69 | 181.6 | 346.7 | 2331.8 | 4016.8 | 6348.6 | 29.66 | 144444.2 | 924.1 | 7793.2 | 8.4 |
| 194/92 | 242.0 | 321.7 | 3107.4 | 3727.2 | 6834.6 | 30.59 | 148973.3 | 485.9 | 4043.2 | 8.3 |

**Table 4**. Partial budget analysis for South Gondar

| Treatment | NPS (Kg) | Urea (Kg) | Cost of NPS (Birr) | Cost of Urea (Birr) | TC (Birr) | Yield (ton) | TR (Birr) | MC (Birr) | MR (Birr) | MRR (Birr/Birr) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0/0 | 0 | 0 | 0 | 0 | 0 | 7.54 | 33930.0 | - | - | - |
| 46/46 | 121 | 50 | 1553.7 | 579.3 | 2133.0 | 13.289 | 59800.5 | 2133.0 | 25870.5 | 12.1 |
| 92/46 | 121 | 150 | 1553.7 | 1737.9 | 3291.6 | 16.294 | 73323.0 | 1158.6 | 13522.5 | 11.7 |
| 92/69 | 181.6 | 125 | 2331.8 | 1448.2 | 3780.1 | 17.388 | 78246.0 | 488.5 | 4923.0 | 10.1 |
| 138/46 | 121 | 250 | 1553.7 | 2896.5 | 4450.2 | 210.0 | 94500.0 | 670.1 | 16254.0 | 24.3 |
| 194/69 | 181.6 | 346.7 | 2331.8 | 4016.8 | 6348.6 | 221 | 99450.0 | 1898.4 | 4950.0 | 2.6 |
| 194/92 | 242.0 | 321.7 | 3107.4 | 3727.2 | 6834.6 | 234 | 105300.0 | 486.0 | 5850.0 | 12.0 |

## Conclusion and recommendation

To improve the productivity of potatoes through NP nutrient management-intensive on-farm research was conducted for three consecutive rainy seasons in northwestern Ethiopia. The finding of the research proved that the yield was improved by two and half fold for the case of south Gondar and by threefold for the case of Yimna Densa. The findings of the research have a tremendous implication on bridging the nutritional and food securities of the nation in general and the northwestern parts of the country in particular as 40% of potato growers are concentrated in this part of the country and potato are better off in nutritional contents. The result revealed that soil fertility management plays a major role in the productivity of potatoes. The research indicated that the response to nitrogen was stronger than the response to phosphorus. The tuber yield of potato was not reduced to the extent of 194 kg N $ha^{-1}$, it rather increased with increasing N rates, indicating we should focus on nitrogen fertilizers to maximally increase the productivity and profitability of potato production. With the current increased trends of potato demands throughout the county, the application of maximum rates of nutrients could lead to more production, profitable and sustainable potato business. For Yilmana Densa and similar niches, 138 kg N $ha^{-1}$ and 46 kg $P_2O_5$ $ha^{-1}$ are recommended as the first option followed by 138 kg N ha-1 and 69 kg $P_2O_5$ $ha^{-1}$ as the second option. For south Gondar, 138 kg N $ha^{-1}$ and 46 kg $P_2O_5ha^{-1}$ are recommended. For south Gondar, the productivity was lower than Yilmana Densa that needs further work on other management aspects. Furthermore, the recommendations could be subjected to change upon fluctuations in the farm price of potato and the cost of fertilizers.

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# On-farm nutrient omission research as a basis for developing site-specific nutrient management practices in the maize belts of west Amhara

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## Abstract

*The potential yields of improved maize varieties could not be fully realized mainly due to inappropriate soil nutrient management in most parts of the country. The site-specific recommendation is not often used to cover diverse agro-ecologies disregarding the variability in the cropping system, soil fertility, and other factors. This has highly hampered maize productivity resulting in an overall low average national maize grain yield. In view of this, a study was conducted for three consecutive rainy seasons in the maize belt areas of the northwestern parts of the Amhara National Regional State to obtain the maximum achievable yield potentials of maize, to determine the most yield-limiting nutrients, and to create a strong database of maize responses to applied nutrients so that decision support tools could be assessed for the study area. The yield-limiting potential of nitrogen, phosphorus, and potassium was intensively evaluated by omitting each of the three nutrients. Sulfur and Zn nutrients, as well as lime and compost, were added to improve the efficiency of NPK on the yield of maize. Two high-yielding hybrid maize varieties (BH-540 and BH-660) were used for the study. BH-540 was used for the Mecha district while BH-660 was used for the south Achefer, Jabitahnan, Burrie, and Womberma districts. The finding of the research showed us that yield was increased by more than 50% due to fertilizer applications. The achievable yield potential of maize for the study sites was more than 12 t ha$^{-1}$ for both varieties. The most yield-limiting nutrient in the study sites was nitrogen followed by phosphorus. Potassium was not a yield-limiting nutrient for the study sites. Without nitrogen, the yield potential of both varieties was insignificant from the control (without nutrients). The result also showed very high variability with sites, indicating site-specific fertilizer consultation is important for the policymakers, farmers, and investors. Finally, intensive plant response to NPK database for maize was generated and could be used to devise site-specific decision support tools.*

**Keywords:** Achievable yield potential, Maize, NPK, Nutrient omission, Yield-limiting nutrients

## Introduction

Soil fertility is one of the factors that limit agricultural productivity in Ethiopia (Amare *et al.*, 2018; Hirpa *et al.*, 2012; Kebede and Ketema, 2017). Applying the right fertilizer source at the right rate, at the right time in the growing season, and in the right place is an essential basis for optimizing the use of nutrients (Chathurika, *et al.*, 2014; Ferguson *et al.*, 2002). The supply of required quantities of plant nutrients according to the demand of the plant in balanced quantities is not commonly practiced and it could be the main soil fertility constraint restricting crop growth in Ethiopia. It is also favorable

space and associated factors are not well quantified and reported in the farming systems of Ethiopia; and its implication on improving the productivity of targeted crop is immense. Supplementary approaches to the conventional field experimentations through decision support tools including crop response to nutrient modeling could help to generate the required information for immediate decision-makers, investors and farmers as well as for capturing existing potentials (MacCarthy *et al.*, 2018). However, to draw reliable conclusions on site-specific decision support tools a strong and well-organized database of nutrient responses that have spatial and temporal dimensions is critically important (Edreira *et al.*, 2018; Hengl, *et al*., 2015; Hengl *et al*., 2017, Kaizzi *et al*., 2017). Under the current situation of Ethiopia, there is a general lack of an organized database for the development crop and site-specific decision support tools.

Maize (*Zea mays*) is one of the major cereal crops with better achievable potentials to ensure food security of the nation and yet with less than 4 t $ha^{-1}$ yield on national average (Abdulkadir *et al*., 2017; FAO, 2014). Under most agro-ecologies and soils of Ethiopia, the response of maize to nitrogen and phosphorus has been very high (Amare *et al*., 2018; Abdulkadir *et al*., 2017) and yet the achievable potential of maize yield is very high with a further increase of NP fertilizers in the maize belts of the country especially in the Northwestern parts. Intensive research and development work on soil fertility is highly needed to transform the current state of maize production to its achievable potential. The maximum attainable potentials of maize should be targeted and reduce the variations among smallholder maize producers. One of the perquisites to improve the productivity and production of maize is to bring on board an intensive database. The International Plant Nutrition Institute (IPNI) has been working with partners in sub-Saharan Africa to improve crop intensifications including maize. IPNI extended its project to maize belts of the Amhara National Regional State for three years (2016-2018) to generate intensive data on the response of maize to the applied nutrients focusing on NPK, to analyze achievable yield potential in the region, and generate a database that could help developing decision support tools.

## Materials and methods

### *The study sites*

The trial sites covered the major maize production districts (Jabitahnan-Burrie-Womberma, south Achefer, and Mecha) in the Amhara region, located in the north-western highlands of Ethiopia

fields represent the main soil types occurring in the area, commonly used cropping systems and farm management practices, and a range of socio-economic conditions (low to high resource endowment). The soil of these districts is dominantly characterized by Nitisols. The general feature of the agricultural landscape where maize takes the larger area coverage is flat, which is good for future expansion and intervention of mechanized agricultural technologies. All districts have a uni-modal type of rainfall which extends from April to October. The main rainy months are June, July, and August. A mixed type of farming system (crop production and livestock raising) is practiced. Generally, this region is rich in water sources. Mecha district receives about 1600 mm annual rainfall on average with a temperature range of 16-20$^{o}$C. The altitudinal range of major maize growing areas of the district ranges from 1900-2200 masl. Maize and finger millet is the dominant cereal crops grown in the Mecha district. Early maturing maize varieties are commonly grown in the district compared to other districts of the study sites. Following the Koga irrigation scheme, crop diversity steadily increased. The district is also known for high production and coverage of eucalyptus. Compared to Mecha, South Achefer receives a higher amount of rainfall with an extended growing period; helping to grow high-yielding late maturing maize varieties. The annual rainfall of Jabitahnan-Burrie-Womberma districts reaches about 1600 mm, with mean minimum and maximum temperatures of 12 and 29$^{O}$C, respectively. The major maize-growing areas of this district are in the mid-altitude of 1700 to 2200 masl. Crop diversity in Jabitahnan-Burrie-Womberma districts is better than Mecha and South Achefer. The major crops grown in this part of the study are maize, wheat, tef, finger millet, pulses, and pepper; maize is the dominant crop. Perennial crops like coffee and fruits are also commonly grown. Because of extended amounts of rainfall, high-yielding and late maturing maize varieties are commonly grown in the district.

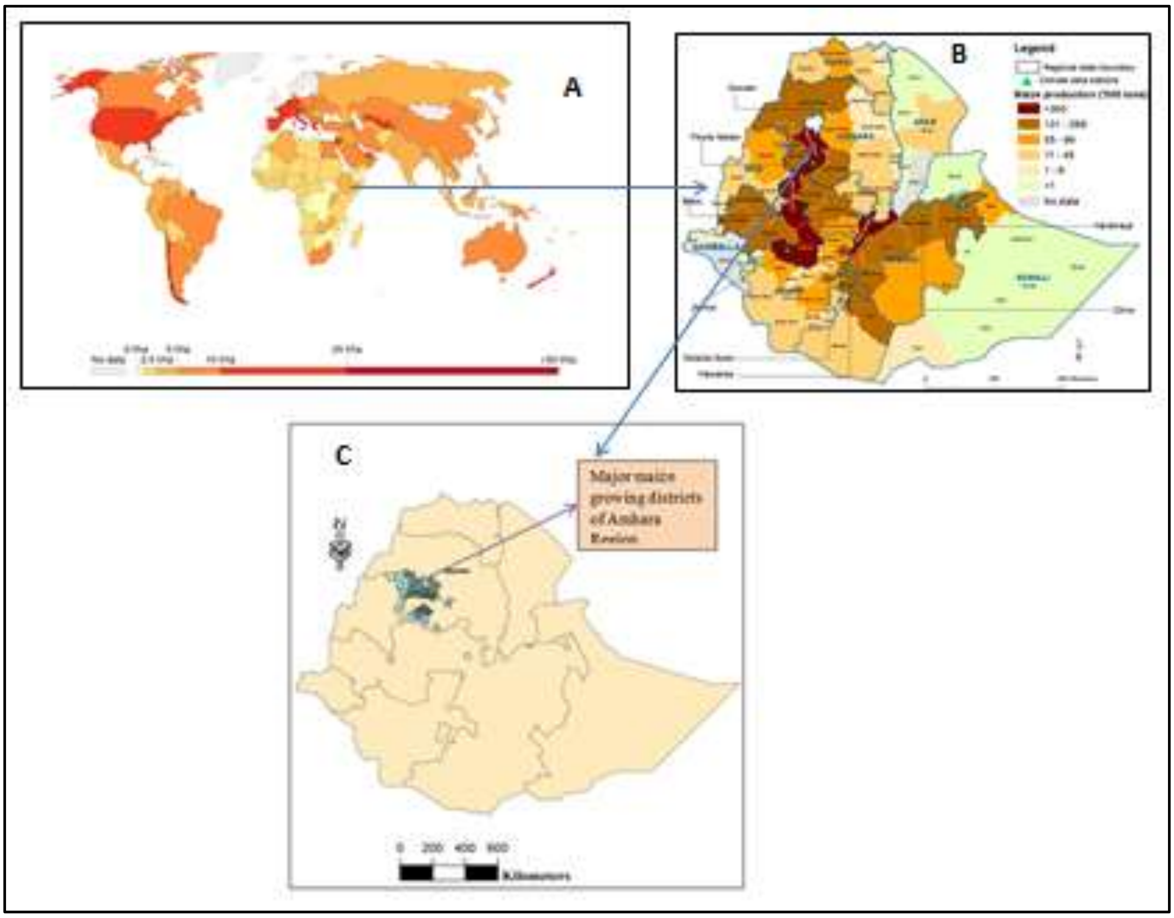


**Figure 1.** **A**: Maize productivity at global level and Ethiopian position (https://ourworldindata.org/grapher/maize-yields), **B**: Maize production and productivity in Ethiopia (Abate *et al.*, 2015), and **C**: Major maize growing districts of the Amhara National Regional State (Mecha, south Achefer, Jabitahnan, Burrie, and Womberma) where the research was conducted.

### *Experimental setup*

The nutrient omission trial was established on 30 sites per year with 11 non replicated treatments per site during the first two years. In the third year, it was established on 15 sites with treatments replicated thrice at each site. The research consisted of NPK stand-alone plots, NPK omission plots, control plots, NPK plus secondary and micronutrients, NPK plus compost, and NPK plus lime treatments (Table 1 and 2).

Table 1. Descriptions of the treatments

| Treatment | Description and justifications of the treatments |
|---|---|
| Control | Soil supplies for NPK could be evaluated |
| N | Provided sufficient N only, other nutrients from indigenous soil supply |
| P | Provided sufficient P only, other nutrients from indigenous soil supply |
| K | Provided sufficient K only, other nutrients from indigenous soil supply |
| PK | N omitted with sufficient P and K amounts applied |
| NK | P omitted with sufficient N and K amounts applied |
| NP | K omitted with sufficient N and P amounts applied. |
| NPK | Provided sufficient NPK input |
| NPKSZn | Provided sufficient NPK plus sufficient sulphur and zinc to assess the contribution of secondary and micronutrients on maize productivity. |
| NPK+Compost | Provided sufficient NPK input plus compost to assess the contribution of compost to maize productivity through its multiple effects including regulation of nutrient supply and water and air circulation. |
| NPK+ Lime | Provided sufficient NPK input plus lime to correct acidity and regulates nutrient |

Table 2. Nutrient application rates

| **Treatments** | **N** | **$P_2O_5$** | **$K_2O$** | **S** | **Zn** | **$ZnSO_4$** |
|---|---|---|---|---|---|---|
| **1. Control** | 0 | 0 | 0 | 0 | 0 | 0 |
| **2. N** | 150 | 0 | 0 | 0 | 0 | 0 |
| **3. P** | 0 | 125 | 0 | 0 | 0 | 0 |
| **4. K** | 0 | 0 | 72 | 0 | 0 | 0 |
| **5. PK** | 0 | 125 | 72 | 0 | 0 | 0 |
| **6. NK** | 150 | 0 | 72 | 0 | 0 | 0 |
| **7. NP** | 150 | 125 | 0 | 0 | 0 | 0 |
| **8. NPK** | 150 | 125 | 72 | 0 | 0 | 0 |
| **9. NPKSZn** | 150 | 125 | 72 | 20 | 5 | 25 |
| **10. NPK+ Compost** | 150 | 125 | 72 | 0 | 0 | 0 |
| **11. NPK + Lime** | 150 | 125 | 72 | 0 | 0 | 0 |

The rate of Nutrients (NPK) was applied at rates required to achieve the expected attainable yield without nutrient limitation in each location. The rate of lime was calculated based on the lime requirements developed for wheat (Agumas *et al.*, 2016.) and applied in rows at planting. The sources of nutrients were: NPS, Urea, TSP, MOP, and $ZnSO_4$. One t $ha^{-1}$ of compost was applied at planting in rows. Nitrogen was applied in three equal splits as follows: 50 kg $ha^{-1}$ at planting, 50 kg $ha^{-1}$ top-dressed at about 35 days after emergence, and 50 kg $ha^{-1}$ at about 60 days after emergence while all other nutrients were applied as basal at the time of planting. Plot sizes were 3 m by 4.5 m and the distance between plots and replications was 1 m while the distance between rows and plants was 0.75 m and 0.3 m; respectively.

*Soil sampling, preparations, and analysis*

Composite soil samples were collected at depths of 0-20 cm before planting for each site. Samples were air-dried; ground using pestle and mortar to pass through a 2-mm sieve. Soil pH was determined in a 1:2.5 soil to water suspension following the procedure outlined by Sertsu and Bekele (2000). Soil organic carbon content was determined by the wet digestion method using the Walkley and Black procedure (Nelson and Sommers, 1982). The available phosphorus was determined following the Olsen procedure (Olsen and Sommer, 1982). The exchangeable potassium was measured by flame photometer after extraction of the samples with 1N ammonium acetate at pH-7 following the procedures described by Sertsu and Bekele (2000).

*Data analysis*

The effect of independent variables (treatments) on the dependent variable (maize yield) was statistically tested. Analysis of variance (ANOVA) was carried out to assess the difference between treatments. Upon the existence of significant difference for ANOVA, ($p < 0.05$), further analysis of

were also employed to evaluate responses.

## Results and discussion

*Results of soil analysis for the study sites*

The results of soil analysis collected before planting are summarized below. The pH of the soil ranged from 4.6 to 5.5 with mean values of 5 for all the study sites of the Mecha district. In south Achefer, it ranged from 4.6 to 5.2 with a mean value of 4.9 while for Jabitahnan-Burrie-Womberma district the average value was 5.2 but with a low level of exchangeable acidity (less than 2

Mean values of the soil organic carbon (SOC) contents were 2%, 2.01%, and 1.75 % for Mecha, south Achefer, and Jabitahnan-Burrie-Womberma districts; respectively. However, there were some sites with SOC values below 1.5%. The average values of available P for Mecha, south Achefer, and Jabitahnan-Burrie-Womberma were 7.4 ppm, 3.6 ppm, and 7.6 ppm; respectively. The mean value of exchangeable potassium was 0.6, 0.61, and 0.75 cmol $kg^{-1}$ of soil for Mecha, South Achefer, and Jabitahinan-Burrie-Womberma districts; respectively.

The pH of the soil for all the sites was acidic (FAO, 1984) but with a low level of exchangeable acidity (less than 2 implying maize yield maximization could be achieved by fertilizer applications and hence acidity could not be considered as a yield-limiting factor at least for the present situation. The SOC contents of the study sites need further attention to improve the SOC for sustainable yield production, to improve crop responses and recovery of applied fertilizers as the critical value is 2% (Loveland and Webb, 2003; Murphy, 2014). Because of the low levels of SOC, the high productivity of maize for the study sites could not be expected without synthetic fertilizers application (NP). Therefore, sustainable maize production could be achieved through integrated

10.8 t $ha^{-1}$ of yield was recorded from NPK application for the year 2016 at Tyatya *Kebele* of Burrie district (only the mean values of all sites in the districts presented in Table 3). The maximum mean grain yield of maize ( $^{-}$ ) in south Achefer with NP fertilizer was recorded in 2018 cropping seasons compared to the control (2.5 t $ha^{-1}$) (only the mean values of all sites in the districts presented in Table 3).

Without nitrogen (omitting nitrogen), the use of phosphorus was not significantly different from the one without nutrient (control) as shown in Figure 3. With nitrogen alone, the yield was better than using phosphorus alone or phosphorus in combination with potassium (Table 3). But when nitrogen was combined with phosphorus, the yield surpassed the one with nitrogen alone and statistically non-significant with treatment combinations of NPK as well as NPK plus other soil amendments (lime and vermicompost). As the farming system of the maize belt in the region is dominated by cereal mono-cropping and less emphasis on soil health restoration, the sustainability of crop production might be broken into difficult situations. Our findings of highest yield records from Mecha and south Achefer districts were maize grown after lupine (*Lupinus albus*) or noug (*Guizotia abyssinica*); indicates the importance of rotation compared to the mono-cropping system or cereal after cereal rotation system.

The result was clearly separated into two groups for the majority of the sites: Treatment 1-6 in one group and treatment 7-11 in the second group (refer to Table 2 for the treatments). Therefore, the significant difference for most of the sites was between these groups while there was no significant difference between treatments above 6; indicating maximum yield potential of maize could be realized by NP fertilizers without any further cost to potassium, lime, and organic matter. The yield-limiting nutrients (NPK) were elaborated by separating the NPK treatment and the control from the rest of the treatments for all sites across the years by omitting each of the nutrients as shown in Figure 2. The yield of maize was slightly higher than the control when N was omitted and the trend was similar for all sites and years. The yield penalty for N omission accounts was higher than the yield penalty by phosphorus. The interaction effect of N and P boosted the productivity of maize as shown even with the omission of potassium (Figure 3).

The productivity of maize without fertilizer was very low compared to the fertilized ones (about less than 50%) with the exception of a few cases. This finding indicated that optimum maize production could be simply achieved by NP nutrient optimization as already analyzed by Abate *et al*. (2015). The findings of our research showed that more than three times achievable grain yield (Figure 2 and Figure 3) compared to the 3t $ha^{-1}$ of the national average (Abate *et al*., 2015) with NP nutrients alone.

In general, the yield found all over the sites across the seasons was above the national average estimated by FAO (2014) (2.5 to 5 t ha$^{-1}$) and 3 t ha$^{-1}$ (Abate *et al*., 2015), indicating the existence of large potential to boost the productivity of maize even with modern old varieties though nutrient optimization. The yield attained with our research could be the highest in the sub-Saharan countries except for South Africa (Abate *et al*., 2015; FAO, 2014; Gudeta *et al*., 2009; Gudeta *et al*., 2010).

As described above in the analysis of soils for the study sites, there was a significant difference (p< 0.01) among and between treatments. Without nitrogen (omitting nitrogen), the use of phosphorus was not significantly different from the one without nutrient (control) and hence the addition of a nutrient without nitrogen leads to economical risk for the farmers and the nation as stated by Gudeta *et al.*, (2010). With nitrogen alone, the yield was better than using phosphorus alone or phosphorus in combination with potassium. But when nitrogen was combined with phosphorus, the yield surpassed the one with nitrogen alone and statistically non-significant with treatment combinations of NPK as well as NPK plus other soil amendments (lime and vermicompost). This indicates that K is not limiting maize yield in the study areas while N and P is the yield-limiting nutrients.

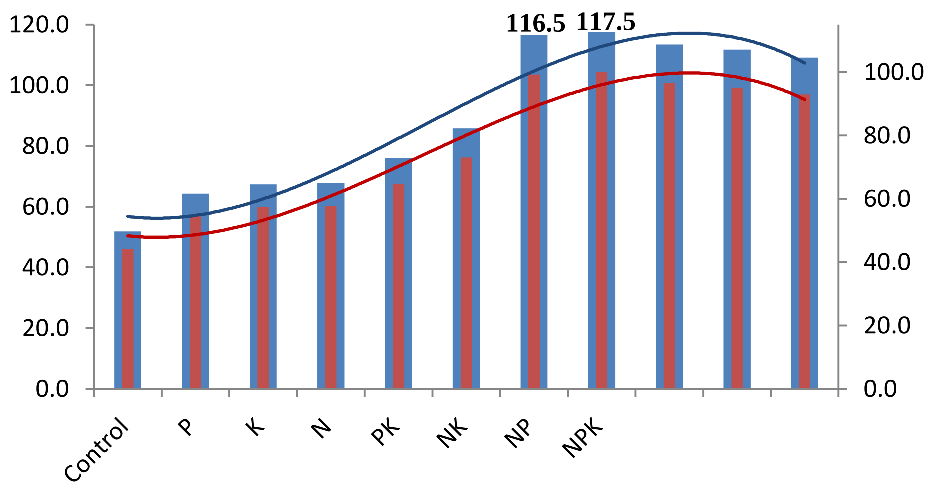


**Figure 1**. Achievable yield potentials and relative yield of maize (variety, BH 540) at Mecha district of Mekeni-Warka site (single site) in 2016 cropping season.

**Table 3**. The effect of nutrients on grain yields (t $ha^{-1}$) of maize across locations over the season affected

| | Mecha | Jabitahinan-Burrie-Womberma | South Achefer |
|---|---|---|---|

The contribution of soil organic matter to improve the efficiency of the nutrient the NPK nutrients was not significant albeit the low levels of the SOC matter all over the study areas; might be because its amount was lower or its effect might not be visible in the short term. Otherwise, the contribution of organic fertilizers to sustainable maize production in sub-Saharan African was recognized and reported (Gudeta, *et al*., 2009, Gudeta, *et al*., 2010). Abate *et al*. (2015) reported a drastic reduction in the use of organic fertilizer sources for the majority of maize-producing areas in the country in general and in the Amhara Regional State in particular. This could be due to its less competent effect compared to the synthetic fertilizers, despite high mobilizations and campaigns towards organic fertilizer, especially for compost. Our result to soil analysis and the yield responses (Table 3) supported each other indicating nitrogen and phosphorus are still the most yield-limiting nutrients and it was again in line with the findings of Amare *et al.* (2018).

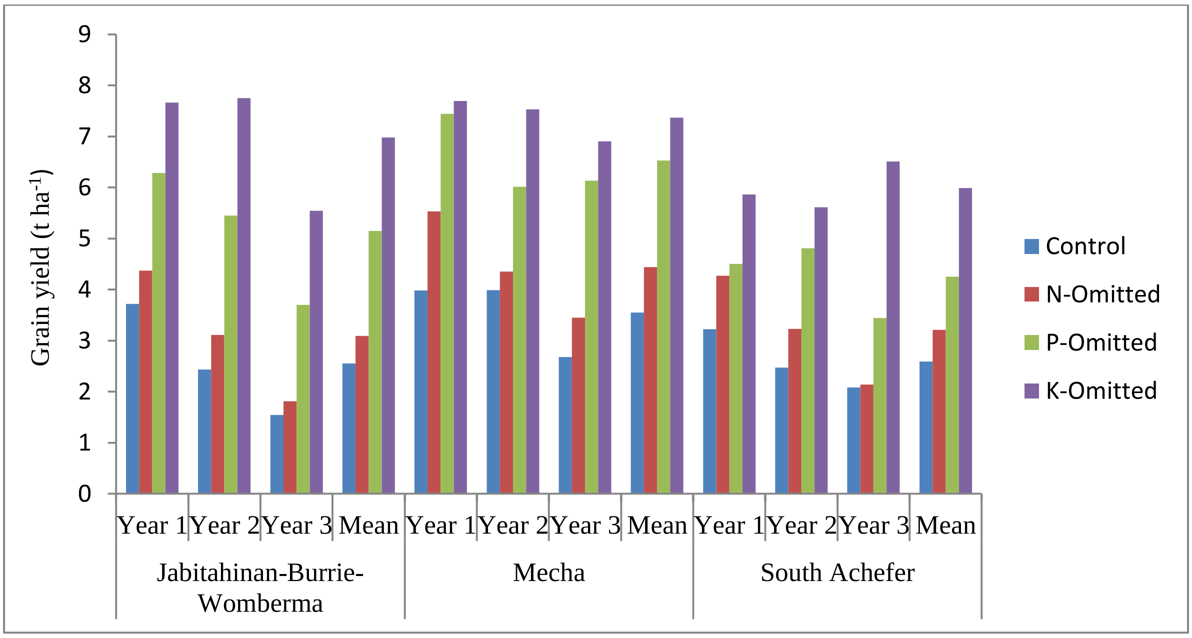


**Figure 3**. The effect of omitting each nutrient (NPK) on the yield of maize for all the study sites across the years.

## Conclusions

The research was conducted on farmers' fields for three consecutive years in the maize-growing belts of the Amhara Regional State. From the research, a strong database for maize yield related to NPK nutrients was generated. The findings of the research showed that the yield of maize could be achieved more than 10 t ha$^{-1}$ with nutrient management even using the old improved varieties (BH-66o and BH540) that were more than three times the national as well as the regional average yield. Our finding indicated maize productivity could be increased through NP nutrient management. Despite similar trends over the years and across the sites, there was high variability between fields with short distances. The only variable that caused the variability could be the history of the farm management (rotation etc.). Therefore, sustainable intensification of maize production should also take into account improving existing farm management practices (rotation, fertilizer application, disease and pest management, etc.). The yield-limiting nutrients for the production of maize for the major maize-producing areas of the region were in the order of nitrogen than phosphorus. Hence intensive research and development focus should be for only NP nutrients to attain optimum maize yield for the study areas. Our research was based on 150 kg N $ha^{-1}$ and 125 kg $P_2O_2$ $ha^{-1}$. Further research work on the appropriate rates of nitrogen and phosphorus nutrients to meet the biological and economic optimum is critically important.

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# On-Farm Verification of Different Phosphorus Levels for Cotton Production in West Gondar Zone Amhara Region

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## Abstract

*The government has launched the 'EthioSIS' project to develop soil fertility maps and generate soil fertility map-based balanced fertilizer recommendations in the country. The map shows deficiencies of seven nutrients (N, P, K, S, B, Zn, and Cu) in many soils of cultivated and cultivable lands of the Amhara region. A field experiment was carried out during the 2018 cropping season at the Metema and Tach Armacheho district, West Gondar zone, ANRS, to verify the effects of different phosphorus (P) levels on seed yield of cotton and validating the soil fertility map of the lowland areas of Amhara region. The experiment was laid out in a randomized complete block design (RCBD) with three replications and the treatment consisted of one rate of N fertilizer (46 N kg ha$^{-1}$) and four levels of phosphorus fertilizer (20, 28.26, 36.52, and 44.78 kg ha$^{-1}$). The application of different rates of*

*$^{-1}$)*

*and lowest (1910.6 kg ha$^{-1}$) seed yields were obtained from the application of 44.78 kg P ha-1 and the control plots (46 kg N ha$^{-1}$), respectively at Metema sites. At Tach Armacheho sites, the highest and lowest seed yields of 3190.7 and 2149.7 kg ha$^{-1}$were recorded for plots received treatment 5 (44.78 kg P ha$^{-1}$) and control plots (46 N ha$^{-1}$), respectively. The highest lint yield of cotton (1729.9.kg ha$^{-1}$) was obtained from treatment 5(44.78 kg P ha$^{-1}$), while the least lint yield (972.2kg ha$^{-1}$) was recorded from treatment 1(46 kg N ha$^{-1}$) at Metema sites. Phosphorus applied at the rate of 44.78 kg P ha$^{-1}$ produced maximum lint yield (1303 kg ha$^{-1}$) while lower lint yield (855.3 kg ha$^{-1}$) was recorded for the control (46 kg N ha$^{-1}$) treatment 1 at Tach Armacheho sites. The application of fertilizer rates 20 kg P ha$^{-1}$ and 64 kg Urea ha$^{-1}$ for Metema and Tach Armacheho, are economically optimum and acceptable rates for cotton production based on the partial budget analysis result of the experiment.*

**Keywords:** Cottonseed yield, Lint yield, Phosphorus, Soil fertility map

## Introduction

Cotton (Gossypium spp.) is grown in about 76 countries, covering more than 32 million ha, under different environmental conditions worldwide and world cotton commerce is about US$20 billion annually (Saranga *et al*., 2001). Cotton plays a considerable role in economic development worldwide and an important source of fiber, oil, and animal feed (Dai and Dong, 2014). China leads the world cotton production with India and the U.S. at second and third, respectively (Darren *et al*, 2009). Cotton growth, development, and maturity are greatly influenced by NPK nutrients application which increases yield and yield components and fiber quality (Xia *et al*., 2011; Adnan *et al*., 2017 and Wajid *et al*., 2017). The NPK are key nutrients required in large quantities by all crop plants and classed as major nutrient elements

Phosphorus is the second most limiting nutrient in crop production after nitrogen. Phosphorus deficiency has a large and rapid negative effect on the growth of a range of crops (Singh *et al.*, 2000). It does not occur as abundantly in the soil as N and K. The total concentration of P in surface soil varies between about 0.01 and 0.02%. Unfortunately, the measure of total P in soil has little or no relationship to the availability of P to plants (Tisdale, 2002). In a cotton crop, the critical-P concentration ranges from 0.20 to 0.31% (Crozier *et al*., 2004). Adequate phosphorus nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, root growth particularly the development of lateral roots and fibrous rootlets (Brady and Weil, 2002).

Chemical fertilizers in Ethiopia have contributed to increasing crop growth and yields to date, although there is potential for further improvement. Ethiopia's Growth and Transformation Plan (GTP) recognizes the importance of fertilizer for maintaining soil fertility and maximizing the agricultural productivity of the country. However, due to the diverse agro-ecologies (soil and climate) in the country, site-specific and soil-test-based fertilizer recommendations are indispensable. Accordingly, the MoANR and ATA have recently completed a detailed soil fertility map for the country. The map shows seven nutrients (N, P, K, S, B, Zn, and Cu) deficiencies in many cultivated and cultivable areas of the Amhara region. The new soil fertility map of the Amhara region shows that P is highly deficient (almost 100%) in the soils of the region (MoANR and ATA, 2016). Therefore, this research aimed to verify the response of cotton to P application and validating the soil fertility map of Metema and Tach Armacheho districts in the lowlands of the Amhara region.

## Materials and Methods

### *Description of the Study Area*

The experiment was conducted on the farmers' field in Metema and Tach Aremacheho Districts in the West Gondar administrative zone in the Amhara National Regional State, Ethiopia. The experimental areas are located at 35.51-37.24 and 12.25-13.14 and 36.62-37.59 and 12.78-13.29 14 longitude and latitude in Metema and Tach Armacheho respectively (Figure 1). The altitude of the areas ranges from as low as 550 to 1608 meter a.s.l.

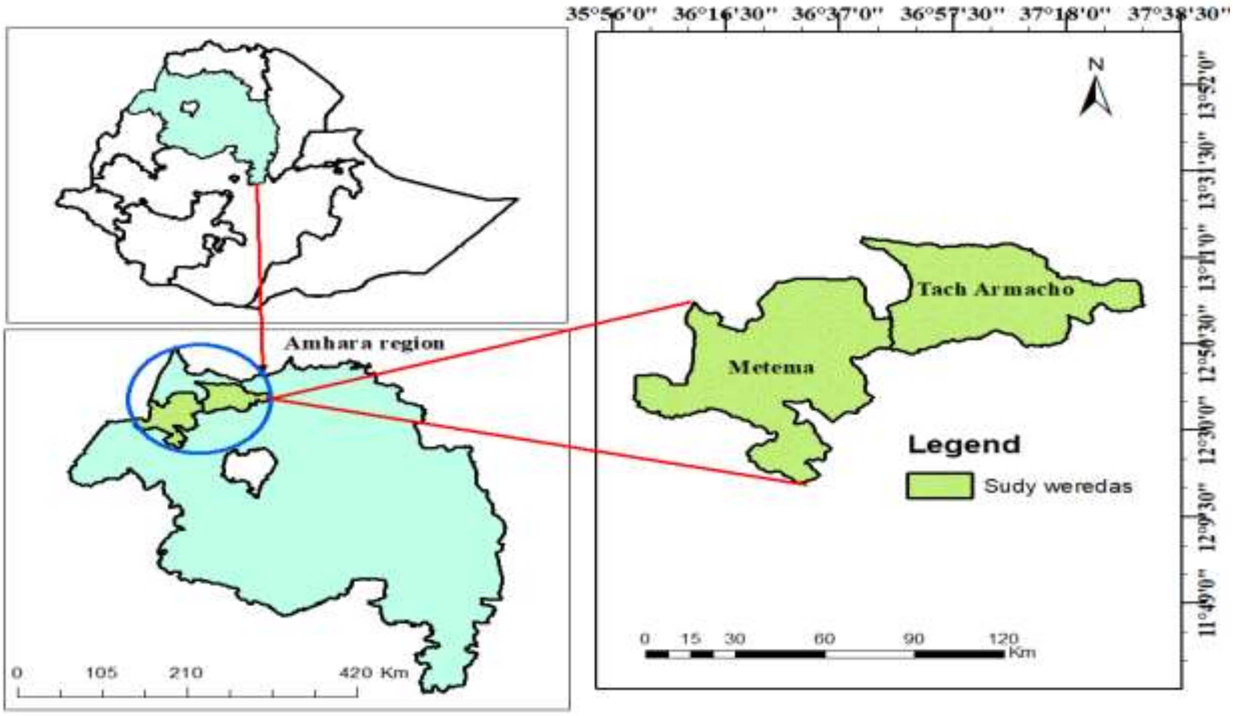


**Figure 1**. Map of the study areas.

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

### *Experimental Design and Treatments*

The experiment was laid out using a Randomized Complete Block Design. The treatments were recommended nitrogen alone (46 kg N ha$^{-1}$), 20, 28.26, 36.52, and 44.78 kg P ha$^{-1}$. The old recommendation for fertilizer use is 100 kg DAP and 100 kg Urea ha$^{-1}$. The plot size was 5.4 m *5 m for cotton. There were 1 m, 1.5 m, 45 cm, and 20 cm between plots, replications, rows, and plants, respectively.

### *Soil Sampling Technique Sample Preparation and Analysis*

Soil samples were randomly collected in a diagonal pattern before sowing from a depth of 0-20 cm. The soil samples were air-dried and passed through a 2 mm sieve for physicochemical analysis. The soil was analyzed for texture and soil total nitrogen, available phosphorous, pH, OC, CEC before sowing. The texture of the soil was determined by the hydrometer method according to (Bouyoucos, 1962). Total soil N was analyzed by the Kjeldahl digestion method with sulphuric acid (Jackson, 1962). Soil pH was determined from the filtered suspension of 1:2.5 soil to water ratio using a glass electrode attached to a digital pH meter (FAO, 2008). Organic carbon content was determined by Walkley and Black method (Walkley and Black, 1934). The available soil phosphorus was determined by the Olsen method (Olsen *et al*; 1954). Exchangeable potassium was extracted by ammonium acetate at pH 7 (Sahalmedhin and Taye, 2000) and determined by an Atomic absorption spectrometer. The cations exchange capacity (CEC) of the soil was determined following the 1N ammonium acetate extraction (pH7) method.

### *Land Preparation and Sowing*

The experimental field was prepared based on the conventional tillage practice of the area. It was manually leveled and then divided into blocks and plots; the blocks were separated by a 1.5-meter-wide open space where the plots in the blocks were 1m apart from each other. Each plot consisted of 12 rows of 5 m in length and spaced 0.45 m apart. The selected cotton variety (Delta pine 90) seeds were sown manually at the equal spacing between plants and rows with a seed rate of 20 kg/ha and depth (3-5 cm) mid-way on the row and slightly covered by soil.

### *Fertilizer Use, Thinning, and Weeding*

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

***Statistical Analysis***

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

*Economic Analysis*

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

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

Net profit = gross benefit - total cost that varies.

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

MRR = change in NB/change in TCV

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

## Results and Discussions

### *Selected soil physical and chemical properties before planting*

The pH of the soil is one of the most important properties influencing plant growth and production as it affects ion exchange capacity and nutrient availability. The pH values of the composite surface (0-20 cm) soil samples were ranged from 6.4-7.0 at Metema, which was slightly acidic to neutral in reaction. At Tach Armacheho pH of the soil samples was also ranged from 6.7-7.3 (Table 1), which was moderately alkaline in reaction. The textural class of the soil was clay. The organic carbon content of the soils of the study area was classified as low to very low (London, 1991). The reasons for the very low content of OC could be intensive cultivation of the land and the total removal of crop residues for animal feed. Moreover, there is no practice of applying organic fertilizers, such as farmyard manure and green manure that would have contributed to the soil OM pool. Ertebo and Sertsu (2002) also indicate that the organic carbon content and nutrient supplying power of most cultivated soils in Ethiopia are low. The available P content of the composite surface soil sample of the experimental sites was low. Generally, the existence of low contents of available P is a common characteristic of most soils of Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002) and the exchangeable potassium of the soil was optimum (Berhanu Debele, 2008). According to Murphy (2007), the cation exchange capacity of the soil was very high.

**Table 1**. Selected physical and chemical properties of the soil.

| Location | Parameters | | | | | |
|---|---|---|---|---|---|---|
| Metema | PH ($H_2O$) | OC | Ava. P (p/ppm) | CEC (cmol/k | Exch.$k^+$ (cmol/kg) | Textural class |
| Site 1 | 6.7 | 1.3 | 3.8 | 69.8 | 0.7 | Clay |
| Site 2 | 7 | 1.5 | 3.7 | 63.1 | 0.6 | Clay |
| Site 3 | 6.4 | 1.5 | 1.9 | 70.2 | 0.4 | Clay |
| Armacheho | | | | | | |
| Site 1 | 7.2 | 1.3 | 3.9 | 74.9 | 1.5 | Clay |
| Site 2 | 7.3 | 1.6 | 3.2 | 44.1 | 0.7 | Sandy clay |
| Site 3 | 6.9 | 1.5 | 3.5 | 58.9 | 0.9 | Clay |
| Site 4 | 6.7 | 1.4 | 4.5 | 74.2 | 0.9 | Clay |
| Site 5 | 6.9 | 1.4 | 2.5 | 62.6 | 0.7 | Silt clay |

## Yield and Yield-Related Parameters

### *Days to maturity*

Cotton plants grown on plots received treatment 1 (46 kg N ha$^{-1}$) showed a delay in maturity (155.3 days) and shorter maturity duration (124.9 days) was recorded for plants grown on plots received treatment 5 (44.78 P ha$^{-1}$) relative to plants grown on plots treated with other treatments at Metema (Table 2). Therefore, the application of phosphorus fertilizer has influenced ($P<0.05$) days to maturity of cotton at Metema sites, but at Tach Armacheho sites does not affect.

### *Cotton-seed yield*

Cotton-seed yield is a very complex attribute. It is a product of several components. The -seed yield. The highest (3226.2 kg ha$^{-1}$) and lowest (1910.6 kg ha$^{-1}$) mean cotton-seed yield was obtained from the application of 44.78 kg P ha$^{-1}$ and the control plots, respectively in Metema. There was also a significant effect between treatments in Tach Armacheho district. The yield of 3190.7 (44.78 kg P ha$^{-1}$) and 2149.7 (46 N ha$^{-1}$) kg/ha has the highest and lowest cottonseed yield, respectively. It did not show a consistent trend with increasing levels of phosphorus in the two districts. Increased cottonseed yield per hectare, as well as earliness in cotton, were achieved with increasing phosphorus levels. Sawan *et al*. (2008) also reported increased cottonseed yield per hectare with the application of increased P levels. However, the increase was non-significant between P levels.

Table 2. Effects of phosphorus levels on days to maturity, seed & lint yields of cotton in Metema and Tach Armacheho districts.

| | | | | |
|---|---|---|---|---|
| | **155.29$^{a}$** | **1910.6$^{c}$** | **972.7$^{c}$** | **2149.7$^{b}$** |
| | | **3226.2$^{a}$** | **1729.9$^{a}$** | **3190.7$^{a}$** |

*NB: DTM=Days to maturity, CSY= Cotton-seed yield, LY= Lint yield, CV= Coefficient of variance, LSD= Least significance difference, and *=Significant*

### *Lint yield*

Analysis of variance of the results revealed that the effect of P levels was significant ($p<0.05$) on the lint yield of cotton. The highest lint yield of cotton (1729.9 kg $ha^{-1}$) was obtained from plots received treatment 5 (44.78 kg P $ha^{-1}$), while the lowest lint yield (972.2 kg $ha^{-1}$) was recorded from plots treated with treatment 1 (46 kg N $ha^{-1}$) in Metema district sites. In Tach Armacheho district experiment sites, phosphorus applied at the rate of 44.78 kg P $ha^{-1}$ produced higher lint yield (1303 kg $ha^{-1}$) while lower lint yield (855.3 kg $ha^{-1}$) was recorded from the control plot with (46 kg N $ha^{-1}$), treatment 1. According to Aslam *et al*., (2009), increased lint yield of cotton per hectare was achieved with increasing phosphorus levels.

### *Partial budget analysis*

The result of the partial budget analysis revealed that the economically most fertilizer application rate varies. Since cottonseed yield is the major worry of this experiment, the economic application rates within the acceptable level of cotton seed yield. Tables 3 and 4 showed an economically feasible application rate at 20 kg P $ha^{-1}$. It has a high marginal rate of return. The other treatments were eliminated by the concept of dominance analysis since the net benefit incurred decreased as the cost increased. The highest MRR (761 and 522 Birr) was obtained from 20 kg P $ha^{-1}$ resulting in a yield of 2788.8 kg and 2814.4 cotton seeds $ha^{-1}$ (Table 3 & 4) in Metema and Tach Armacheho districts, respectively. This indicates that farmers can obtain 761 & 522 Birr extra by investing one birr buying fertilizer to apply 20 kg P $ha^{-1}$. The farmers should apply 100 kg DAP to obtain 20 kg P $ha^{-1}$. The application of phosphorus fertilizer above 20 kg P $ha^{-1}$ is not economically beneficial for both districts.

**Table 3**. Partial budget analysis of phosphorus fertilizer for cotton production in Metema district

| No. | Treatment (TSP) | Total Revenue | TVC |
|---|---|---|---|

**Table 4**. Partial budget analysis of phosphorus fertilizer for cotton production in Tache Armacheho district.

| No. | Treatment (TSP) | Total Revenue | TVC | Net Revenue | MRR (%) |
|---|---|---|---|---|---|
| | (kg) | (birr) | (birr) | (birr) | (birr) |
| 1 | 0 | 34825.1 | 0 | 34825.1 | _ |
| **2** | **20** | **45596.5** | **1652** | **43944.5** | **552** |
| 3 | 28..3 | 48830.0 | 2334 | 46496 | 109 |
| 4 | 36.5 | 47506.5 | 3017 | 44489.5 | -66 |
| 5 | 44.8 | 51689.3 | 3899 | 47790.3 | 84 |

*No.=serial number, TVC=Total vary cost, MRR=Marginal rate of return*

## Conclusions

There were significant effects of P levels on some cotton parameters such as on cotton-seed yield and lint yield in both districts. The rest parameters have no significant difference. This is not mean that no response of cotton in terms of those parameters to applying different amounts of phosphorus. The result indicated that there was a 68.8 % and 48.4 % yield advantage over the unfertilized plot on Metema and Tach Armacheho respectively. The application of fertilizer rates 20 kg P ha$^{-1}$ and 64 kg Urea ha$^{-1}$ for Metema and Tach Armacheho, are economically optimum and acceptable rates for cotton production based on the partial budget analysis result of the experiment.

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# Effect of phosphorous on Sorghum (*Sorghum bicolor*) Yield in the lowland areas of Eastern Amhara

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## Abstract

*Chemical fertilizers in Ethiopia have contributed to crop yield growth to date, although there is potential for further improvement. Phosphorus (P) is an element a primary constituent of plant and animal life. This study was conducted in East Amhara National Regional State of Raya-Kobo and Dawa-Cheffa districts in the 2018 cropping season to verify crop responses to phosphorous fertilizer. The test crop was sorghum (var. Girana one) for both districts. The treatments were: Control, Recommended NP, 50 Kg $ha^{-1}$NPS, 100 Kg $ha^{-1}$NPS, and 150 kg $ha^{-1}$ NPS with a uniform rate of nitrogen. The design was RCBD and treatments were replicated three times per site. Recommended nitrogen was used uniformly for all treatments. The collected data were subjected to analysis of variance using SAS version 9.0. The Result showed that there was no statistical significance yield difference ($p > 0.05$) between different rates of P fertilizer. Therefore, applying high amount of phosphorous fertilizers for the study districts for the test crops not advisable. Nonetheless, application of 10 Kg P $ha^{-1}$ for the maintenance of soil phosphorus is advised.*

**Keywords:** *Fertilizer, Nutrient, Phosphorous, Sorghum*

## Introduction

Chemical fertilizers in Ethiopia have contributed to crop yield growth to date, although there

recognizes the importance of fertilizer for maintaining soil fertility and maximizing agricultural growth in the country. Phosphorus (P) is an element that is a primary constituent of plant and animal life. P plays a series of functions in the plant metabolism and is one of the essential nutrients required for plant growth and development (Marschner, H., 2011). Among the most significant functions of plants on which P has an important effect are reproduction, photosynthesis, N-fixation, crop maturity (flowering and fruiting including seed formation), root development (particularly of the lateral and fibrous rootlets), the strength of straw in cereal crops, thus helping to prevent lodging and finally, quality and quantity of products (Brady and Weil, 2002).

Phosphorus availability in most soils is at a maximum in the pH range of 5.5 to 6.5. At low pH values, the retention results largely from the reaction with Fe and Al and precipitation as $AlPO_4$ and $FePO_4$ oxides. Above pH 7, Ca precipitate with P as Ca-P minerals (Tisdale et al., 2002). Phosphorous is highly deficient (almost 100%) in the soils of the region including the study sites and districts (MoANRC and ATA, 2016).

Researches were conducted in Srinka agricultural Research center in the lowland areas of Eastern Amhara indicated that there was little response to phosphorus application. The kebeles level extension workers are forced by the governments to distribute P source fertilizer like DAP and NPS to all locations irrespective of the responses. The farmers are complaining application of P fertilizers. So, it is highly important to re-examine the soil P status and crop response to applied P fertilizer for yield in different locations in the lowland areas of Eastern Amhara. Therefore, the research was conducted to verify the response of sorghum to phosphorous fertilizer.

## Materials and Methods

### *Description of experimental sites*

The experiments were conducted during the main cropping season in 2018 at Raya-Kobo and Dawa-Cheffa districts in the Eastern Amhara Region. Raya-Kobo district has an altitude of about 1468 m above sea level (masl). The district receives a mean annual rainfall, maximum and minimum temperature of 630 mm, 29 $^{O}$C, and 15 $^{O}$C respectively with considerable year to year variation. The area is characterized by seasonal moisture stress and erratic rainfall. Dawa-Cheffa is located about 325 km away from Addis Ababa in the Northeastern direction. It has an altitude ranges from 1000 to 2500 meters above sea level (masl). The district receives a maximum temperature of 33°C and a minimum temperature12°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.

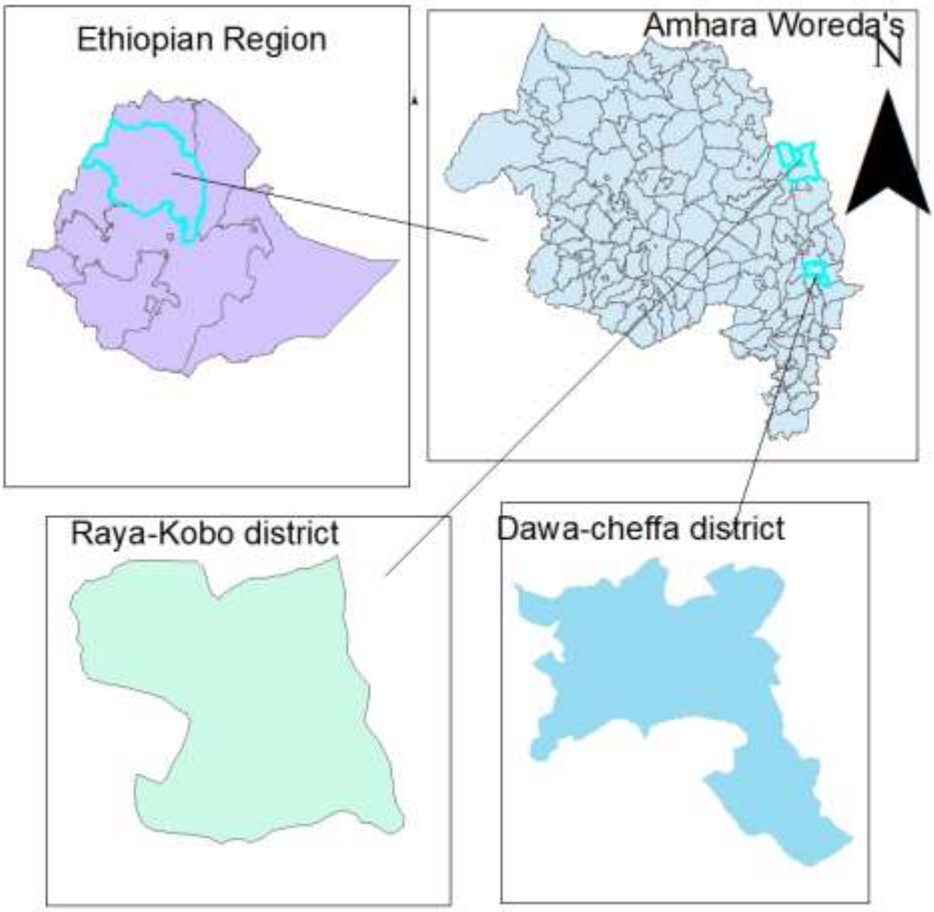


**Figure 1**. Map of the study districts

***Experimental set-up and procedures***

The experimental sites were prepared using standard cultivation practices before planting. Trial fields were plowed using oxen-drawn implements by a farmer as usual. The experiment included five levels of phosphorous. Crop and site-specific recommended nitrogen rate was applied for all treatments.

*Treatments*

The treatments used were:

1. Control (only recommended N without p fertilizer)
2. Recommended NP
3. 50 Kg $ha^{-1}$ NPS (N was adjusted to the recommended rate)
4. 100 Kg $ha^{-1}$ NPS (N was adjusted to the recommended rate) and
5. 150 Kg $ha^{-1}$NPS (N was adjusted to the recommended rate).

The recommended rate of 69 Kg $ha^{-1}$N and 69 Kg $ha^{-1}$ $P_2O_5$ was applied for both districts. The rate of Nitrogen was equal for all treatments in the location.
Treatments were randomized laid in a randomized complete block design (RCBD) with a plot size of 5m x 4.8m ($24m^2$) with three replications for each site and four sites per district. The spaces between plots and blocks were 0.5m and 1m respectively. Spacing between plants and rows were 15cm and 75 cm respectively. Girana one sorghum variety was used as a test crop. Sowing was done the first week of July. Phosphorus was applied as triple super-phosphate for recommended rate (treatment two) and NPS for the rest rates of phosphorous and also nitrogen was from NPS and Urea. Nitrogen was applied half at planting and half at knee height stage just after weeding with the presence of small rainfall. Karatin was sprayed for the protection of boll armyworm during the vegetative stage. The experiments were maintained to be free of weeding.

***Sampling and data collection***

*Soil data collection and analysis*

Surface soil samples (0-20 cm) were collected randomly in a zigzag pattern before sowing from the entire experimental field and composited. The soil samples were air-dried and passed through a 2 mm mesh sieve and analyzed in Sirinka Agricultural Research Center. Selected chemical and physical soil properties (texture, pH, OC, Total N, and available P) were determined. Soil pH was determined from the filtered suspension of 1:2.5 soil to water ratio using a glass electrode attached to a digital pH meter (potentiometer). The texture of the soil was determined by the hydrometer method. Organic carbon and total nitrogen were determined by the method of Walkely and Black (1934) and Kjeldahl methods, respectively, while, available phosphorus was determined by the methods of Olsen (1954).

***Yield and Yield components***

Harvesting was done from the third week of November to the last weeks of November. To measure total aboveground biomass and grain yields the central 4 rows of each plot were parameters such as grain yield, plant height, and aboveground biomass were collected as follows:

***Grain yield:*** Grain yield was measured by harvesting the crop from the net middle plot area to avoid border effects, after threshing seeds were cleaned and weighed, and adjusted to a moisture content of 12.5% using grain moisture analysis result.

***Biomass yield:*** At maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area was harvested and the biomass was measured (dry matter basis). Stalk sample was collected randomly at harvesting to adjust dry biomass based on moisture content using the oven drying method.

***Data analysis***

Collected data were subjected to analysis of variance using SAS version 9.0. The least significant difference (LSD) test at a 5% level of significance was used to compare the means.

## Results and Discussions

***Physico-chemical properties of the soil***

The results of soil analysis (Table 1) showed that the soil had moderate total nitrogen content in all experimental sites (Tekalign, 1991). The soil organic matter ranges from 1.55-2.95% in Dawa-Cheffa and 1.63-2.48 % in Raya-Kobo which is categorized under low to moderate content of organic matter according to Berhanu (1980) in both districts. The laboratory results also indicated that the textural class of the experimental site was clay & clay loam based on USDA textural classification. The soil test result reveals that the available phosphorus content of the soil is based on the rating of Olsen (1954) categorized under high range for both districts. According to this result, the soil data implies that available p is optimal for crop production & Phosphorous fertilizer application is not mandatory.

**Table 1**. Result of soil parameters taken at planting.

| Site | pH | OM (%) | TN (%) | Available P (ppm) | Textural class |
|---|---|---|---|---|---|
| - | - | - | - | - | |
| - | - | - | - | - | |

*Note: pH=power of Hydrogen, OM=organic matter, TN=total nitrogen, P=available phosphorus*

***Sorghum yield response to applied phosphorous fertilizer***

The statistical analysis indicated that grain yield of sorghum (Girana one) not significantly ($p>0.05$) responded (i.e., Yield increases compared to the control) to phosphorous application rates for districts (Table 2 & 3). But the highest Grain yield was observed from the application of - - 57 - $P_2O_5$+69 - N (Table 3) - -

**Table 2** - -

| | | | | | |
|---|---|---|---|---|---|
| LSD (5%) | NS | NS | NS | NS | NS |

**Table 3**. Effect of P fertilizer on sorghum Grain yield ($Kgha^{-1}$) at Dawa- Cheffa

| Treatment | Farm 1 | Farm 2 | Farm 3 | Farm 4 | Means |
|---|---|---|---|---|---|
| 69 N only | 5660 | 3382 | 4672 | 3357 | 4268 |
| 19$P_2O_5$+69N | 5965 | 3216 | 4590 | 3459 | 4307 |
| 38$P_2O_5$+69N | 6090 | 3757 | 4506 | 3756 | 4527 |
| 57$P_2O_5$+69N | 6076 | 3672 | 4388 | 4209 | 4586 |
| 69$P_2O_5$+69N | 5591 | 3964 | 4454 | 3672 | 4420 |
| LSD (5%) | NS | NS | NS | NS | NS |
| CV (%) | 7.6 | 22.6 | 9.6 | 12.6 | 12.3 |

In addition to grain yield, biomass yield response of sorghum to phosphorus fertilizer was not significant from a statistical point of view. But, with some irregularities, the result indicates an increasing trend with an increase in P rates (Table 4 and 5).

**Table 4**. Biomass yield (kgha$^{-1}$) of sorghum at Raya-Kobo

| Treatment | Farm 1 | Farm 2 | Farm 3 | Farm 4 | Means |
|---|---|---|---|---|---|
| 69 N only | 15486 | 25870 | 12977 | 24850 | 19796 |
| $19P_2O_5$+69N | 15519 | 26999 | 13686 | 24486 | 20173 |
| $38P_2O_5$+69N | 17035 | 25343 | 14069 | 27202 | 20912 |
| $57P_2O_5$+69N | 16764 | 28625 | 12847 | 26260 | 21124 |
| $69P_2O_5$+69N | 19198 | 26477 | 11758 | 25030 | 20616 |
| CV (%) | 13.2 | 8.7 | 15.2 | 12 | 11.36 |

**Table 5**. Biomass yield (kgha$^{-1}$) of sorghum at Dawa-Cheffa

| Treatment | Farm 1 | Farm 2 | Farm 3 | Farm 4 | Means |
|---|---|---|---|---|---|
| 69 N only | 20482 | 13406 | 11906 | 12638 | 14608 |
| $19P_2O_5$+69N | 19157 | 12380 | 12687 | 12764 | 14247 |
| $38P_2O_5$+69N | 21653 | 12491 | 12295 | 14568 | 15252 |
| $57P_2O_5$+69N | 21805 | 14240 | 11624 | 15326 | 15749 |
| $69P_2O_5$+69N | 19038 | 14818 | 11496 | 13141 | 14623 |
| LSD (5%) | NS | NS | NS | NS | NS |
| CV (%) | 12.6 | 13.5 | 7.2 | 14.4 | 12.75 |

It is known that Phosphorus is a macronutrient that plays several important roles in plants. Crop response to applied P fertilizer depends on the quantity of plant-available P already in the soil and the ability of a crop to take up it. An adequate supply of available P in soil is associated with increased root growth, which means roots can explore more soil for nutrients and moisture. This result disagreed with the work of Alemu *et al*., (2016) who found that the application of 46 kg ha$^{-1}$ $P_2O_5$ gave 134.82% biomass yield increment over the control. Gebrekidan (2003) stated that the application of 46 $P_2O_5$ fertilizers with N and moisture conservation increases the grain yield of sorghum up to 38% in the moisture stress areas of Eastern Ethiopia. In addition to this Masebo and Menamo, (2016) also reported that nitrogen and phosphorus fertilizer increases the grain yield of sorghum. However, the response of sorghum biomass yield to the different phosphorus rates was not statistically significant in this research.

Plant availability of P can be also affected by soil pH. Soil P is slightly more available in a pH range of 6.0 to 7.5 pH (McKenzie, 2013) which agrees with our study site soil pH values. This finding also in line with Bereket *et al*, (2014) which states in fields with higher initial soil phosphorus levels, there is no need of applying phosphate fertilizer. McKenzie, (2013) states that soil moisture and temperature affect P availability. Optimal soil moisture and temperature can help accelerate microbe activity, thereby releasing more P from organic matter. Temperature is the most important climatic factor controlling soil N and P cycles. Temperature increases generally facilitate the decomposition of soil organic matter and accelerate the accumulation of soil available nutrients (Conant, *et al*. 2011).

Beegle and Durst (2002) revealed that phosphorus nutrition could be affected by root growth. Factors affecting root growth will affect the ability of plants to get adequate phosphorus. Young seedlings have limited root growth. Due to this, it may be affected by phosphorous deficiency even if the soil has a high available phosphorous level. But the test crop for this research was deep-rooted which could be exploring adequate phosphorous in the soil solution and also during seedling stage deficiency symptom of phosphorous was not observed. The ability of a plant to take up phosphorus is largely due to its root distribution relative to phosphorus location in soil. Because phosphorus is very immobile in the soil, it does not move very far in the soil to get to the roots. Kamran (2018) stated that phosphorus sources have a significant effect on producing crops such as application of phosphorus from TSP (Triple Super Phosphate) increased the yield and yield components of maize. For this study, TSP and NPS were the sources of P fertil a significant yield difference. Grain yield of sorghum significantly affected by combination of NP fertilizer rate (Workat and Merse, 2018).

Farmers were forced to apply an excess amount of phosphorous fertilizer in the study districts without additional yield increments, but this over-application can lead to the buildup of phosphorus in the soil. The source of phosphorous fertilizer was DAP and NPS in the districts. The amounts required vary from field to field because of heterogeneity in the inherent P fertility of agricultural soils due to parent material, soil types, and agricultural practices. In this research work, the crop response result strengthens the soil results which indicate high available P in the study districts. In the study, district farmers are selective in applying nutrients to crops and commonly prioritize crops that have a higher and immediate benefit in terms of income and food security than perennial crops with long-term benefits. Not only crops but also, they select appropriate fertilizer type which gives high grain and biomass yields relatively. Most of the time the farmers apply urea fertilizers during the vegetative stage of the crop and when the crop stand is poor.

## Conclusion and Recommendation

Phosphorus is the second most limiting soil nutrient in crop production. The application of the right amount of fertilizer is necessary to achieve maximum yield. As indicated in the differences for different phosphorous fertilizer rates and sources (TSP & NPS). So that for such area no need of applying high amounts of phosphorous fertilizer rather than applying small amounts for maintenance (10 P ha$^{-1}$), and also to save farmers from the extra expenditure. Applying a high amount of P fertilizer from different sources in such areas is economically wasteful and can also damage the environment.

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# Verification of phosphorus on teff (*Eragrostis teff*) and bread wheat (*Triticum aestivum)* yields in Vertisols of Eastern Amhara

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## Abstract

*Plants utilize nutrients in different ways, and each plant has a different set of nutrient requirements. The biological activity contributes to P solubilization through mineralization, weathering, and other physicochemical reactions, so that the plow layer is the major source of soil available p for crops. This study was conducted in East Amhara National, Regional State of Jamma district in the 2018 cropping season to verify the yield of teff and bread wheat due to phosphorus fertilizer application. Teff (variety, Dega teff) and bread wheat (variety,*

*50 Kg ha$^{-1}$NPS, 100 Kg ha$^{-1}$NPS, and 150 kg ha$^{-1}$NPS. The design was RCBD and treatments were replicated three times per site. Recommended nitrogen was used uniformly for all treatments. Collected data were subjected to analysis of variance using SAS version 9.0. Results indicated that applications of P fertilizer significantly improved the grain yield of wheat and teff. The result showed that there was a statistical significance yield difference ($p < 0.05$) between different rates of P fertilizer. So, the application of P fertilizer is essential for the study district.*

**Keywords:** *Mineralization, Nutrient, phosphorous, Teff, Wheat, yield*

## Introduction

Sustaining soil fertility and enhancing crop production on smallholder farms is a critical challenge in Ethiopian agriculture. Fertilizer recommendation in Ethiopia was mainly based on very general crop-specific guidelines or more often, a single blanket recommendation for most crops (100 kg urea $ha^{-1}$ and 100 kg DAP $ha^{-1}$). This blanket application can lead to excesses or deficiency in relation to plant nutrient requirements. Increasing climate erraticism, declining soil fertility status of the soil, inadequate land size, and low crop and livestock productivity is the major challenges of the Ethiopian agricultural sector (Agegnehu and Amede 2017).

Plants utilize nutrients in different ways, and each plant has a different set of nutrient requirements. How, where, and when plants utilize nutrients can greatly affect the overall yield and plant production. For a farmer seeking to maximize crop yields and lower input costs, it can be critical to understanding Phosphorus is the second most important nutrient after nitrogen in Ethiopia, which is a particularly most limiting nutrient in areas where the soil is acidity or alkalinity problem. Phosphorus is critical in the early developmental stages of growth, and in energy transfer within the plant throughout the growing season (Hodges, S.C., 2010) as well as for maturity. Availability of phosphorus from fertilizers may be affected by the soil reaction, the degree of soil phosphorus deficiency, rate, and method of application.

The biological activity contributes to P solubilization through mineralization, weathering, and other physicochemical reactions, so that the plow layer is the major source of soil available p for crops. In regions of developed countries where intensive livestock production occurs, disposal of animal manure on relatively small land base has led to a massive accumulation of soil available p, as well as more soil organic matter and buildup of organic P compound (Ziadi et al., 2013). According to ATA and the Ministry of Agriculture and Natural Resource (2016), phosphorous fertilizer is recommended for entire of the district. So, it is highly important to re-examine the soil P status and crop response to applied P fertilizer for yield in the Jamma district of Eastern Amhara. Therefore, the current research was designed to verify the response of teff and wheat crops to phosphorous fertilizer application.

## Materials and Methods

*Description of experimental sites*

The experiments were conducted during the main cropping season of 2018 in Jamma district. Jamma district lies between the geographical coordinates of 10$^{o}$ $^{o}$ 39$^{o}$ $^{o}$ an altitude of 2630 meters above sea level (masl) (Figure 1) and the rainfall patterns of the district are indicated in Figure 2. The dominant soil type of the study district is Vertisols. The major crops widely grown in the study areas include wheat, teff, and faba bean.

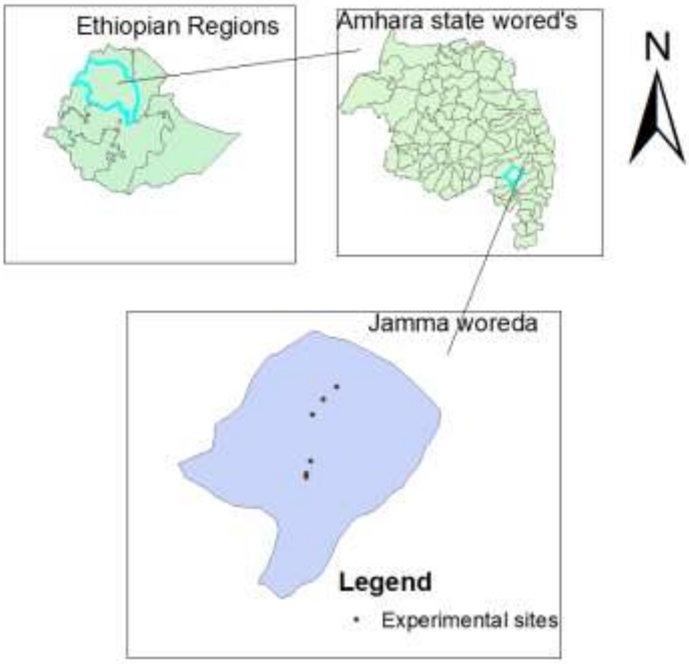


**Figure 1**. Location of Jamma district and experimental sites

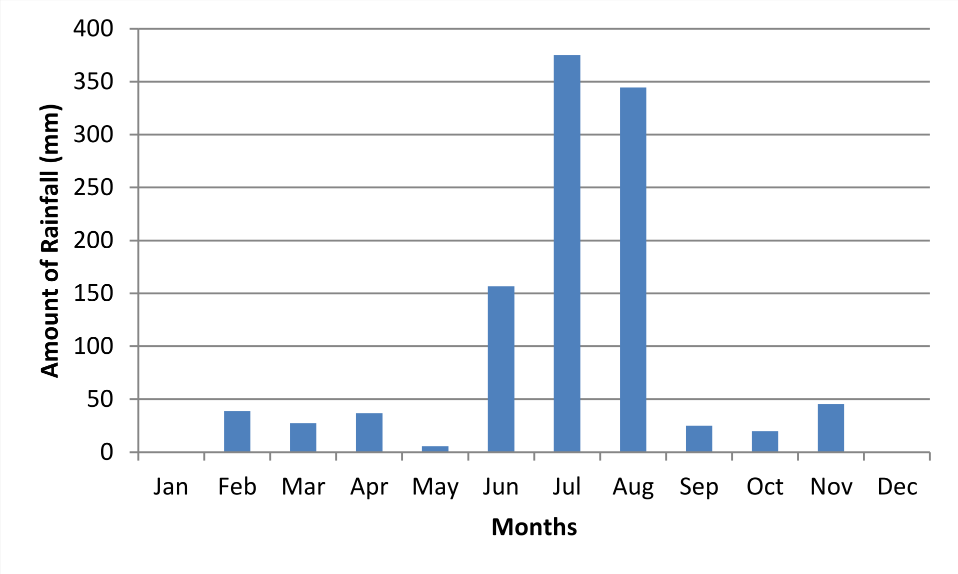


**Figure 2**. Monthly Rainfall of Jamma District in 2018

***Experimental set-up and procedure***

The experimental sites were prepared using standard cultivation practices before planting. Trial fields were plowed using oxen-drawn implements by a farmer as usual. After plowing broad bed furrow (BBF) was prepared manually, in order to drain excess water in the experimental sites. The experiment comprised of five levels of phosphorous (0, 19, 38, 57 and recommended $P_2O_5$kg ha$^{-1}$). The full recommended nitrogen rate was applied for all treatments uniformly and clearly indicated below.

***Treatments:***

1. Crop and location-specific recommended N only
2. Recommended (crop and location-specific) NP
3. 50 kg ha$^{-1}$ NPS (N was adjusted to recommended)
4. 100kg ha$^{-1}$ NPS (N was adjusted to recommended) and
5. 150kg ha$^{-1}$ NPS (N was adjusted to recommended).

The recommended N & P rates were: 115 kg ha$^{-1}$ N & 69 kg ha$^{-1}$ $P_2O_5$ for wheat. While for teff 92 kg ha$^{-1}$N & 46 kg ha$^{-1}$$P_2O_5$.Recommended nitrogen rate was uniformly applied for all the treatments. Treatments were arranged in a randomized complete block design (RCBD). Plot sizes were: 5m by 5m (25 m$^2$) for teff and 5m by 4.8m (22m$^2$) for wheat. Treatments were replicated three times for each site. Three sites for teff and five sites for wheat were addressed. BBF (80cm *40 cm) was used for wheat production. The spaces between treatments and blocks were 0.5 m and 1 m, respectively for both crops. Spacing between rows was 20 cm for wheat and teff was planted as broadcast. Sowing was done in the second week of July for teff and wheat trials. Phosphorus was applied as triple super-phosphate for recommended rate of NP (for treatment two only) and NPS for the rest rates of phosphorous and also nitrogen was from NPS and Urea. Nitrogen was applied half at planting and the other half at tillering stage for teff and wheat with the presence of small rainfall.

***Sampling and data collection***

***Soil data collection and analysis***

Surface soil samples (0-20 cm) were collected randomly in a zigzag pattern before sowing from the entire experimental field for the analysis of texture, pH, OC, TN, and available P. Soil sample were air-dried and passed through a 2 mm mesh sieve and analyzed at Sirinka Agricultural Research Center. 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 (potentiometer). The texture of the soil was determined by the hydrometer method. Organic carbon and total nitrogen were determined by the method of Walkely and Black (1934) and Kjeldahl methods, respectively. Available phosphorus was determined by the methods of Olsen (1954).

***Yield data***

Harvesting was done in the second week of December for wheat and in the first week of January for teff. To measure total above-ground biomass and grain yields the central BBF was harvested for wheat and the teff above-ground biomass was harvested using quadrant (4m*4m). At maturity, the whole plant parts, including leaves, stems, and seeds from the net plot area were harvested. Then the biomass was measured (dry matter basis). Grain yield was measured by harvesting the crop from the net middle plot area to avoid border effects after threshing seeds were cleaned, weighed, and adjusted to a moisture content of 12.5% using grain moisture analysis result (only for wheat crop).

***Data analysis***

Analysis of variance was carried out for the yield using SAS Version 9.0. Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) procedures test at a 5% level of significance.

## Result and discussion

*Physico-chemical properties of the soil*

The results of soil analysis (Table 1) showed that the soil had moderate total nitrogen content in all experimental sites (Tekalign, 1991). The soil has organic matter (Table 1) which ranges from 0.86%-1.61% which is categorized under the low range (Berhanu, 1980). The textural class of the experimental site is clay-based on USDA textural classification (Hillel, 1998). The soil test result (Table 1) reveals that the available phosphorus content of the soil was moderate to high level based on the rating of Cottenie (1980).

**Table 1**. Result of soil parameters taken at planting.

| Site | pH | OM (%) | TN (%) | Available P (ppm) | Textural class |
|---|---|---|---|---|---|
| | - | - | - | - | |
| | - | - | - | - | |

*Note: pH=Power of Hydrogen, OM=Organic matter, TN=Total nitrogen, P=Phosphorus*

***Yield and yield-related data***

***Teff yield response to applied phosphorous fertilizer***

The combined analysis indicated that grain yield of teff was not significantly (p 0.05) responded (i.e., yield not increased relative to the control) to different phosphorus rates. As observed in the result (Table 2) among the three sites in two sites, there was no statistically significant yield variation among different P rates and without P treatments while for one site there was a significant yield difference among different phosphorus rates. The highest grain yield (1532 Kg $ha^{-1}$) of teff was recorded with the application of recommended rate of nitrogen and phosphorus fertilizer ( - - without statistical significance difference with the application of different rate of phosphorous. According to the combined statistical analysis above ground biomass yield of teff was not statistically significant ($p > 0.05$) between the different rates of phosphorus and control (without P treatments). The highest biomass yield was obtained from the application of 46 Kg $ha^{-1}$ $P_2O_5$ (Table 4).

**Table 2**. Effect of P fertilizer on teff grain yield (kg ha$^{-1}$)

### *Wheat yield response to applied phosphorous fertilizer*

Applications of different rates of phosphorus were significantly affecting (*P*
biomass yield of wheat (Table 3). Except, Farm 3 (Table 3) and Farm 2 (Table 5) in all sites application of different rate of P fertilizer increase yield of wheat in comparison with control (without P fertilizer application). This result implies that the application of phosphorus with nitrogen fertilizer increases the yield of wheat in Vertisols of Jamma district. The highest grain yield (2646 Kgha$^{-1}$) and biomass yield (6087 Kgha$^{-1}$) were obtained from the application of 57 kg ha$^{-1}$ $P_2O_5$ with 115 kg ha$^{-1}$ N. Application of 57 kg ha$^{-1}$ $P_2O_5$ with 115 kg ha$^{-1}$ nitrogen resulted in 22% and 26% grain yield and biomass yield advantage over the control (without P treatment) respectively (Table 3 and 5).

**Table 3**

| Treatment | Farm 1 | Farm 2 | Farm 3 | Farm 4 | Farm5 | combined |
|---|---|---|---|---|---|---|
| 92 N only | 2140 | 2095 | 3165 | 1921 | 1477 | 2160 |
| 19$p_2o_5$+115N | 2817 | 2243 | 3362 | 2276 | 1616 | 2463 |
| 38$p_2o_5$+115N | 2774 | 2379 | 3513 | 2154 | 1794 | 2523 |
| 57$p_2o_5$+115N | 2498 | 2546 | 3597 | 2370 | 2218 | 2646 |
| 69$p_2o_5$+115N | 2305 | 2742 | 3397 | 2138 | 1852 | 2487 |
| CV (%) | 11.0 | 12.6 | 8.9 | 10.8 | 17.2 | 11.8 |
| LSD (0.05) | 520 | 569 | 575 | 445 | 580 | 213 |

| Treatment | Farm 1 | Farm 2 | Farm 3 | Combined |
|---|---|---|---|---|
| 92 N only | 5889 | 6903 | 7768 | 6853 |
| 19$p_2o_5$+92N | 6396 | 7275 | 7692 | 7121 |
| 38$p_2o_5$+92N | 6322 | 6728 | 7225 | 6759 |
| 46$p_2o_5$+92N | 6089 | 8347 | 7440 | 7292 |
| 57$p_2o_5$+92N | 6750 | 7618 | 7365 | 7244 |
| CV (%) | 5.5 | 6.3 | 8.5 | 11.3 |
| LSD (0.05) | 647 | 867 | 1198 | 376.5 |

The results of this study showed that the use of chemical phosphorus fertilizer in combination with nitrogen consistently enhanced the grain yield of wheat and teff compared to inorganic nitrogen fertilizer applied alone. But the result of pre-planting soil shows high available phosphorus in the study sites. The result obtained disprove the thought that there is no increase in yield or benefit to crop quality when; applying phosphorus to soil having sufficient readily-plant-available P. The result of this research disagreed with the findings of Bereket *et al.*, (2014) who stated that for areas with higher initial soil phosphorus application of phosphate fertilizer is wastage for wheat production. On the other hand, continuous application of phosphate fertilizers in time tends to increase the level of this nutrient in the soil and in particular its level in the labile forms which can release phosphorus to the soil solution (Brady and Weil.,2002). As indicated in Table 1, the pre-planting soil analysis result shows the high level of available P. Even if the soil data revealed the high range of available P; both crops responded to applied P fertilizers.

**Table 5**

| | | | | | |
|---|---|---|---|---|---|
| 4533 | 4533 | 7167 | 1921 | 3767 | 4800 |
| 6233 | 4733 | 7900 | 2276 | 3867 | 5560 |
| 6567 | 5333 | 9033 | 2154 | 4233 | 5953 |
| 5667 | 5567 | 8700 | 2370 | 5167 | 6087 |

there was no significant difference between and among treatments. To say there is crop response to applied phosphorus there must be a visible difference between treatments that received the targeted nutrient and without. Plants showed normal growth with the application of phosphorus and resulted in improved agronomic traits which lead toward improved grain yield.

**Conclusions and Recommendations**

Application of phosphorus fertilizer significantly affected wheat but not for teff grain yield over the control. The combined analysis over sites indicates that there was a significant yield response of wheat grain yield to the application of phosphorus fertilizer. In addition to grain yield, biomass yield of wheat was significantly affected by different rates of phosphorus fertilizer but biomass yield of teff was not affected by phosphorus fertilizer. In this result, there was no significant yield difference between different rates of applied phosphorus for grain and biomass yield of teff. This implies that a small amount of P fertilizer could be sufficient to increase the yield of both crops. Therefore; appropriate phosphorus fertilizer rate determination should be needed with different rates of nitrogen fertilizer in the districts for both crops.

**Acknowledgment**

We would like to express our sincere appreciation to Sirinka Agricultural Research Center for funding the research fund and for supporting most of the research materials and equipment to undertake the research. Many thanks to Sirinka Agricultural Research Center soil and water management researchers and Jamma research site researchers who devoted much of their valuable time to this work.

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# Concentrations of Plant Nutrients and Heavy Metals in Sludge from Kombolcha Textile Factory, North Central Ethiopia

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## Abstract

*Waste effluents from textile industries have been reported as a major environmental threat because of large amounts of water and dyes involved in the manufacturing processes. A study was carried out to quantify concentrations of plant nutrients and heavy metals in textile sludge. Samples were collected from Kombolcha textile factory, located in north-central Ethiopia. Nitrogen, phosphorus, and potassium were determined following standard procedures. Subsamples were dry digested for extraction of micronutrients and heavy metals. The concentrations of micronutrients and heavy metals were determined by ICP-OES with a radial plasma test tube. Results revealed that nitrogen, phosphorus, and potassium contents of textile sludge were 1.665, 0.29, and 0.358%, respectively. The mean concentrations of heavy metals in mg/kg were Cu (846.25) Fe (17340.60), Zn (597.73), Ni (30.83), Co (6.66), Mn (1165.43), Cr (71.01), Cd (2.25), Hg (2.96), Sn (60.03), Pb (27.70), As (10.72)). All the heavy metals concentrations, except Pb and Cr in the sludge samples, were higher than the acceptable ranges set by WHO to use the sludge as a fertilizer in agricultural soil. Based on the results from this study, it can be concluded that pre-treatment processes in order to reduce concentrations of heavy metals are mandatory before the sludge to be used as a soil conditioner or fertilizer for agricultural production.*

**Keywords:** *Fertilizer, Macro and micronutrients, Textile Effluents, Toxic metals*

## Introduction

Textiles being the essential necessitate of human being undoubtedly, textile industries have great trade and industrial significance. The textile industry involves the processing of raw materials and fabric into finished cloth involving various stages of processes and operations consuming large quantities of water and various types of chemicals and dyes (Adinew, 2012). In addition, the input of a wide range of chemicals and dyestuffs, which are generally organic compounds of complex structure is required for those processes (Gaber et al.,2011).

Uses of wide ranges of chemicals and dyestuffs and discharge of effluents in the processes of manufacturing have placed textile industries in the kind of most polluting industries in the world. Typically, textile effluents contain dissolved organic and inorganic substances, colloidal or suspended forms and it is typically colored due to the presence of residual dyestuffs. In addition, it is often contaminated with non-biodegradable organics termed refractory materials. Detergents are typical examples of such materials. Textile wastewater from dyeing and finishing processes is the major cause of environmental pollution. As a consequence; textile waste effluents cause grave environmental problems and concerns. Being one of the biggest industries, Textile, and dyeing, are now observed as a major environmental risk in the industrial area of Ethiopia and they contribute vast amounts of sludge in wastewater treatment processes (Mehari and Mulu, 2013). The final removal of industrial sludge in the country has become a critical issue due to public concern and the limited land for waste disposal. The most effective line of management is to reuse or reduce the quantity of sludge produced by various industrial processes. If a reduction is not practicable, then the reuse is the most alternate management option of sludge as to be considered (Aziz e*t al.* 2012). Although characteristics of sludge depend on the wastewater treatment process and sludge stabilization methods, it contains substantial amounts of toxic heavy metals (Singh *et al*.,2004)

Heavy metals are very unsafe because of their toxic nature to the organism, elongated natural half-lives, and their perspective to be accumulated in different body parts (Manaham, 2005). Too much accumulation of heavy metals in agricultural soils through the application of textile wastewater may not only result in soil contamination but also affect food quality and safety (Wilson and Pyatt, 2007). Heavy metals such as Cd, Pb, Cu, Zn, and Ni have carcinogenic or toxic effects on human beings and the environment (Muchuweti and Lester,2006)

Heavy metals like cadmium, copper, zinc, chromium, and iron have also been found in the dye effluents. As all of them are not enclosed in the final product, they may be thrown away and caused disposal problems. Huge quantities of unused materials including dyes in the wastewater generated during various stages of textile processing with inappropriate waste management practices i.e. straight discharge of wastewater into an environment that can affect ecological status by causing various adverse effects(Muchuweti and Lester,2006). Subsequently, this can lead to contamination of surface and groundwater; affect public health and atmosphere due to diffusion of bad odor problems from wastes. It is usually expected that the textile effluents contain highly toxic dyes, salts, acids, alkalis, and bleaching agents (Udom and Agbim, 2004). If applied to soils, the actual toxicity of heavy metal will affect the organic matter, pH, and biological properties of soil. The health effects of exposure to heavy metals depend on the quantity and length of coverage, *i.e*. the volume of contaminated soil or food consumed over time (Wong and Min, 2002)

Land application of textile sludge can be an excellent solution, whereas it is a lucrative retention method for treatment plants and also can provide a complimentary fertilizer for agricultural lands (Kocasoy and Sahin, 2007). Analysis of plant nutrients and organic matter contents in textile sludge conducted in Bangladesh indicates its potential application as a fertilizer (Kocasoy and Sahin, 2007). This provides an economical alternative for the final disposal of the textile sludge (Kocasoy and Sahin, 2007). But heavy metals in textile sludge are always an issue restricting its use as fertilizers. So, pre-treatment of textile sludge earlier to the land application is likely to be a possible and practical means for reducing heavy metal contents. Similarly, characterization of the sludge in terms of heavy metals and plant nutrients content is vital to use textile sludge as complementary fertilizer for agricultural production. So the objective of this study was to assess plant nutrients and heavy metals content in textile sludge in order to use as organic fertilizer for agricultural production.

## Materials and Methods

### *Study Area Description*

The study area is located in northern central Ethiopia at 380 km north of Addis Ababa and has an elevation ranging from 1842-1915 m.a.s.l. It has a latitude and longitude of 11º 5' N 39 º 44 'E. It is characterized as a sub-humid climate with bimodal rainfall distribution. The main rainy season is from July to September while March to October is the period for a small amount of rainfall.

*Sludge Sampling and Sample preparation*

Textile sludge samples were collected from Kombolecha textile factory from sludge discharge thank. The collected samples were subjected to basic sample preparation procedures, air drying, and grinding. The air-dried sludge samples were ground well with a mortar and pestle to get the final ground powder and kept for analysis. The concentration of nitrogen, phosphorus and potassium in textile sludge analysis result is presented in Table 1.

***Laboratory analysis***

*Nitrogen*

Three samples of textile sludge of weight 1.000 g were weighted and transfer into a dry Kjeldahl flask. Kjeldahl tablets (selenium tablets) were added to each Kjeldahl flask containing the samples. Then 10.00 ml of concentrated sulphuric acid was added and flasks were placed on the heating device inclining the neck at an angle of about120$^o$. Heating was continued for 180 minutes until the solution has become colorless or clear. Few boiling chips and 150.0 ml of distilled water were added to the digested mixture in the Kjeldahl flask. Then45.0 ml of 45%NaOH (aq) was added and the mixture was heated until it boiled. In the distillation step, a Boric acid solution (20.0 ml) and five drops of the Bromo cresol green indicator were added to conical flasks. Distillation was carried out using (Indicate apparatus used for distillation). Distillates were collected in flasks containing boric acid solution. Titration was carried out using 0.5 M $H_2SO_4$ (aq) solution against sample distillates and blank sample for determination of ammonium nitrogen.

*Determination of phosphorus*

The sludge samples which were prepared for analysis weighted on an analytical balance and calcinated in a muffle furnace. The residuals ashes after calculations were dissolved in 6 N HCl and filtered into 250 ml volumetric flasks, then filled up to the mark with distilled water. The calibration curve was created using a standard phosphate solution of potassium dihydrogen phosphate ($KH_2$

*Determination of potassium*

Potassium standards were prepared from potassium chloride (1.9070 g). Sludge samples (5.g, were placed in a crucible and keep in a
samples were digested to ashes. Then samples were cooled to room temperature. Conc. HCl (2.5ml) was added and keep in a steam bath for about 30 minutes and filtered into a 100.0 ml flask. Total potassium contents of these three samples were determined using AAS.

*Digestion methods*

The determination of metals was proceeded using the dry digestion method (Haynes, 1980) using a muffle furnace by placing 1.25g samples into a high-form porcelain crucible. After digestion, the residuals were wetted with a small amount of distilled water, and then5 ml of 6 N HCl was added. The aliquot of the final solution was placed into an ICP test tube and all measurements were performed with spectra across optical emission spectrometer The detection limits for the selected heavy metals were 1.00 mg/kg (Ellis *et al*., 1975).

**Table 1**. Concentration of nitrogen phosphorus and potassium in textile sludge

| Nutrients | Contents (%) |
|---|---|
| Nitrogen | 1.665 |
| Phosphorus | 0.29 |
| Potassium | 0.355 |

## Results and discussion

*Comparison of Nitrogen, Phosphorus and Potassium Contents of Textile Sludge with Their Respective Chemical Fertilizer and Manure*

The percentage of most important nutrients (N, P, and K) in textile sludge were compared with common organic manure and chemical fertilizer in Table 2. The concentration of N in textile sludge is higher than its content in all organic manures listed in Table 2. However, the concentration of P in textile sludge is typically lower than its content in all manures except in compost. Phosphorus in textile sludge is almost equal to its content in compost. This suggests textile sludge is as good as compost considering only its P content. The concentration of K is lower than its content in all manures listed, but the amount is better to be used with zero K chemical fertilizers.

### *Plant micronutrients and heavy metals*

Heavy metals are of great significance in geochemistry and ecotoxicology because of their toxicity at low levels and tendency to accumulate in human organs (Aziz et al. 2012). The current study indicated that the average concentration of lead in the sludge samples was 27.01 mg kg-1, (Table 3). This result revealed that examined sludge samples contained a relatively lower amount of Pb. According to the US Environmental Protection Agency (EPA) guidelines, the background of Pb in sludge to use a fertilizer in agricultural soil is 100 mg kg-1 (Aziz et al. 2012). So the concentration was acceptable for only over the short term on a site-specific basis (Kempster and Van, 1991).

**Table 2**. Comparison of N, P, and K of textile sludge with some commonly used chemical fertilizers and organic sources of plant nutrients.

| Manures/ chemical fertilizers | Nitrogen (N) % | Phosphorus (P) % | Potassium(K)% |
|---|---|---|---|
| Textile sludge | 1.665 | 0.29 | 0.355 |
| Cow dung | 0.5-1.5 | 0.4-0.8 | 0.5-1.9 |
| Poultry manures | 1.6 | 1.5 | 0.85 |
| Farmyard manure | 0.5-1.5 | 0.4-0.80 | 0.5-1.9 |
| Compost(general) | 0.4-0.8 | 0.3-0.6 | 0.7-1.0 |
| Urea | 46 | - | - |
| Ammonium sulphate | 21 | - | - |
| Diammonium phosphate | 18-21 | 20 | - |

The average concentration of cadmium of the sludge samples was 2.25 mg kg-1 (Table 3). The permissible level of Cd in textile sludge to be used as fertilizer in agricultural soils set by US Environmental Protection Agency (EPA) is 0.6 mg kg-1.Even natural background level of $^{-1}$ (Mehari and Mulu, 2013). So, the values of Cd found in the present investigation were higher than the critical value set by the international guidelines and other researchers. Some cadmium compounds are able to leach through soils to groundwater. Therefore, the use of the investigated sludge, with regard to its Cd concentration, as a soil conditioner or fertilizer can cause severe environmental pollution. In addition, Cadmium is strongly adsorbed by soil clay minerals and co-precipitated with iron and manganese oxides and oxy-hydroxides. For these reasons, cadmium has a limited vertical movement in neutral to alkaline soils. Its availability to plants increases at low pH levels and with increasing chloride concentrations. Plant availability of cadmium decreases when the concentration of organic matter is high. Cadmium can be expected to be retained in the soil surface layers because of its strong sorption by the soil exchange complex. It is highly unlikely that cadmium can be economically removed from sludge. Cadmium can be most conveniently removed by raising the pH and precipitating the insoluble cadmium salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5 (Berman, 1980). However, this range of pH value is not suitable for normal growth of most plants.

The concentration of Zn was 597mg kg-1 in the sludge samples, which was higher than those of permissible levels in textile sludge given by different guidelines and nations. The maximum Zn value in light soil used in cultivation in India given by (Wong and Min, 2002), was 100 mg kg-1. The entry natural background values of Zn in crop soils and paddy soils in $^{-1}$ At higher concentrations it causes toxic responses by inducing iron deficiency. So the pretreatment of sludge to reduce Zn concentration should be proceeded by applying agricultural lime in order to raise (or maintain) soil pH to neutral to slightly alkaline; or huge quantities of organic material and switch to a crop that is more tolerant to zinc (Page and Chang, 1990)

The Cu content in the sludge samples was 846.25 mg kg-1 which was also extremely higher than that of the kg-1). Some well-documented studies revealed that heavy metals such as zinc (Zn) and copper (Cu) are the principal elements restricting the use of sludge as fertilizer for agricultural purposes (Udom and Agbim, 2004). Copper is an essential plant micro-nutrient and is an important component of several plant enzymes. Copper deficiency symptoms occur in plants grown in soil that have a low copper concentration. Approximately 6 mg/kg of copper in the soil is the lower limit for healthy plant growth. Copper toxicity is usually associated with soil concentrations in the range of 150 - 400 mg/kg. Depending on plant species, copper toxicity occurs in nutrient solutions at concentrations between 0.1 and 1 mg/kg. This research work indicates that the concentration of Cu was found higher than the safe limit. Thus the application of agricultural lime with sludge in order to raise (or maintain) soil pH to neutral to slightly alkaline and ample phosphate fertilizers or iron salts are important as reported by Page and Chang (1990).

The average concentration of chromium (Cr) in the samples was 71.01 mg kg-1. The maximum content of Cr reported by Zorpas et al. (2008) in soil used in cultivation was 100 mg kg$^{-1}$. The natural background of Cr in agricultural soils based on the 90 mg kg$^{-1}$. The Cr content in textile sludge obtained from the present study was lower than the permissible levels recommended by the above sources. Chromium has no known plant physiological function and is not an essential plant nutrient, but at low concentrations, it has been found to have a beneficial effect on plant growth (Devereals and Fujii, 1990).

Extensive term contact of iron from the sludge into soils may contaminate it and change the soil structure and thus make it harmful for cultivation. The concentrations of Fe in textile sludge to use as fertilizer in agricultural soils in different countries varying from 289.3-338.5 mg $kg^{-1}$ (Dai *et al.,* 2007). The Fe content in sludge obtained from the present study was17340.6 mg kg-1 which is higher than the permissible value described by SEPA and the above researcher. Iron-rich sludge can cause a number of problems; an iron coating sludge sample application on land may be deposited on plant leaves or fruit. It could be in the form of light brown spotting, a silvery coating, or a thick black coating. This interferes with normal photosynthesis, transpiration, and respiration and may lead to damage and eventual plant death. So, sludges should be pretreated before applying as a source of fertilizer or be applied with agricultural lime in order to raise (or maintain) soil pH to neutral to slightly alkaline.

Since cobalt is retained strongly by soils, it is likely to be accumulated to phototoxic concentrations before equilibrium between sorption and desorption reactions are reached, cobalt can be removed by precipitation at alkaline pH, with lime, or by flocculation and co-precipitation with a ferric salt. Alternatively, ion exchange can be used (Page and Chang, 1990). Plants vary in their sensitivity to manganese and toxicity has been observed at a fraction of a mg/kg in a nutrient solution. The concentration of Mn was 1165.44 gm/kg and highly accumulated in the sludge. Excessive manganese in the sludge can cause manganese toxicity if applied to the soil without pretreatment. Thus, as mentioned above pretreatment or application of agricultural lime with sludge, in order to raise or maintain soil pH to neutral to slightly alkaline is mandatory (Page and Chang, 1990). Other toxic elements contents of sludge (Ni, Co, Hg, Sn, As, and B) were higher than the permissible values set by Rodríguez-Eugenio et al., (2018) SEPA/FAO (Table 3).

**Table 3**. Concentrations of micronutrients and heavy metals in textile sludge samples from Kombolcha textile factory

| Parameter | Result (mg/kg) | SEPA/FAO limit |
|---|---|---|
| Lead | 27.70 | 100.00 Mg/kg |
| Cadmium | 2.25 | 0.60 Mg/kg |
| Zinc | 597.73 | 300.0 Mg/kg |
| Copper | 846.25 | 100.00 Mg/kg |
| Chromium | 71.01 | 100.00 Mg/kg |
| Iron | 17340.60 | 338.50Mg/kg |
| Nickel | 30.83 | 1.00Mg/kg |
| Cobalt | 6.66 | 5.00Mg/kg |
| Manganese | 1165.44 | 50.00Mg/kg |
| Mercury | 2.96 | 1.00Mg/kg |
| Tin | 60.03 | 5.0 Mg/kg |
| Arsenic | 10.72 | 10.00Mg/kg |
| Boron | 27.75 | 15.00Mg/kg |

## Conclusion

The results revealed that analysis of textile sludge in terms of principal plant nutrients namely nitrogen, phosphorous, and potassium was highly victorious. More significantly, experimentally found average nitrogen content in textile sludge (1.665%) was considerable compared to nitrogen content present in commonly used manure. Secondly, average phosphorus (0.29%) and potassium (0.358%) content were approximately analogous to amount of phosphorus (0.3%-0.6%) and potassium (0.5%) concentrations found in common manure. From the results of the elemental analysis of textile sludge, it can be affirmed that levels of heavy metals were generally higher than the standards, except Pb and Cr. The concentrations of Cd, Zn, Cu, Ni, Co, Mn, Hg, and Fe in the sludge samples were beyond the safe limit set by SEPA limits whereas Pb and Cr were found within the safe limits of the respective heavy metals. From this study, it could be concluded that a pre-treatment process should be carried out in order to reduce concentrations of heavy metals in sludge to use as complementary organic fertilizer or should be applied with agricultural lime to raise or maintain soil pH to neutral to slightly alkaline. These are mandatory before the sludge can be used as a soil conditioner or fertilizer for agricultural production.

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# Effect of Lime Application Methods on Selected Soil Chemical Properties and Yield of Maize (*Zea Mays L.*) in Acidic Nitisols of Mecha District, Amhara Region, Ethiopia

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## Abstract

*Soil acidity is the major soil chemical constraints that limit agricultural productivity in the highland of Ethiopia receiving high rainfall amount. This study was conducted to evaluate the effect of different lime application methods on selected soil chemical properties and yield of maize (Zea mays L.) on acidic Nitisols of Mecha district, Amhara Region, Ethiopia in the 2018 cropping season. The experiment had 10 treatments (0, 0.06, 0.12, 0.18, 1, 2, 3.5, 4, 7, and 14 tons ha$^{-1}$ lime) which were calculated in 3 different lime rate determination methods and applied through 3 different methods (spot, drill, and broadcast). The experiment was designed in RCBD with four replications. N 180 and $P_2O_5$ 138 kg ha$^{-1}$ were used, respectively. A full dose of P and lime as a treatment were applied at planting. Whereas N was applied in split, 1/2 at planting, and 1/2 at knee height stage. One composite soil sample before planting and soil samples from each experimental unit after harvesting were taken to analyze the required parameters with their appropriate procedure. The drill lime application method showed better efficiency with having more than 200% cost reduction advantage comparative to the broadcast method to ameliorate the same level of soil acidity. Grain and above-ground biomass of maize yields showed a significant difference among treatments. The application of 3.5 tons lime ha$^{-1}$ in the drilling method is recommendable and best to ameliorate soil acidity. But, from an economic point of view, the application of 0.12 tons lime ha$^{-1}$ in the micro-dosing method is acceptable due to low variable cost.*

**Keywords:** *Exchangeable acidity, Lime, maize, pH- buffer, pH-$H_2O$*

## Introduction

Agriculture in Ethiopia has long been a priority and focus of national policy, such as Agricultural Development Led Industrialization (ADLI) and various large-scale programs, like Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Close to

more than 85% of the population, generates over 46% of GDP and 80% of export earnings, and has a significant role to play in improving food security (Alemayehu Seyum, 2008). Soil supports plant growth and is vital to humanity. It provides nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium, sulfur, and many other trace elements that support biomass production. Also, it gives service as an anchor for plant roots and as a water holding tank for needed moisture and it provides a hospitable place for a plant to take root. Some of the soil properties like texture, aggregate size, porosity, aeration (permeability), and water holding capacity affecting plant growth (FAO and ITPS, 2015).

Maize is one of the three most important cereals with 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 Shiferaw *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 Shiferaw *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). The estimated average yields of maize for smallholder farmers in Ethiopia is about 3.2 tons $ha^{-1}$ (CSA, 2014; Tsedeke Abate *et al.*, 2015), which is much lower than the yield recorded under experimental plots of 5 to 6 tons $ha^{-1}$ (Dagne Wegary *et al*., 2008). To solve soil fertility problems and maximizing maize yield, different research activities have been undertaken in Ethiopia using various fertilizer sources (Birhan Abdulkadir *et al*., 2017).

Acid soils are toxic for plants during their production period as a result of nutritional disorders, deficiencies or unavailability of essential nutrients such as Ca, Mg, P, and Mo, and toxicity of Al, Mn, and H activity (Jayasundara *et al.,* 1998). In acid soils, excess Al primarily injures the root apex and inhibits root elongation. This poor root growth again leads to reduced water and nutrient uptake and consequently crops grown on acid soils faced poor nutrients and water availability with the net effect of reducing growth and yield of crops (Wassie Haile and Shiferaw Boke, 2014). Occurrences of an increasing trend of soil acidity in arable and abandoned lands are attributed due to the high amount of rainfall, intensive cultivation, and continuous use of acid-forming inorganic fertilizers (Abdenna Deressa *et al.*, 2007). As Taye Belachew (2007) reported, soil acidity in Ethiopia is expanding both in scope and magnitude and becoming severely limiting crop production.

To solve such type of problems application of lime properly is the fundamental action as stated by Adane Buni (2014) which was reported as soil pH increase from 5.03 to 6.72 by applying 3.75 tons $ha^{-1}$ lime and similarly increased CEC and available P of the soil. But, inversely EA and most micronutrient availabilities significantly decreased due to liming which is supported by (Goedert *et al.*, 1997; Kebede Dinkecha and Dereje Tsegaye, 2017) findings. Therefore, the interest of this study was to investigate the effect of different lime application methods determined through different rate determination methods on selected soil chemical properties and maize (*Zea mays L.*) yield.

## Materials and Methods

*Description of the Study Area*

The study was conducted at Kudemie *kebele* (lowest administrative unit of Ethiopia), Mecha district that is approximately 525 km far away from Addis Ababa in the north direction. Specifically, the study site is located at 11° 23' 33.49" Northing and 37° 06' 25.23" Easting at 1972 meters a.s.l (Figure 1). Based on CSA (2015) data, Mecha district had a total population size of 222,373. From the total population size, 201,147 people live in the rural *kebeles* and the remaining 21,226 people live in Merawie town.

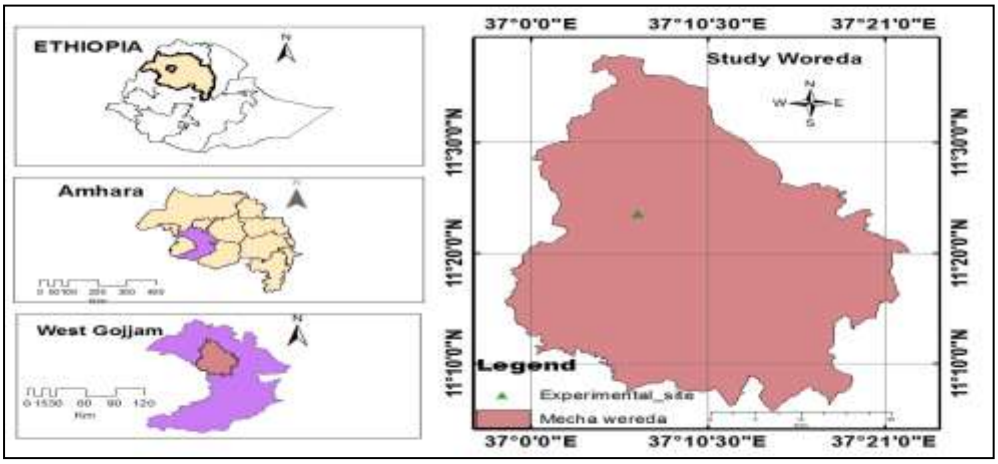


**Figure 1**. Location of the study area

***Topography, soil type, and climate***

The study area has dominantly 70% flat topographic coverage. From the total area of the district, 13% is undulated and the remaining 8% and 4% of the area are covered by mountainous and valley topographies, respectively. The annual mean rainfall amount of the district is 1572 mm and the mean temperature is 25°C (Mekonnen Getahun, 2015). According to Ethiopian traditional agro-ecological classification, the study district is classified under *Weyina Dega* (1800 to 2400 m.a.s.l) (Mekonnen Getahun, 2015). Specifically, the mean annual rainfall and temperature of the experimental site during the cropping season were 314.9 mm and 19.3°C, respectively. From the total area coverage of the district, 5,927 ha which is 4% is included under the Koga irrigation command area (Eyasu Elias, 2016).

***Farming system and land use of the area***

The dominant farming system of the district is a mixed farming system that is livestock with crop production and rainfall dependent where the average productivity has been substantially decreased due to the major co2 raitis lieof y nd a(e)4,( )479(a)4(nd )59[(c)4(rop )464(pe)42



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unpublished). The amount of lime added in terms of time and ways of application was based on the treatment setup indicated in Table 1.

**Table 1**. Treatment setup of the conducted experiment

| No. | Treatments | Application methods |
|---|---|---|
| 1 | Control | Treatment without lime |
| 2 | 0.06 ton $ha^{-1}$ | Micro-dosing in a spot near the seed hill |
| 3 | 0.12 ton $ha^{-1}$ | Micro-dosing in a spot near the seed hill |
| 4 | 0.18 ton $ha^{-1}$ | Micro-dosing in a spot near the seed hill |
| 5 | 1 ton $ha^{-1}$ | ¼ FDEA = in drilling along the rows |
| 6 | 2 ton $ha^{-1}$ | ½ FDEA = in broadcasting |
| 7 | 3.5 ton $ha^{-1}$ | ¼ FDB = in drilling along the rows |
| 8 | 4 ton $ha^{-1}$ | FDEA = in broadcasting |
| 9 | 7 ton $ha^{-1}$ | ½ FDB = in broadcasting |
| 10 | 14 ton $ha^{-1}$ | FDB = in broadcasting |

*Note: FDEA=Full dose based on exchangeable acidity, FDB= Full dose based on pH-buffer*

### *Lime Rate Determination*

The amount of lime rates used was determined through 3 mechanisms. The first 4 rates (0, 0.06, 0.12, and 0.18 tons $ha^{-1}$) were added directly as micro-dosing levels. The other 3 rates (1, 2, and 4 tons $ha^{-1}$) were calculated based on the EA method which was formulated by (Birhanu Agumas *et al.,* 2016) as indicated below in (Eq-1) and the remaining 3 rates (3.5, 7, and 14 tons $ha^{-1}$) were calculated based on SMP-pH-buffer to attained 6.5 target pH value from the initial result based on SMP-pH-buffer lime amount determination stated by Van Reeuwijk (1992).

LR $CaCO_3$ (kg $ha^{-1}$) = (Eq-1)

Where: EA=2.54 $Cmol_{+}$ $kg^{-1}$, Bulk density=1.41 $Mg/m^3$ taken from pre-liming soil analysis result.

### *Soil Sampling, Preparation and Analysis Methods*

One composite soil sample before planting and from each experimental unit after harvesting was taken in the depth of (0-15) cm. Soil pH-$H_2O$, pH buffer, EA, CEC, OC, AP, TN, and all exchangeable cations were analyzed. The above parameters were analyzed in Adet soil laboratory following their appropriate procedural methods. Based on the above soil parameters, BS and AS percentage values were also calculated through the formulas stated below.

BS = ; AS = -2)

*Other Agronomic Data Collected:* Important agronomic data like plant height, ear length, ear diameter, 1000 grain weight, harvest index (HI), and all biological yields (grain + straw) were taken.

*Cultural Practice:* Weeding and other necessary agronomic practices were implemented mechanically. Agro-lambarcin pest controlling chemical was used at the time of vegetative to control the American worm (which is also called Temich in Amharic).

*Statistical Tools Used:* SAS software version 9.0 was used to analyze all collected agronomic data. LSD was used for mean separation comparison. The economic analysis was done following the methodology of CIMMYT (1988).

## Results and Discussion

### *Effect of Lime on Selected Soil Chemical Properties*

#### *Soil pH-$H_2O$ and pH-buffer*

As shown in Table 2 and 3, pH-$H_2O$ raised from 4.85 to 6.21 which is from very strongly acidic to slightly acidic pH range Murphy (1968) and Tekalign Tadese (1991) through the application of 3.5 tons ha$^{-1}$ lime with drilling application. This value is the maximum value scored in the experiment which is suitable for maize production (Ndubuisi and Deborah, 2010). But, a minimum (4.87) value was recorded on treatment 2 which received 0.06 tons ha$^{-1}$ lime through the spot application method. Comparing the 3 lime application methods, maximum pH-$H_2O$ values were obtained on the drill lime application method. In general, pH-$H_2O$ of the soil in the study site showed an increasing trend with a significant difference ($p<0.001$) among treatments due to an increase in the amount of lime applied.

This result is agreed with (Achalu Chimdi *et al.,* 2012 and Getachew Alemu *et al.,* 2017) findings which were stated as soil pH was sharply increased by liming. Like that of pH-$H_2O$, pH buffer had a significant difference ($p<0.001$) among treatments with an increasing trend due to the increasing amount of lime applied in the experimental area. Similarly, minimum and maximum pH buffer values were observed on points where the minimum and maximum pH-$H_2O$ values were recorded in magnitudes of 4.98 and 6.03, respectively (Table 3).

**Table 2**. Soil chemical properties before application of lime

| Parameters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| pH ($H_2O$) | pH (Buffer) | OC (%) | CEC ($Cmol_+kg^{-1}$) | AP ($mgkg^{-1}$) | TN (%) | EA ($Cmol_+kg^{-1}$) | Exchangeable bases ($Cmol_+ kg^{-1}$) | | | |
| | | | | | | | Ca | Mg | K | Na |
| 4.85 | 5.24 | 2.19 | 19.95 | 18.03 | 0.17 | 2.54 | 9.8 | 2.68 | 1.14 | 0.31 |

*Note: OC=organic carbon, TN=total nitrogen, CEC=cation exchangeable capacity*

Based on Tekalign Tadese (1991) nutrient rating level both pre-planting and post-harvest soil sample OC and TN% values were grouped under medium levels as shown in Tables 2 and 3. But, based on Murphy (1968) and Ethiosis (2016) the recorded TN% values could be grouped from medium to high (0.10-0.15%) and low to optimum (0.15-0.25/0.3%), respectively. As reported by Kebede Dinkecha and Dereje Tsegaye (2017); Jafer Dawid and Gebresilassie Hailu (2017) and Mesfin Kassa *et al*. (2014), OC and TN% of the soil in thi show any significant difference among treatments through the application of different lime amounts in different application methods (Table 3). This indicated that OC and TN are not giving quick responses for liming within a short time.

*Cation exchange capacity (CEC)*

Based on the analysis of variance (ANOVA) result, soil CEC values showed a significant difference ($p<0.05$) between treatment 3 and 7 which received 0.12 and 3.5 tons $ha^{-1}$ lime and applied in spot and drilling application methods with the magnitudes of 21.85 and 25.41 $Cmol_+ kg^{-1}$, respectively. These values were minimum and maximum values in the study site, respectively. Based on Landon (1991); Hazelton and Murphy (2007) nutrient rating level, all recorded CEC values for post-harvested and before liming soil samples were grouped under moderate ranges. As a general trend, CEC values observed in the experiment slightly increased with increasing of the amount of lime applied up to treatment 7 which received 3.5 tons $ha^{-1}$ lime applied through drilling system that agreed with the finding reported by Achalu Chimdi *et al.* (2012) who stated as numerically the mean values of soil exchangeable $Ca^{2+}$ and CEC of each land-use type showed increments with the increase of applied lime rates and Adane Buni (2014) who also stated as all lime levels resulted in a significant increment to soil CEC values over the control plots.

*Available phosphorus (AP)*

The recorded AP values for all treatments were above the critical P concentration (>11.6 mg $kg^{-1}$ ) which was reported by Yihenew G.Selassie *et al.* (2003). As shown in Table 3, AP values among the treatments showed a significant difference ($p<0.001$) due to the different amounts of lime application through different application methods. In this study, AP showed a decreasing trend with an increasing amount of lime applied, which is contrary to the findings reported by several authors Adane Buni (2014), Dessalegn Tamene *et al.* (2017), Getachew Alemu *et al.* (2017), and Kebede Dinkecha and Dereje Tsegaye (2017). But, this result agreed with the finding reported by Haynes (1982). According to Haynes (1982) at high soil pH and low $Al^{3+}$ concentration values, the precipitation of insoluble calcium phosphates has the power to reduce P availability. Therefore, in this study context, the laboratory soil analysis results showed zero exchangeable Al readings and this may be caused

$ha^{-1}$). According to Olsen *et al.* (1954), the recorded AP values for before and after liming samples were attained at a higher level. Minimum and maximum values were observed on the control treatment (17.17 mg $kg^{-1}$) and micro-dosing level (0.06 tons $ha^{-1}$ lime) (37.80 mg $kg^{-1}$) (Table 3).

*Exchangeable acidity (EA)*

As the soil laboratory analysis result showed, exchangeable $Al^{3+}$ for all samples was in a trace amount in the study area. Therefore, the source of soil acidity was only $H^+$ concentration. Besides this, EA on the experimental site showed a highly significant difference ($p<0.01$) among treatments (Table 3). As indicated in Table 3 EA showed a decreasing trend with the reverse of the amount of lime applied. This is usually true and agreed with many findings such as Achalu Chimdi *et al.* (2012); Adane Buni (2014); Dessalegn Tamene *et al.* (2017) and Getachew Alemu *et al.* (2017) which were stated as EA reduced due to an increase of the applied lime.

**Table 3**. Soil pH-H2O, pH-buffer, OC, CEC, AP, and EA values for post-harvested soil samples

| Treatments | Parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | pH ($H_2O$) | pH (buffer) | OC (%) | TN (%) | CEC ($Cmol_+kg^{-1}$) | AP (mg $kg^{-1}$) | EA ($Cmol_+kg^{-1}$) |
| Control (no lime) | 5.11$^{de}$ | 5.14$^{de}$ | 1.94 | 0.166 | 22.81$^{ab}$ | 17.17$^{d}$ | 1.939$^{a}$ |
| 0.060 ton $ha^{-1}$ | 4.87$^{e}$ | 4.98$^{e}$ | 2.01 | 0.149 | 22.89$^{ab}$ | 37.80$^{a}$ | 2.020$^{a}$ |
| 0.120 ton $ha^{-1}$ | 4.95$^{e}$ | 5.01$^{e}$ | 2.07 | 0.168 | 21.85$^{b}$ | 33.56$^{b}$ | 1.788$^{a}$ |
| 0.180 ton $ha^{-1}$ | 5.27$^{de}$ | 5.07$^{de}$ | 1.95 | 0.168 | 23.47$^{ab}$ | 34.47$^{ab}$ | 0.936$^{b}$ |
| 1 ton $ha^{-1}$ | 5.52$^{cd}$ | 5.75$^{ab}$ | 1.89 | 0.139 | 24.53$^{ab}$ | 31.86$^{bc}$ | 0.480$^{bc}$ |
| 2 ton $ha^{-1}$ | 5.28$^{de}$ | 5.33$^{dc}$ | 2.09 | 0.161 | 24.82$^{ab}$ | 29.12$^{c}$ | 0.460$^{bc}$ |
| 3.5 ton $ha^{-1}$ | 6.21$^{a}$ | 6.03$^{a}$ | 1.95 | 0.162 | 25.41$^{a}$ | 31.34$^{bc}$ | 0.070$^{c}$ |
| 4 ton $ha^{-1}$ | 5.49$^{cd}$ | 5.65$^{b}$ | 2.09 | 0.144 | 23.38$^{ab}$ | 20.01$^{d}$ | 0.116$^{c}$ |
| 7 ton $ha^{-1}$ | 5.77$^{bc}$ | 5.55$^{bc}$ | 2.00 | 0.163 | 23.22$^{ab}$ | 18.93$^{d}$ | 0.288$^{c}$ |
| 14 ton $ha^{-1}$ | 6.17$^{ab}$ | 6.01$^{a}$ | 1.95 | 0.142 | 24.50$^{ab}$ | 20.90$^{d}$ | 0.048$^{c}$ |
| Mean | 5.46 | 5.45 | 1.99 | 0.156 | 23.69 | 27.52 | .814 |
| P | ** | ** | Ns | Ns | * | ** | ** |
| CV (%) | 5.55 | 3.97 | 10.49 | 15.05 | 10.24 | 10.53 | 50.31 |

In between this, minimum and maximum EA values were recorded on treatments that received 14 tons $ha^{-1}$ lime (applied in broadcasting) and 0.06 tons $ha^{-1}$ lime (applied in the spot) with magnitudes of 0.048 and 2.020 $Cmol^{+}kg^{-1}$ of soil, respectively. Control treatment showed a clear significant difference from treatment 4 to 10 (Table 3).

*Exchangeable base values*

As shown in Table 4, exchangeable Ca and Mg showed a highly significant difference among treatments ($p<0.001$) whereas, exchangeable K and Na showed a significant difference among treatments ($p<0.015$) and ($p<0.02$), respectively due to liming. It is apparent that the applied lime showed a positive response for all exchangeable bases which is agreed with many findings reported by Hirpa Legesse *et al.* (2013); Holland *et al.* (2017); Jafer Dawid and Gebresilassie Hailu (2017); Achalu Chimdi *et al.* (2012); Adane Buni (2014) and Getachew Alemu *et al.* (2017) which were collectively stated as treating of acid soils with lime showed an increasing trend of exchangeable bases and decrease micronutrients and EA in the soil solutions exchange complex and helped to increase of plant nutrient availabilities due to enhancing of soil pH value.

All minimum and maximum exchangeable base values were recorded on treatment 2 and 7 that received 0.06 and 3.5 tons $ha^{-1}$ lime through spot and drill lime application methods, respectively in exception of maximum exchangeable Mg. This showed that drill lime application is more efficient for the amendment of the base cation in acid soil than the broadcast application methods that agreed with the finding of (Birhanu Agumas *et al.*, 2016). Based on FAO (2006) nutrient rating, recorded exchangeable Ca, Mg, K, and Na grouped under high, medium to high, high to very high, and medium rating levels, respectively.

*Base and acid saturation percentages*

The amount of lime applied in the study area showed a positive and significant difference with the increasing trend on soil base saturation percentage among treatments. In opposite, acid saturation percentage showed a decreasing trend when the amount of lime applied increased which is in agreement with findings of Achalu Chimdi *et al.* (2012); Adane Buni (2014), and Getachew Alemu *et al.* (2017) (Table 4). Based on Hazelton and Murphy (2007) all the observed base saturation percentage values are grouped at a high rating level which is from 60-80%. Acid saturation percentage reduced from 8.69% in the 0 ton $ha^{-1}$ to 0.19% at 14 tons $ha^{-1}$ lime application.

**Table 4**. Soil exchangeable base cations, BS, and AS for post-harvested samples

| Treatment | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | BS (%) | AS (%) |
| Control (no lime) | $10.73^{de}$ | $2.90^{bc}$ | $1.38^{dc}$ | $0.48^{bc}$ | $69.03^{ab}$ | $8.69^{a}$ |
| 0.060 ton $ha^{-1}$ | $10.18^{e}$ | $2.30^{c}$ | $1.20^{d}$ | $0.44^{c}$ | $62.06^{b}$ | $8.80^{a}$ |
| 0.120 ton $ha^{-1}$ | $10.85^{cde}$ | $2.68^{bc}$ | $1.43^{bcd}$ | $0.45^{c}$ | $71.61^{ab}$ | $8.01^{a}$ |
| 0.180 ton $ha^{-1}$ | $11.38^{bcd}$ | $3.03^{b}$ | $1.48^{abc}$ | $0.44^{c}$ | $70.43^{ab}$ | $3.81^{b}$ |
| 1 ton $ha^{-1}$ | $12.30^{ab}$ | $3.05^{b}$ | $1.63^{ab}$ | $0.61^{ab}$ | $72.37^{ab}$ | $1.92^{bc}$ |
| 2 ton $ha^{-1}$ | $11.85^{abcd}$ | $3.05^{b}$ | $1.53^{abc}$ | $0.58^{abc}$ | $68.69^{ab}$ | $1.84^{bc}$ |
| 3.5 ton $ha^{-1}$ | $12.95^{a}$ | $3.98^{a}$ | $1.70^{a}$ | $0.65^{a}$ | $75.85^{ab}$ | $0.27^{c}$ |
| 4 ton $ha^{-1}$ | $11.75^{bcd}$ | $3.15^{b}$ | $1.42^{bcd}$ | $0.56^{abc}$ | $74.64^{ab}$ | $0.49^{c}$ |
| 7 ton $ha^{-1}$ | $12.03^{abc}$ | $3.88^{a}$ | $1.52^{abc}$ | $0.47^{bc}$ | $78.71^{a}$ | $1.25^{c}$ |
| 14 ton $ha^{-1}$ | $12.50^{ab}$ | $4.30^{a}$ | $1.52^{abc}$ | $0.64^{a}$ | $78.19^{a}$ | $0.19^{c}$ |
| Mean | 11.65 | 3.23 | 1.48 | 0.53 | 72.16 | 3.53 |
| P | ** | ** | * | * | * | ** |
| CV (%) | 7.02 | 14.13 | 10.96 | 19.29 | 13.58 | 46.65 |

***Recommended Lime (LR) Equations Based on Important Soil Acidity Indices***

As shown in Figures 2 and 3, the LR decreased when soil pH buffer and pH-$H_2O$ increased for both drilling and broadcast lime application methods. However, LR increases when the EA of soil increased for the same methods of lime application (Figure 4) which is agreed with the findings reported by Shoemaker *et al.* (1961) and Van Reeuwijk (1992).

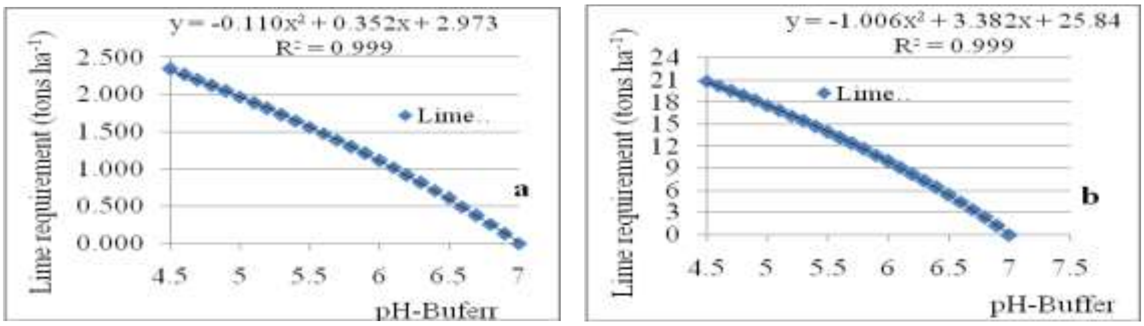


**Figure 2.** LR equations for drill (a) and broadcast (b) application methods using pH-buffer index

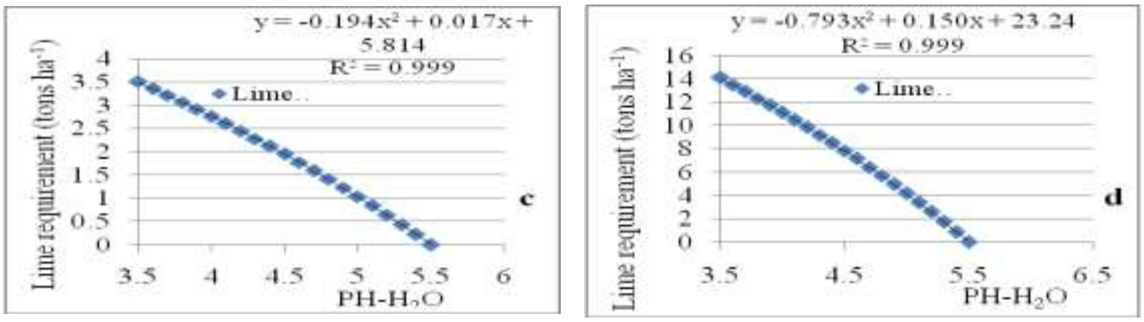


**Figure 3**. LR equations for drill (c) and broadcast (d) application methods using pH-$H_2O$ index

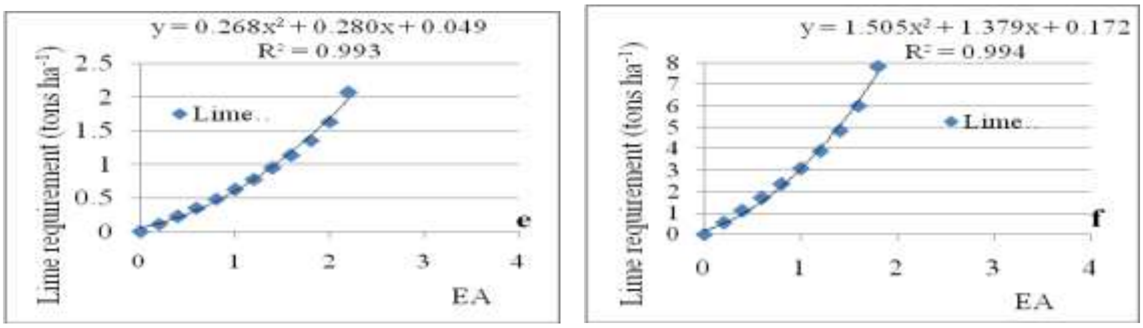


**Figure 4**. LR equations for drill (e) and broadcast (f) application methods using EA index.

Based on the deriving equations indicated in Table 5, calculated LR based on pH-buffer, pH-$H_2O$, and EA ranged from 0.13 to 2.34, 0.22 to 3.50 and 0.11 to 2.07 tons $ha^{-1}$ for drilling and 1.18 to 20.83, 0.90-14.11 and 0.53 to 7.86 tons $ha^{-1}$ for the broadcast method, respectively. Based on these readings, the amount of lime required through drilling is much lower compared to the broadcast application method to ameliorate the same level of acidity within the same soil acidity indices and which is agreed with the finding reported by Birhanu Agumas *et al*. (2016).

**Table 5**. LR equations developed from soil acidity indices

| Application methods | Acidity index | Index unit | LR equations | $R^2$ |
|---|---|---|---|---|
| Broadcast | PH- buffer | ---------- | $Y = -1.0063x^2 + 3.383x + 25.845$ | 0.9998 |
| | PH-H2O | ---------- | $Y = -0.7935x^2 + 0.151x + 23.249$ | 0.9999 |
| | EA | $Cmol_+kg^{-1}$ | $Y = 1.5051x^2 + 1.3794x + 0.1728$ | 0.9946 |
| Drilling | PH- buffer | ---------- | $Y = -0.1106x^2 + 0.353x + 2.9735$ | 0.9998 |
| | PH-H2O | ---------- | $Y = -0.1947x^2 + 0.017x + 5.8147$ | 0.9999 |
| | EA | $Cmol_+kg^{-1}$ | $Y = 0.2681x^2 + 0.280x + 0.0497$ | 0.9939 |

*Note: Y=Lime rate to be applied, x=Soil acidity index value*

***Effect of Lime on Yield and Yield Components of Maize***

As shown in Table 6, the applied lime didn't show any significant difference in maize plant height, ear length, ear diameter, thousand seed weight, harvest index, and straw yield among treatments. Although the experiment didn't show any significant difference in the above-listed yield components, the maximum values of each component were recorded on treatments that received a high amount of lime which is supported by Gitari *et al.* (2015) and Opala (2017) findings. But, maize grain and above-ground biomass yields showed a significant difference treatments. Generally, both grain and above-ground biomass yields in the experiment showed an increasing trend due to liming which is supported by findings reported by Komljenovic *et al.* (2015) and Oloo (2016). As Agrama (1996) stated, the trend of grain yield is parallel with trends shown on yield components of maize.

**Table 6**. Plant height, ear length, ear diameter, harvest index, thousand seed weight, grain yield, straw yield, and above-ground biomass yield

| Treatment | PH (cm) | EL (cm) | EDI (cm) | HI (%) | TSW (g) | GY(kg ha$^{-1}$) | STY (kg ha$^{-1}$) | AGBM (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Control (no lime) | 201.05 | 15.40 | 4.54 | 37.87 | 397.75 | 6479.1$^{b}$ | 8526.5 | 15004.6$^{b}$ |
| 0.060 ton ha$^{-1}$ | 202.00 | 15.48 | 4.63 | 38.44 | 399.75 | 6628.3$^{b}$ | 9101.4 | 15721.8$^{ab}$ |
| 0.120 ton ha$^{-1}$ | 200.15 | 16.35 | 4.61 | 38.91 | 400.75 | 6840.3$^{ab}$ | 9131.9 | 15972.2$^{ab}$ |
| 0.180 ton ha$^{-1}$ | 200.00 | 16.03 | 4.66 | 39.84 | 401.50 | 6621.8$^{b}$ | 9311.9 | 15930.6$^{ab}$ |
| 1 ton ha$^{-1}$ | 201.00 | 16.60 | 4.73 | 40.22 | 407.00 | 6862.4$^{ab}$ | 9466.5 | 16333.3$^{ab}$ |
| 2 ton ha$^{-1}$ | 201.80 | 16.65 | 4.63 | 39.86 | 406.50 | 6871.4$^{ab}$ | 9748.7 | 16620.4$^{ab}$ |
| 3.5 ton ha$^{-1}$ | 202.60 | 16.40 | 4.65 | 39.83 | 405.25 | 6964.3$^{ab}$ | 9420.4 | 16375.0$^{ab}$ |
| 4 ton ha$^{-1}$ | 201.80 | 17.30 | 4.62 | 41.72 | 408.75 | 7719.1$^{a}$ | 10467.0 | 18180.6$^{a}$ |
| 7 ton ha$^{-1}$ | 206.90 | 16.53 | 4.69 | 39.26 | 410.25 | 6988.0$^{ab}$ | 9510.1 | 16504.6$^{ab}$ |
| 14 ton ha$^{-1}$ | 205.93 | 16.20 | 4.74 | 40.48 | 404.50 | 7106.3$^{ab}$ | 9807.2 | 16912.0$^{ab}$ |
| Mean | 202.32 | 16.29 | 4.65 | 39.64 | 404.20 | 6908.01 | 9449.2 | 16355.5 |
| P | Ns | Ns | Ns | Ns | Ns | * | Ns | * |
| CV (%) | 6.31 | 11.17 | 5.51 | 9.52 | 8.44 | 10.9 | 15.2 | 10.6 |

*Note: FDB=full dose of the buffer, FDEA=full dose of exchangeable acidity, PH=plant height, EL=Ear length, ED=Ear diameter, HI=harvest index, TSW=Thousand seed weight, LSD=least significant difference, CV=Coefficient of variation, SE±=Standard error of the mean, Ns=non-significance of F-test at alpha 0.05 level.*

### *Economic Analysis*

MRR was calculated after ordering the treatment TVC values in increasing order and excluding dominated treatments. According to CIMMYT (1988), when all the comparable treatments showed more than 100% MRR value in the experiment, treatment having the highest NB value can be taken as economically profitable and recommendable to the users. Based on CIMMYT (1988) rule, the treatment that received 0.120 tons ha$^{-1}$ lime and applied through the spot application method gave >100% MRR value and the highest NB (60,897.6 Birr) which can be taken as an economically acceptable and recommendable lime rate for users.

## Conclusions and Recommendations

In conclusion, the drill lime application method gave a better response to improve selected soil chemical properties significantly. This application method showed high efficiency to ameliorate soil acidity with more than 200% lime cost reduction advantage comparative to the broadcast application method. Application of different lime rates affected maize grain yield and slightly affected maize yield components. From an economic point of view, the use of 0.12 tons ha$^{-1}$ lime in the micro-dosing application method had an acceptable economic profit. Therefore, the following points are suggested as recommendations. For farmers who afford to apply much amount of lime, it is recommended to apply 3.5 tons ha$^{-1}$ lime through the drill lime application method to improve the basic soil chemical properties in a short time for residual effect. However, for farmers who are unable to apply the above-recommended lime rate, it is possible to use the micro-dose rate (0.12 tons $ha^{-1}$) to get an efficient and acceptable economic profit. Moreover, further studies are required on replicated sites for consecutive years to get more reliable and granted results.

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# Effect of Lime and Different Phosphorus Fertilizer Source on Faba bean (*Vicia fabae L.*) And Chemical Properties of Acidic soil of Ethiopia

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## Abstract

*Acidic soils cause poor plant growth resulting from aluminum ($Al^{+3}$) and manganese (Mn) toxicity or deficiency of essential nutrients like phosphorus, calcium, and magnesium. Hence, improving the fertility of this soil through appropriate management is a major priority as the demand for food and raw materials is increasing rapidly. To this end, a field experiment was carried out at Gozamen district of the Western Amhara region to determine the effect of different phosphorous fertilizer levels and liming on grain yield of faba bean (Vicafaba L.) and chemical properties of the soil. The experiment had two sets; lime and un-lime which were conducted separately. The treatments include a combination of different phosphorous fertilizer type with eight levels (0, GPAPR 146, 219+ 26 UREA, MOHP 175, 116+26 UREA, NAFAKA 287, 191 + 26 UREA, and NPSZnB 136+26 UREA kg ha-1) and 1/4$^{th}$ of recommended lime. The experiment was laid in a randomized complete block design with three replications of each. The highest grain yield 1352 kg ha$^{-1}$ was obtained with the application of lime with 287 NAFAKA kg ha$^{-1}$ followed by the application of 191 kg ha$^{-1}$ without lime which recorded a grain yield of 1337 kg ha$^{-1}$. At Gozamen the net benefits 14781.5 ETB ha$^{-1}$ with marginal rate of return 895.1% and 21657.5 ETB ha$^{-1}$ with marginal rate of return 92.7% were obtained from the combination of 287 NAFAKA kg/ha plus lime and 191 kg ha$^{-1}$ NAFAKA without lime respectively.*

**Keywords:** *Fertilizer, Grain yield, Lime, Phosphorus, Soil pH*

## Introduction

Faba bean (*Viciafabae* L.) fixes atmospheric nitrogen in symbiosis with *Rhizobium leguminosarumbv.viciae* (Hardarson et al 1991.) It grows on loamy to clay loam soil types but prefers deep, loamy soil with neutral to alkaline pH (7.0-9.0). Typical environmental stresses faced by the legume nodules and the symbiotic partners may include water stress, salinity, soil pH, temperature, heavy metals, and so on (Amanuel et al 2000). The average annual yield of faba bean is 21.9 Q/ha in Ethiopia (CSA, 2017). $N_2$-fixation in root nodules is sensitive to extremes of pH: nodulation & N-fixation are reduced where pH < 5.5 & >8.0 or with excessive salinity.

Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. Although acidification is a natural process in many soil environments, agricultural practices, environmental pollution, mining and other human activities have aggravated the process (Oguntoyinbo *et al*., 1996; Curtin and Syers, 2001). Its severity is extremely variable due to the effects of parent materials, landform, vegetation, and climate pattern (Rowell, D. L., 1994). Its effects on crop growth are those related to the deficiency of major nutrients and the toxicity of aluminum (Al), manganese (Mn), and hydrogen (H) ions in the soil to plant physiological processes (Mesfin, 2009). In order to secure sustainable crop production and reasonable yield, acidic soils have to be corrected by the addition of agricultural lime to a pH range that is suitable for faba bean (Mesfin, 2009). The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P, and Mo availability, stimulate microbiological activity in soil; improve the physical structure of soil by clumping together or flocculation, clay into more stable aggregates (Fageria and Baligar, 2008). Liming raises the soil pH by adding calcium & magnesium to soil and causes the aluminum and manganese to go out from the soil solution back in to precipitate then solid (nontoxic) chemical forms. The lime requirement will vary depending upon the types of soil, the desired change in pH, buffering capacity of the specific soil, type of liming material, and the fineness of texture of the lime material (Birhanu, 2010).

Phosphorus P is one of the essential macronutrients that determine crop growth and productivity. However, its deficiency is one of the largest constraints on crop productivity in soils of the humid tropics because of high P fixation by iron (Fe) and aluminum (Al) oxides (Kamprath, 1984). Therefore, an appropriate P-management system is increasingly becoming important in marginal acid soils to enhance crop productivity. One of the appropriate P-management methods is applying the optimum rate of P and this significantly improves plant growth (Shaikh et al.,2008). Moreover, the addition of lime to acid soils has long been widely adopted as the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia. The appropriate combination of lime and P fertilizer is, therefore, an important strategy for improving crop growth in acid soils. There is, however, a scarcity of information on the interactive effects of lime and P fertilizer application on crop performance in western Amhara Ethiopia. Phosphate rock is recommended for application to acid soils where phosphorus is an important limiting nutrient on plant growth. The objective of this study was, therefore, to investigate the interactive effects of lime and P fertilizer on faba bean grain yield on the selected soil chemical properties under acid soil conditions in Western Amhara, Ethiopia.

## Materials and Methods

### *Description of Study Area*

The study was conducted for two consecutive years during 2016 to 2017 main cropping seasons in Gozamen districts of East Gojjam zone in western Amhara, Ethiopia. Gozamen is located at s above sea level in western Amhara, Ethiopia. The site is typically characterized by highland with a cool subtropical climate.

The area (Gozamen) receives an annual mean rainfall of 1145 mm with the unimodal distribution of June to September. The site with an acidity problem (pH <5.2) and with no liming history was selected for this experiment. Some of the chemical characteristics of the experimental site are summarized in Table 1.

**Table 1**. soil chemical properties of the experimental site

| Location | pH | P/ppm | OC% | OM% | Exch acidity meq/100gm | Exch Al meq/100gm |
|---|---|---|---|---|---|---|
| Gozamen | 5.1 | 8 | 1.6 | 2.82 | 1.5 | 0.9 |

*Note: P=phosphorus, OC=Organic carbon, OM=Organic matter*

### *Experimental setup*

The experiment was conducted separately in two sets (Lime & un-lime) in a randomized complete block design with three replications of each. Four types of P fertilizer with eight levels (0, 146, 219 GPAPR + 26 UREA, 175, 116 MOHP +26 UREA, 287, 191 NAFAKA + 26 UREA, and 136 NPSZnB +26 UREA kg $ha^{-1}$) and 1/4$^{th}$ of recommended lime based on exchangeable acidity ($Al^{3+}$ plus $H^{1+}$) adapted from (Kamprath, 1984). Lime was applied uniformly in a row by hand to every year. The experimental plots were kept permanent to observe the residual effects of phosphorous and lime application over years. The entire dose of phosphorous and the recommended N rate (26 kg/ha) were applied at planting. Gross and net plot sizes were 3 m × 4 m and 3 m × 3.2m respectively. Faba bean variety Wolkie was used as a test crop.

*Soil sampling*

Before planting and before application of lime composite soil samples were taken from the experimental site using a soil auger from 0-20 cm soil depth. At harvesting, soil samples were collected from each treatment and independently analyzed. Soil samples were air-dried under shade, grounded by mortar & pestle, and sieved to pass through 2 mm mesh for further chemical analysis.

*Soil analysis*

The soil pH was determined using a glass electrode pH meter in 1:2.5 soils to water ratio and exchangeable acidity ($Al^{+3}$ and $H^{+}$

(Keeney et al 1982). Available phosphorous was determined by Olsen (Olsen & Sommer, 1982). Soil organic carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Van Reeuwijk, 1992)

*Agronomic Data Collection and Interpretation*

Dry biomass and grain yield were collected at physiological maturity. Analysis of variance (ANOVA) for straw and grain yield data were conducted using SAS 9.2 version (SAS, 2008). In conditions where ANOVA is significant, the treatment means were compared using the Least Significance Difference test (LSD).

*Economic Analysis of Treatment*

Partial budget analysis of treatments was done according to CIMMYT (1988). The mean grain yield data of faba bean which was produced by each treatment over two experimental years (2016 and 2017) was used for the partial budget analysis. The mean grain yield data were further adjusted down by 10% to minimize the yield gap that may occur due to plot management differences by researchers and farmers (CIMMYT, 1988). The average prices of relevant data which were needed to do the partial budget analysis were collected from different sources. Thus, the field price of 1 kg of faba bean in 2018 at the local market was 22 Ethiopian Birr (ETB) and was taken as a field price of faba bean. Thus, the current price of

Urea 12.76 ETB $kg^{-1}$, NPSZnB 13.82 ETB $kg^{-1}$, KCl 10 ETB $kg^{-1}$and lime 1.6 ETB kg-$^{1}$. The price of different phosphorous source fertilizers (NAFAKA, MOHP, and GPAPR) were calculated by the current price NPSZnB fertilizer.

## Results and Discussions

### *Grain yield*

The analysis of variance indicated that lime and P fertilizer application not significantly affected Fababean grain yield in both years (Table 2). The initial soil pH of our experiment area was 5.1. Hence faba bean grain yield was low as compared to the crop potential probably due to acidity. According to (Hardarson et al 1991.) Faba bean grows on soil with neutral to alkaline (7.0-9.0). The effect of lime and P fertilizer application on grain yield of faba bean was found significant only during the first year (Table 2). The highest faba bean grain yields 1352 kg $ha^{-1}$ on combined analysis was obtained from the application of 1/4$^{th}$ of the recommended lime based on exchangeable acidity with 287 kg/ha NAFAKA phosphorous fertilizer followed by a full dose of MOHP under a limed condition which recorded the grain yield of 1326 kg $ha^{-1}$ (Table 2).

Many researchers also revealed that lime application improved the grain yield of crops (Liu et al., 2004; Achalu et al., 2012; Caires et al., 2005). According to Achalu et al. (2012), the increase in crop yield through the application of lime may be attributed to the neutralization of $Al^{3+,}$ supply of $Ca^{2+}$ and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime is ascribed to its favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that application of lime brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils these of our experiment with lime better grain yield than un-limed. In the present study, the better grain yield realized from the calcitic lime application during the first year indicates a fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

**Table 2**. Result main effect of lime and different source of phosphorous fertilizer on Faba bean yield at Gozamen District

| Treatment | 2016 | | | | 2017 | | | | Combined | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Straw Yield Kg ha-1 | | Grain yield Kg ha-1 | | Straw Yield Kg ha-1 | | Grain yield Kg ha-1 | | Straw Yield Kg ha-1 | | Grain yield Kg ha-1 | |
| | Un-lime | lime | Un-lime | lime | Un-lime | lime | Un-lime | lime | Un-lime | lime | Un-lime | lime |
| Control | 2203 | 2100 | 965 | 901 | 3701 | 5059 | 1000 | 1586 | 1608 | 1648 | 864 | 738 |
| 2/3 GPAPR | 2920 | 3039 | 1365 | 1425 | 4735 | 5842 | 2227 | 2835 | 2166 | 2154 | 1168 | 1080 |
| Full GPAPR | 2997 | 3100 | 1427 | 1431 | 4927 | 5830 | 2243 | 2597 | 2456 | 2338 | 1229 | 1108 |
| 2/3 MOHP | 2478 | 2456 | 1141 | 1114 | 4726 | 4897 | 2147 | 2271 | 1692 | 1878 | 885 | 1087 |
| Full MOHP | 2365 | 2911 | 1075 | 1387 | 4590 | 5048 | 2162 | 2395 | 1986 | 2272 | 1027 | 1326 |
| 2/3 NAFAKA | 2808 | 2600 | 1319 | 1120 | 4303 | 5674 | 2006 | 2709 | 2114 | 2024 | 1237 | 1071 |
| Full NAFAKA | 1955 | 3164 | 892 | 1500 | 4752 | 5301 | 2142 | 2462 | 2185 | 1622 | 1200 | 1352 |
| Rec. NPSZnB | 3855 | 3156 | 1840 | 1479 | 5680 | 6026 | 2585 | 2782 | 2222 | 2802 | 1152 | 915 |
| CV % | 14.2 | 17 | 17.4 | 19.5 | 13 | 14.3 | 14.6 | 18.3 | 13.7 | 19.8 | 17 | 34.6 |
| LSD 5% | 639.2 | NS | 362.7 | NS | NS | NS | NS | NS | NS | NS | NS | NS |

### *Soil Chemical Properties*

Generally, the trend of the result indicated that liming increased soil pH and available P and reduced exchangeable acidity (Table 3). Essentially amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in a decrease in Al solubility thereby minimizes its toxic effect on plants. These findings are in agreement with those of Anetor and Akinrinde (2006) who reported increased pH and available P while lime was applied which in turn reduced P fixation. In addition, the same study revealed that lime combined with phosphorous fertilizer increased available P in Nigeria. Kisinyo et al. (2012) reported that positive effects on soil pH and available P in acid soil of Western Kenya, with the application of lime and P fertilizer in combination. The exchangeable acidity decreased from 0.49-0.91 Meq/100gm. These results compare well those of Busari et al. (2005) and White et al (2006) indicated that lime improves soil physical condition, increase soil pH, availability of nutrient, and decrease aluminum, Fe and other micronutrient toxicity.

**Table 3**. Lime and phosphorus residual effect on some soil chemical property of Gozamen District

| Treatment | Without lime | | | | | | lime | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | P/PPm | OC% | OM% | Exch Acidity meq/100 gm | Exch Al meq/100 gm | pH | P/PPm | OC% | OM % | Exch Acidity Meq/100gm | Exch Al meq/100 |
| Control | 5.1 | 8.29 | 1.32 | 2.28 | 0.77 | 0.09 | 5.0 | 6.9 | 1.63 | 2.80 | 0.73 | 0.00 |
| 2/3 GPAPR | 5.4 | 8.17 | 1.29 | 2.23 | 1.13 | 0.00 | 6.1 | 10.9 | 1.58 | 2.70 | 0.72 | 0.00 |
| Full GPAPR | 5.4 | 11.60 | 1.42 | 2.44 | 0.66 | 0.10 | 6.3 | 12 | 1.68 | 2.80 | 0.71 | 0.05 |
| 2/3 MOHP | 5.5 | 7.12 | 1.53 | 2.64 | 0.89 | 0.00 | 6.1 | 9.3 | 1.61 | 2.80 | 0.66 | 0.06 |
| Full MOHP | 5.4 | 6.24 | 1.35 | 2.27 | 1.04 | 0.00 | 6.1 | 9.2 | 1.70 | 2.90 | 0.91 | 0.02 |
| 2/3 NAFAKA | 5.6 | 11.6 | 1.70 | 2.93 | 0.86 | 0.00 | 6.0 | 10.2 | 1.55 | 2.70 | 0.59 | 0.00 |
| Full NAFAKA | 5.7 | 7.14 | 1.63 | 2.81 | 0.21 | 0.00 | 6.5 | 10.9 | 1.68 | 2.90 | 0.60 | 0.00 |
| Rec. NPSZnB | 5.6 | 6 | 1.46 | 2.51 | 0.65 | 0.00 | 5.7 | 7.1 | 1.57 | 2.70 | 1.05 | 0.08 |

*Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter*

### *Economic Feasibility of liming and different P sources/rates*

Partial budget analysis of the combination of lime with different phosphorus fertilizers was presented in Table 4. The net benefit of ETB 14781.5 ha$^{-1}$ and marginal rate return of 895.1 % was obtained from a combination of 287 kg ha$^{-1}$ NAFAKA plus lime for faba bean production. Similarly, net benefit 21657.5 ETB ha$^{-1}$ and the marginal rate return of 92.7 % were generated from the sole use of 191 kg NAFAKA phosphorus fertilizer. Therefore, the combination of 287 kg NAFAKA ha$^{-1}$ with lime or sole use of 191 kg ha$^{-1}$ NAFAKA phosphorus fertilizer was economically feasible for barley production in Gozamene area.

**Table 4**. Partial budget analysis of lime and different phosphorus sources for faba bean

| Treatment With lime | TVC (ETB$^{-1}$) | GY (kg$^{-1}$) | AdY(kg$^{-1}$) | STY (kg$^{-1}$) | AdSTY (kg$^{-1}$) | GB (ETBha-1) | NB (ETBha-1) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 478.3 | 738 | 664.2 | 1648 | 1483.2 | 16095.6 | 15617.3 | |
| 2/3 GPAPR | 4987.3 | 1080 | 972 | 2154 | 1938.6 | 23538 | 18550.7 | 238.5 |
| Full GPAPR | 4996.9 | 1352 | 1216.8 | 2338 | 2104.2 | 28873.8 | 23876.9 | D |
| 2/3 MOHP | 3581.7 | 1087 | 978.3 | 1878 | 1690.2 | 23212.8 | 19631.1 | 831.6 |
| Full MOHP | 4388.4 | 1326 | 1193.4 | 2272 | 2044.8 | 28299.6 | 23911.2 | 718.7 |
| 2/3 NAFAKA | 3744.4 | 1071 | 963.9 | 2024 | 1821.6 | 23027.4 | 19283 | D |
| Full NAFAKA | 4957.5 | 915 | 823.5 | 1622 | 1459.8 | 19739 | 14781.5 | 895.1 |
| Rec. NPSZnB | 3359.1 | 1178 | 1060.2 | 2802 | 2521.8 | 25846.2 | 22487.1 | D |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.*

**Table 5**. Partial budget analysis of different phosphorus sources for faba bean

| Treatment Without lime | TVC ($ETB^{-1}$) | GY ($kg^{-1}$) | AdY($kg^{-1}$) | STY ($kg^{-1}$) | AdSTY ($kg^{-1}$) | GB (ETBha-1) | NB (ETBha-1) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 0 | 864 | 777.6 | 1447.2 | 1608 | 18715.2 | 18715.2 | 0 |
| 2/3 GPAPR | 4509 | 1168 | 1051.2 | 1949.4 | 2166 | 25292.4 | 20783.4 | D |
| Full GPAPR | 4518.6 | 1229 | 1093.1 | 2210.4 | 2456 | 26504.2 | 21985.6 | 26.6 |
| 2/3 MOHP | 3103.4 | 885 | 796.5 | 1522.8 | 1692 | 19215 | 16111.6 | D |
| Full MOHP | 3910.1 | 1027 | 934.3 | 1787.4 | 1986 | 22540.6 | 18630.5 | D |
| 2/3 NAFAKA | 3266.1 | 1152 | 1036.8 | 1902.6 | 2114 | 24923.6 | 21657.5 | 92.7 |
| Full NAFAKA | 4479.2 | 1200 | 1080 | 1966.5 | 2185 | 25874 | 21394.8 | 21.7 |
| Rec. NPSZnB | 2880.8 | 1237 | 1113.3 | 1999.8 | 2222 | 26714.6 | 23833.8 | 84.7 |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (EB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and EB=Ethiopian Birr.*

## Conclusions and Recommendation

The objective was to assess the effect of different sources of phosphorus fertilizer for faba bean production with acidic soil at Gozamen District in 2016-2017. However, the interaction effect of lime and P fertilizer application on grain yield of faba bean was significant only during the first year. But the combined analysis of variance over years showed no significance. The results of soil increased soil pH and available P, while exchangeable acidity and $Al^{3+}$ had decreased by the application of 1/4$^{th}$ recommended lime based on exchangeable acidity. The application of 287 and 191 kg $h^{-1}$ NAFAkA phosphorus source fertilizer both limed and un-limed were recommended for the study location and similar agro-ecologies in acidic soil of Ethiopia.

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# Effect of Lime and Different Phosphorus Fertilizer Sources on Barley (Hordeum vulgare L.) Yield and Chemical Properties of Acidic soils of Banja and Gozamen Districts, Western Amhara

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## Abstract

*In acid soils phosphorus reacts with Fe and Al oxides/hydroxides to form insoluble phosphates, hence reducing P availability to plants. Therefore, plant growth is highly impaired in acidic soils due to deficiency of phosphorus in addition to Al toxicity. To this end, a field experiment was carried out to determine the effect of different phosphorous fertilizer levels and lime on the grain yield of barley and chemical properties of acidic soils at Gozamen and Banja districts, western Amhara region, Ethiopia. The experiment had two sets; lime and un-limed which were conducted separately. The treatments include a combination of different phosphorous fertilizer type with eight levels (0, GPAPR 146, 219+ 100 UREA, MOHP 175, 116+100 UREA, NAFAKA 287, 191 + 100 UREA, and NPSZnB 136+100 UREA kg ha-1) and ¼ of exchangeable acidity lime. The experiment was laid in a randomized complete block design with three replications of each. At Gozamen the highest grain yield (2470 kg ha-1) was obtained with the application of lime together with 136 NPSZnB + 100 UREA kg /ha followed by the application of 146 GPAPR + 100 UREA kg ha-1 which recorded a grain yield of 2195 kg ha-1 without lime. At Gozamen the highest net benefits 49914.2 ETBha-1 with marginal rate of return 590.8% and 39746.3 ETB ha-1 with marginal rate of return 292.2% were obtained from the application of 1/4th lime plus 136 NPSZnB + 100 UREA kg /ha and sole use of 146 GPAPR + 100 UREA kg ha-1respectivly. In the case of Banja district, the application of 146 kg ha-1 GPAPR and 1/4th lime obtained the net benefit of 29893.8ETB ha-1 with marginal rate return of 1483.1% and sole application of 191 kg ha-1 NAKFA+100 kg ha-1 UREA generated 8765.45 ETBha-1 net benefits with marginal rate return of 584.6%. Generally, lime increased soil pH and reduced exchangeable acidity, and increase the availability of phosphorus.*

**Keywords:** *Acid soil, Grain yield, Lime, Phosphorus, Soil pH.*

## Introduction

Barley *(Hordeum vulgare L.)* is a major cereal crop in Ethiopia and accounts for 8% of the total cereal production (Wosene et al., 2015). Barley has a long history of cultivation in Ethiopia as one of the major cereal crops and it is reported to have coincided with the beginning of plow culture (Mulatu et al., 2011). In the highlands of the country, barley is grown in Oromia, Amhara, Tigray, and part of the Southern Nations, Nationalities, and

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cereal crop after wheat, maize, and rice (Martin et al,. 2006). Despite its importance and long history of cultivation in Ethiopia, the productivity of barley is lower than other major cereals. The national average yield of barley is about 2.16 t/ha, compared to 2.74 t/ha for wheatand3.94 t/ha for maize (CSA, 2018). One of the major constraints limiting the productivity of barley is poor soil fertility (Berhane et al., 1996; Tarekegne et al., 1997).

Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. Although acidification is a natural process in many soil environments, agricultural practices, environmental pollution, mining and other human activities have aggravated the process (Oguntoyinbo *et al*., 1996; Curtin and Syers, 2001). Its severity is extremely variable due to the effects of parent materials, landform, vegetation, and climate pattern (Rowell, 1994). Its effects on crop growth are those related to the deficiency of major nutrients and the toxicity of aluminum (Al), manganese (Mn), and hydrogen (H) ions in the soil to plant physiological processes (Mesfin, 2009). In order to secure sustainable crop production and reasonable yield, acidic soils have to be corrected by the addition of agricultural lime to a pH range that is suitable for better yield of crop production (Mesfin, 2009). The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P, and Mo availability, stimulate microbiological activity in soil; improve the physical structure of soil by clumping together or flocculation, clay into more stable aggregates. Liming raises the soil pH by adding calcium & magnesium to soil and causes the aluminum and manganese to go out from the soil solution back in to precipitate then, solid (nontoxic) chemical forms (Johnston et al., 1986). The lime requirement will vary depending upon the types of soil, the desired change in pH, buffering capacity of the specific soil, type of liming material, and the fineness of texture of the lime material (Birhanu, 2010).

Phosphorus reacts with Fe and Al oxides/hydroxides under acidic conditions to form insoluble phosphates, hence reducing P availability to plants (Kamprath, 1984). Phosphorus deficiency often, therefore, occurs simultaneously with $Al^{3+}$ toxicity in these soils. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. The addition of lime to acid soils has long been widely adopted as, the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia. Application of lime at an appropriate rate brings several chemical and biological changes in the soil which is beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H: improves soil structure (aeration): improves the availability of Ca, P, Mo, and Mg, pH and $N_2$ Fixation; and reduces the availability of Mn, Zn, Cu, and Fe leaching loss of cations (Fageria and Baligar, 2008). The appropriate combination of lime and P fertilizer is, therefore, an important strategy for improving crop growth in acid soils. There is, however, a scarcity of information on the interactive effects of lime and P fertilizer application on crop performance in western Amhara Ethiopia. Phosphate rock is recommended for application to acid soils where phosphorus is an important limiting nutrient on plant growth. The objective of this study was, therefore, to investigate the interactive effects of lime and P fertilizer on barley grain yield on the selected soil chemical properties under acid soil conditions in Western-Amhara, Ethiopia.

## Materials and Methods

### *Description of Study Area*

The study was conducted for three consecutive years during 2015to 2017 main cropping seasons at Banja district, Awi zone, and Gozamen district East Gojjam zone in western

2338m asl in the western Amhara, Ethiopia. The site with lower pH (<5.2) and with no liming history was selected for this study. Some of the selected chemical characteristics of the experimental sites are summarized in Table 1.

**Table 1**. Soil chemical properties of the experimental site

| Location | pH(1:2.5 soil water) | [P olson](ppm) | OC% | OM% | Exchangable acidity meq/100gm | Exchangable Al meq/100gm |
|---|---|---|---|---|---|---|
| Gozamen | 5.1 | 9.2 | 1.6 | 2.82 | 1.5 | 0.9 |
| Banja | 5.2 | 11.7 | 1 | 1.72 | 1.9 | 1 |

*Note: P=phosphorus, OC=Organic carbon, OM=Organic matter*

*Experimental setup*

The experiment was laid out separately in two sets (Lime & un-limed) in a randomized complete block design with three replications of each. Four types of P fertilizer with eight levels (0, GPAPR 146 , GPAPR 219, MOHP 116, MOHP 175 NAFAKA 191 NAFAKA 287.5 NPSZnB 132.5 and 100 Urea kg/ha). For limed treatments, 1/4$^{th}$ of the recommended lime was uniformly applied in rows by hand every year during planting and thoroughly incorporated in the soil. Lime requirement of the soil was calculated based on its exchangeable acidity ($Al^{3+}$ plus $H^{1+}$) adapted from (Kamprath, 1984). The experimental plots were kept permanent to observe the residual effects of phosphorous and lime application over years. The entire dose of phosphorous was applied at planting, while the recommended N rate of 46 kg/ha was applied in split, half at sowing, and the remaining half side dressed at tillering stage of barley. Gross plot sizes were3 m × 4m and net plot sizes 3 m × 3.6m for both districts. Food barley variety BH-1307 was used as a test crop in both districts.

*Soil sampling*

Before planting and application of lime, composite soil samples were taken from the experimental site using a soil auger from 0-20 cm soil depth. At harvesting, soil samples from each treatment were taken and independently analyzed. Soil samples were air-dried under shade, grounded by mortar & pestle, and sieved to pass through 2 mm mesh for further chemical analysis.

*Soil analysis*

The soil pH was determined using glass electrode pH meter in 1:2.5 soils to water ratio volume and exchangeable acidity ($Al^{+3}$ and $H^{+}$) were extracted with KCl solutions using the (Keeney et al 1982). Available phosphorous was determined by (Olsen & Sommer, 1982). Soil organic carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Van Reeuwijk, 1992)

*Agronomic Data Collection and Interpretation*

Dry biomass and grain yield data were collected and analyzed using the analytical procedure of SAS 9.2 version (SAS, 2008). In a condition where ANOVA is significant, the treatment means were compared using the Least Significance Difference test (LSD).

*Economic Analysis of Treatment*

Partial budget analysis of treatments was done according to CIMMYT (1988). The mean grain yield data of barley which was produced by each treatment over three experimental years (2015 and 2017) were used to do the partial budget analysis. The mean grain yield data were adjusted down by 10% to minimize the yield gap that may occur due to plot management differences by researchers and farmers (CIMMYT, 1988). The average prices of relevant data which were needed to do the partial budget analysis were collected from different sources. Thus, the field price of 1 kg of barley in 2018 at the local market was 15 Ethiopian Birr (ETB) and was taken as a field price of barley. The current price of Urea 12.76 ETBkg$^{-1}$, NPSZnB 13.82 ETBkg$^{-1}$ and lime was 1.6 ETB kg$^{-1}$. The price of different phosphorous fertilizers sources (NAFAKA, MOHP, and GPAPR) were calculated by the current price of NPSZnB fertilizer.

## Results and Discussions

*Grain yield*

The analysis of variance indicated that lime and P fertilizer application significantly ($P<0.05$) affected the grain yield of barley in two years at Gozamen District (Table 2). However, the effect of lime and P fertilizer application on grain yield of barley was found significant only during the initial and the last years at Gozamen (Table 2). But in the case of Banja district, no significant effect of lime and phosphorous fertilizer all year. The combined analysis of variance over years of both districts showed a significant ($P<0.05$) effect of P and lime application. In general, progressive increases in grain yields were recorded from the first year to second year lime and P fertilizer application. Grain yield response was found more pronounced with the second than the first due to the residual effect of lime and P application. This implies that the application of phosphate rock (PR) would benefit farmers at least from the second planting season. The extractable soil P at the second cropping season that PR continued to decompose and release P (residual effect) into the soil (Husnain., 2013).

**Table 2**. The main effect of lime and different source of phosphorous fertilizer on Barley yield at Gozamen District

| Treatment | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Straw Yield kgha-1 | | Grain yield Kgha-1 | | Straw Yield Kgha-1 | | Grain yield Kgha-1 | | Straw Yield Kgha-1 | | Grain yield Kgha-1 | |
| | Unlime | Lime | Unlime | lime | Unlime | lime | Unlime | lime | Unlime | lime | Unlime | lime |
| Control | 1803 | 1963 | 579 | 695 | 3701 | 5059 | 1564 | 1586 | 1967 | 2722 | 1009 | 1391 |
| 2/3 GPAPR | 2673 | 2952 | 1349 | 1523 | 4735 | 5842 | 2227 | 2835 | 5007 | 5907 | 2710 | 2881 |
| Full GPAPR | 2838 | 2973 | 1405 | 1483 | 4927 | 5830 | 2243 | 2597 | 4781 | 4981 | 2708 | 2781 |
| 2/3 MOHP | 2445 | 2363 | 1131 | 1145 | 4726 | 4897 | 2147 | 2271 | 3804 | 5130 | 2053 | 2861 |
| Full MOHP | 2501 | 2357 | 1122 | 1114 | 4590 | 5048 | 2162 | 2395 | 4204 | 4874 | 2996 | 3247 |
| 2/3 NAFAKA | 2404 | 2580 | 1183 | 1284 | 4303 | 5674 | 2006 | 2709 | 4878 | 5085 | 2674 | 3418 |
| Full NAFAKA | 2268 | 2734 | 1033 | 1341 | 4752 | 5301 | 2142 | 2462 | 4833 | 3456 | 2697 | 2088 |
| Rec. NPSZnB | 2960 | 4227 | 1342 | 1950 | 5680 | 6026 | 2585 | 2782 | 3407 | 4911 | 1693 | 2797 |
| CV % | 16.3 | 23.8 | 22.2 | 22.5 | 13 | 14.3 | 14.6 | 18.3 | 29 | 22.6 | 32 | 23.9 |
| LSD 5% | 675.8 | 1098.7 | 423.8 | NS | NS | NS | NS | NS | NS | 1835.7 | NS | 1112.8 |

The combined analysis over years at both locations revealed that all P sources and/or rates significantly increased grain yield of barley compared to the untreated control under limed and un-limed conditions (Table 3 and 4). At Gozamen the highest grain yields (2470 kg $ha^{-1}$) of barley were recorded from the application of ¼ the recommended lime together with 136 kg/ha NPSZnB fertilizer, followed by 191 kg $ha^{-1}$NAFAKA which recorded a grain yield of 2469 kg $ha^{-1}$. But it was statistically at par with all the rest treatments except the control (Table 3). Similarly, the highest grain yield (1675 kg $ha^{-1}$) at Banja district was recorded from the application of 136 kg/ha NPSZnB under limed condition followed by the application of 146 kg ha GPAPR phosphorous in combination with 1/4$^{th}$ the recommended lime which recorded the grain yield of 1669 kg $ha^{-1}$ (Table 4). Mean barley grain yield increment of Goazamen district in the combined analysis at 136 NPSZnB kg/ha P fertilizer plus ¼ of recommended lime was 12.4Q/ha yield difference over the limed control treatment (Table 4). ication of lime increased barley grain yield over the un-limed condition.

**Table 3**. The main effect of lime and different source of phosphorous fertilizer on Barley yield at Gozamen District combined over year

| Treatment | Pooled over year | | | |
|---|---|---|---|---|
| | Straw Yield kgha-1 | | Grain yield kgha-1 | |
| | Un-limed | lime | Un-limed | Lime |
| Control | 2490 | 3248 | 1051 | 1224 |
| 2/3 GPAPR | 4138 | 4900 | 2119 | 2380 |
| Full GPAPR | 4182 | 4595 | 1954 | 2287 |
| 2/3 MOHP | 3658 | 4130 | 1777 | 2092 |
| Full MOHP | 3765 | 4093 | 2093 | 2252 |
| 2/3 NAFAKA | 3862 | 4446 | 2095 | 2469 |
| Full NAFAKA | 3951 | 3830 | 1957 | 1964 |
| Rec. NPSZnB | 4016 | 5055 | 1873 | 2470 |
| CV % | 15 | 13.4 | 18.6 | 14.9 |
| LSD 5% | 990.1 | 1004.3 | 608.2 | 559.3 |

According to Achalu, (2012), the increase in crop yield through the application of lime may be attributed to the neutralization of $Al^{3+}$ supply of $Ca^{2+}$ and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime could be due to the favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that the application of lime brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils. In the present study, the higher grain yield realized from the calcitic lime application during the initial years indicates fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

**Table 4**. The Main effect of lime and different source of phosphorous fertilizer on Barley yield at Banja District

| Treatment | 2016 | | | | 2017 | | | | combined | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Straw Yield Kgha-1 | | Grain yield Kgha-1 | | Straw Yield kgha-1 | | Grain yield Kgha-1 | | Straw Yield kgha-1 | | Grain yield Kgha-1 | |
| | Un-limed | lime | Un-limed | lime | Un-limed | lime | Un-limed | lime | Un-limed | Lime | Un-limed | Lime |
| Control | 2037 | 2762 | 553.9 | 1363 | 1000 | 2111 | 327 | 804 | 1519 | 2436 | 440.5 | 1083 |
| 2/3 GPAPR | 2593 | 3300 | 638.8 | 1412 | 2296 | 3741 | 1377 | 1881 | 2537 | 3520 | 854.4 | 1669 |
| Full GPAPR | 2284 | 2991 | 727.4 | 1574 | 2667 | 4148 | 1356 | 1952 | 2475 | 3570 | 830.3 | 1637 |
| 2/3 MOHP | 2593 | 3300 | 734.4 | 1426 | 2007 | 2778 | 799 | 1337 | 2300 | 3039 | 766.6 | 1455 |
| Full MOHP | 2346 | 2960 | 601.7 | 1289 | 2139 | 3296 | 1075 | 1563 | 2242 | 3128 | 838.5 | 1426 |
| 2/3 NAFAKA | 2438 | 3331 | 693.4 | 1550 | 2243 | 3370 | 967 | 1709 | 2340 | 3351 | 1041.7 | 1629 |
| Full NAFAKA | 2593 | 3084 | 632.7 | 1417 | 2870 | 3148 | 1246 | 1565 | 2731 | 3116 | 939.4 | 1491 |
| Rec. NPSZnB | 2438 | 3238 | 606.6 | 1426 | 3185 | 4102 | 1442 | 1923 | 2812 | 3670 | 1024.4 | 1675 |
| CV % | 18.1 | 14.8 | 24.5 | 10.1 | 23 | 19.8 | 14.9 | 15.5 | 25.5 | 21.3 | 33.1 | 13.6 |
| LSD 5% | NS | NS | NS | NS | 882.8 | NS | 266.1 | NS | 695.5 | 791.6 | 320.4 | 236.6 |

*Soil Chemical Properties*

As shown in Tables 5 and 6 generally liming slightly increased soil pH and available P and reduce exchangeable acidity. Essentially amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in a decrease in Al solubility thereby minimizes its toxic effect on plants (Gover et al.,2017). The increase in the grain yield of barley due to lime application in combination with different P sources and/or rates could be related to the improvement in the soil pH and availability of P which is in line with the finding of (Olabanji, 2015). Application of lime and phosphate rock its residual effect highly decreased exchangeable acidity and $Al^{+3}$ from the initial (Table 5 and 6). Meng et al. (2004) reported similar findings with the application of lime; acidity, particularly exchangeable $Al^{3}$+, was reduced from 5.46 to 1.52 cmol/kg.

**Table 5**. Lime and phosphorus residual effect on some soil chemical property of Gozamen District

| Treatment | Unlime | | | | | | lime | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | P/PPM | OC % | OM % | Exch Acidity meq/100gm | Exch Al meq/100 gm | pH | P/PPM | OC % | OM% | Exch Acidity meq/100gm | Exch Al meq/100 gm |
| Control | 5.3 | 10.9 | 1.60 | 2.82 | 1.20 | 0.09 | 5.4 | 12.9 | 1.60 | 2.76 | 0.73 | 0.00 |
| 2/3 GPAPR | 5.2 | 14.1 | 1.40 | 2.57 | 0.80 | 0.00 | 5.6 | 15.4 | 1.81 | 3.12 | 0.85 | 0.00 |
| Full GPAPR | 5.0 | 12.1 | 1.50 | 2.63 | 1.14 | 0.10 | 5.4 | 11.8 | 1.51 | 2.61 | 0.71 | 0.04 |
| 2/3 MOHP | 5.3 | 12.0 | 1.40 | 2.57 | 0.66 | 0.00 | 5.4 | 14.7 | 1.48 | 2.58 | 0.94 | 0.06 |
| Full MOHP | 5.3 | 12.7 | 1.30 | 2.23 | 0.89 | 0.00 | 5.3 | 14.2 | 1.95 | 3.36 | 0.88 | 0.02 |
| 2/3 NAFAKA | 5.2 | 11.1 | 1.50 | 2.58 | 1.08 | 0.00 | 6.1 | 17.2 | 1.54 | 2.66 | 0.59 | 0.00 |
| Full NAFAKA | 5.2 | 12.1 | 1.50 | 2.66 | 0.86 | 0.00 | 5.6 | 14.4 | 1.76 | 3.03 | 0.60 | 0.00 |
| Rec. NPSZnB | 5.2 | 12.6 | 1.60 | 2.69 | 0.87 | 0.00 | 5.5 | 16.6 | 1.28 | 2.20 | 1.05 | 0 |

*Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter*

**Table 6**. Lime and phosphorus residual effect on some soil chemical property of Banja District

| Treatment | Unlime | | | | | | lime | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | P/PPM | OC% | OM% | Exch Acidity Meq/100 gm | Exch Al Meq/100 gm | pH | P/PPM | OC % | OM % | Exch Acidity Meq/100 gm | Exch Al meq/100gm |
| Control | 5.2 | 11.7 | 1.003 | 1.73 | 0.971 | 0.216 | 5.2 | 12.9 | 0.78 | 1.35 | 1.36 | 0.798 |
| 2/3 GPAPR | 5.5 | 14.0 | 0.672 | 1.16 | 0.824 | 0.256 | 5.7 | 15.4 | 0.55 | 0.94 | 1.05 | 0.282 |
| Full GPAPR | 5.3 | 11.6 | 1.017 | 1.75 | 0.941 | 0.194 | 5.5 | 14.4 | 0.76 | 1.31 | 1.17 | 0.958 |
| 2/3 MOHP | 5.6 | 11.8 | 0.427 | 0.74 | 0.531 | 0.169 | 5.6 | 11.9 | 0.95 | 1.64 | 1.51 | 0.568 |
| Full MOHP | 5.4 | 12.6 | 0.863 | 1.49 | 0.869 | 0.245 | 5.5 | 12.5 | 0.82 | 1.42 | 1.70 | 0.856 |
| 2/3 NAFAKA | 5.4 | 13.8 | 0.798 | 1.38 | 0.704 | 0.000 | 5.4 | 12.1 | 0.75 | 1.29 | 1.21 | 0.531 |
| Full NAFAKA | 5.6 | 15.2 | 0.518 | 0.89 | 0.416 | 0.000 | 5.5 | 12.2 | 0.94 | 1.63 | 1.35 | 0.666 |
| Rec. NPSZnB | 5.3 | 10.0 | 1.009 | 1.74 | 1.432 | 0.661 | 5.4 | 11.7 | 0.98 | 1.68 | 1.04 | 0.337 |

*Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter*

### *Economic analysis*

Partial budget analysis of lime with different phosphorus fertilizers was presented in Table 7 to Table 10. The net benefit of 49914.2 ETB ha$^{-1}$ and marginal rate return of 590.8 % was obtained from the application of 136 kg NPSzB ha$^{-1}$ and lime for barley production at Gozamen district. The next higher net benefits 39746.3ETB ha$^{-1}$ and the marginal rate return of 292.2% was gained from sole use of 146 kg GPAPR phosphorus fertilizer. At Banja district, the net benefit 29893.8ETB ha$^{-1}$ and marginal rat return of 1483.1% was obtained from the application of 146 kg GPAPR ha$^{-1}$ and lime. The next higher MRR (584.6%) with a net benefit of17618 ETB ha$^{-1}$ was obtained from the sole use of 191NAFAKA kg ha$^{-1}$ phosphorus fertilizers.

**Table 7**. Partial budget analysis of lime and different phosphorus sources on barley at Gozamen

| Treatment With lime | TVC ($ETB^{-1}$) | GY ($kgha^{-1}$) | AdGY ($kgha^{1}$) | ST Y ($kgha^{1}$) | Ad STY ($kgha^{1}$) | GB ($ETBha^{-1}$) | NB ($ETBha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 478.3 | 1224 | 1101.6 | 3248 | 2923.3 | 16524 | 29200.1 | |
| 2/3 GPAPR | 5573.42 | 2380 | 2142 | 4900 | 4410 | 32130 | 46201.58 | 50.0 |
| Full GPAPR | 5783.02 | 2287 | 2058.3 | 4595 | 4135.5 | 30874.5 | 43701.23 | D |
| 2/3 MOHP | 4367.82 | 2092 | 1887.8 | 4130 | 3717 | 28317 | 40675.68 | D |
| Full MOHP | 5174.52 | 2252 | 2026.8 | 4098 | 3683.7 | 30402 | 41804.13 | D |
| 2/3 NAFAKA | 4526.27 | 2470 | 2223 | 4446 | 4001.4 | 33345 | 46825.03 | 570.3 |
| Full NAFAKA | 5501.68 | 1964 | 1767.6 | 3830 | 3447 | 26514 | 36523.82 | D |
| Rec. NPSZnB | 3984.6 | 2476 | 2228.4 | 5055 | 4549.5 | 33426 | 49914.15 | 590.8 |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.*

**Table 8**. Partial budget analysis of different phosphorus sources on barley at Gozamen

| Treatment Without lime | TVC ($ETBha^{-1}$) | GY ($kgha^{-1}$) | AdGY ($kgha^{-1}$) | STY ($kgha^{-1}$) | AdSTY ($kgha^{-1}$) | GB ($ETBha^{-1}$) | NB ($ETBha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 0 | 1051 | 945.9 | 2490 | 2241 | 24273 | 24273 | |
| 2/3 GPAPR | 5295.12 | 2095 | 1885.5 | 4138 | 3724.2 | 45041.4 | 39746.28 | 292.2 |
| Full GPAPR | 5304.72 | 2119 | 1907.1 | 4182 | 3763.8 | 45543.6 | 40238.88 | 9.3 |
| 2/3 MOHP | 3889.52 | 1777 | 1599.3 | 3658 | 3292.2 | 38804.4 | 34914.88 | D |
| Full MOHP | 4696.22 | 2093 | 1883.7 | 3765 | 3388.5 | 43503.75 | 38807.53 | 82.9 |
| 2/3 NAFAKA | 4047.97 | 1954 | 1758.6 | 3862 | 3475.8 | 42020.1 | 37972.13 | D |
| Full NAFAKA | 5023.38 | 1957 | 1761.3 | 3951 | 3555.9 | 42421.05 | 37397.67 | D |
| Rec. NPSZnB | 3506.3 | 1873 | 1685.7 | 4016 | 3614.4 | 41550.3 | 38044 | 18.4 |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.*

**Table 9**. Partial budget analysis of lime and different phosphorus sources on barley at Banja

| Treatment With lime | TVC ($ETBha^{-1}$) | GY ($kgha^{-1}$) | AdGY ($kgha^{-1}$) | STY ($kgha^{-1}$) | AdSTY ($kgha^{-1}$) | GB ($ETBha^{-1}$) | NB ($ETBha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 3263.6 | 1083 | 974.7 | 2436 | 2192.4 | 25582.5 | 22318.9 | |
| 2/3 GPAPR | 8558.72 | 1675 | 1507.5 | 3520 | 3168 | 38452.5 | 29893.78 | 1483.1 |
| Full GPAPR | 8568.32 | 1637 | 1473.3 | 3570 | 3213 | 38164.5 | 29596.18 | D |
| 2/3 MOHP | 7153.12 | 1455 | 1309.5 | 3039 | 2735.1 | 33318 | 26164.88 | D |
| Full MOHP | 7959.82 | 1426 | 1283.4 | 3128 | 2815.2 | 33327 | 25367.18 | D |
| 2/3 NAFAKA | 7311.57 | 1629 | 1466.1 | 3351 | 3015.9 | 37071 | 29759.43 | 514.6 |
| Full NAFAKA | 8286.98 | 1491 | 1341.9 | 3116 | 2804.4 | 34150.5 | 25863.52 | 399.4 |
| Rec. NPSZnB | 6769.9 | 1689 | 1520.1 | 3670 | 3303 | 39316.5 | 32546.6 | 291.7 |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.*

**Table 10**. Partial budget analysis of different phosphorus sources on barley at Banja

| Treatment Without lime | TVC ($ETBha^{-1}$) | GY ($kgha^{-1}$) | AdY ($kgha^{-1}$) | STY ($kgha^{-1}$) | AdSTY ($kgha^{-1}$) | GB ($ETBha^{-1}$) | NB ($ETBha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|
| Control | 0 | 440.5 | 396.4 | 1519 | 1503.1 | 12709.95 | 12709.95 | |
| 2/3 GPAPR | 5295.12 | 854.4 | 768.9 | 2537 | 2521.1 | 22878.45 | 17583.33 | D |
| Full GPAPR | 5304.72 | 1041.7 | 937.5 | 2475 | 2459.1 | 25128.45 | 19823.73 | 391.0 |
| 2/3 MOHP | 3889.52 | 766.6 | 689.9 | 2300 | 2284.1 | 20626.95 | 16737.43 | D |
| Full MOHP | 4696.22 | 838.5 | 754.6 | 2242 | 2226.1 | 21336.45 | 16640.23 | D |
| 2/3 NAFAKA | 4047.97 | 830.3 | 747.2 | 2340 | 2324.1 | 21666.45 | 17618.48 | 584.6 |
| Full NAFAKA | 5023.38 | 939.4 | 845.4 | 2731 | 2715.1 | 24898.95 | 19875.57 | 51.0 |
| Rec. NPSZnB | 3506.3 | 1024.4 | 922.2 | 2812 | 2796.1 | 26415.45 | 22909.15 | 124.9 |

*Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.*

## Conclusions and Recommendation

Information on crop response to lime and different P sources of fertilizer rates is crucial to come up with profitable and sustainable barley production. The application of 136 kg NPSZnB $ha^{-1}$ together with $1/4^{th}$ of recommended lime annually was found to be economically feasible for barley production around Gozamen district. However, farmers who have no access to lime can apply 146 kg $ha^{-1}$ GPAPR phosphorus for optimum production of barley in the area. At Banja, the combined application of 146 kg $ha^{-1}$ GPAPR and $1/4^{th}$ of recommended lime applied annually and sole use of 191 kg $ha^{-1}$ NAFKA was economically feasible.

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# Response of Bread Wheat (*Triticum aestivum* L.) to Sulfur Rates under Balanced Fertilization at Basona Worena District, North Shewa Zone, Amhara Region, Ethiopia

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## Abstract

*Sulphur (S) is becoming an important limiting nutrient to agricultural production in Ethiopian soil. The field experiment was conducted for consecutive three years (2013/14-2015/16) to evaluate effects of S levels on yield and yield components of bread wheat grown on two soil types (Cambisols and Vertisols), North Central of Ethiopia. An experiment consisting of six levels S (0, 10, 20,30,40 and 50 kg ha$^{-1}$) laid out in RCB design with three replications. Results revealed that, yield components were not affected by different levels of S while, yield of wheat were significantly affected by S in both soil types. S applied on cambisols at 30 and 40 kg ha$^{-1}$ increased grain yield (GY) of wheat by 9.0 and 10.1 % over control respectively. The corresponding increases on Vertisols were 8.0 and 10.0 % over control respectively. Application of 10 and 30 kg S ha$^{-1}$ produced the highest marginal rate of return (MMR) (4913.31 and 1277.24%) respectively. The current finding presents additional evidence to research claims that S is becoming a limiting nutrient in some Ethiopian soils. Application of 10 and 30 kg S ha$^{-1}$ are found to be the most economically feasible treatments for bread wheat production in Cambisols and Vertisols of the district respectively.*

Keywords: Balanced fertilization, *Cambisols*, Sulfur, *Vertisols*

## Introduction

Bread wheat (*Triticum aesativum* L.) is one of the most important cereal crops produced and consumed in Ethiopia. It stands third among cereals in terms of area cultivated annually and grain production next to barley and tef (CSA, 2016). Traditionally, wheat grains are used to prepare household bread, beverage and pancake. It is also processed in factories to produce flour for commercial production of bread for consumers in cities and towns. Despite its importance and growing demand for bread wheat in Ethiopia, its production and productivity are desperately very low. The current average productivity of wheat is below 3 t $ha^{-1}$ (CSA, 2016) despite its potential productivity greater than 5t$ha^{-1}$ (Birhan *et al*., 2016). Consequently, the country imports large amounts (30-50% of total annual demand) wheat grains every year from abroad to meet domestic demand (Minot *et al*., 2015) which has grave consequence on foreign currency reserve of the country.

Declining soil fertility is one of the major factors that accounts for low productivity of wheat in Ethiopia (Yesuf and Duga, 2000; Amsal *et al*., 1997) which is caused by soil erosion, continuous cropping of same land year after, deforestation, depletion of organic matter is the main challenge not only to wheat production but also to the production of all crops (Birhan *et al*., 2016). It is an issue of great concern in Ethiopia as soil nutrient depletion is becoming severe and severe with time since little efforts are being made to reverse the problem.

There were several occasions whereby the yields of crops produced per unit area were increased by more than 100 % in many areas of Ethiopia (Kelsa *et al*., 1992). For example, Gebreyes (2008) reported that application of 92 kg nitrogen (N) $ha^{-1}$ increased grain yield of wheat by 185 % over the control in central Ethiopia. Thus, due to dramatic positive impact, there was a steady increase in annual fertilizer consumption from 14000 million tons (mt) in 1974/75 to 500, 000 mt in 2010 (IFPRI, 2012). However, crop yield gain due to N and phosphorus (P) fertilizer application is declining over time despite steady increases in fertilizer consumption in Ethiopia (IFPRI, 2010). Declining crop yield responses to N and P fertilizers is attributed to decreasing soil organic matter (SOM) content (IFPRI, 2010). Moreover, depletion of other nutrients in addition to N and P could be additional factor for decreasing response of crops to N and P fertilizers (Wassie and Tekalign, 2013).

Sulphur (S) could be one of the most likely limiting nutrients in Ethiopia soils. Sulphur is one the plant essential nutrients required for their growth and developments and a building block of protein, key ingredient in the formation of chlorophyll (Duke and Reisenaue, 1986). It plays important role in protein synthesis as it is the component of two essential amino acids called cysteine and methionine. It is also a key component of many enzymes in plants. For instances, the S is important component of nitrogenase enzyme, an enzyme that fixes atmospheric nitrogen in legume-rhizobia biological nitrogen fixation system. Sulphur also interacts with nutrients in soils and the interaction could be positive or negative depending on several factors. For example, Aulakh and Chhibba (1992) observed enhanced root uptakes of P and S when both nutrients were supplied at low rates. Increased uptake and assimilation of N by crops has reported by with adequate than low supply of S (Kumar *et al.*, 2012). Thus, deficiency of S in soils will have adverse consequences on protein synthesis, biological nitrogen fixation, chlorophyll synthesis, enzyme activity etc. ultimately compromising yield and quality of crops. It has been reported that S deficient plants exhibits reduced plant height and stunted growth, reduced tillers, spikelets and delayed maturity. Sulfur deficient plants are shown to be less resistance under stress conditions (Doberman and Fairhurst, 2000).

In this regards, emerging research evidences are showing that S one of the nutrients becoming deficient in some Ethiopian soils limiting crop production. For instance, Assefa (2016) studied the response of wheat to S application on 18 sites reported that wheat significantly responded to S fertilizer application in 72 % of experimental sites. He further reported that soils of responding sites had S content below critical level (11-13 mg $kg^{-1}$ $SO_4^{-2}$-S) for optimum production of wheat.

However, the current assertion that S is becoming nutrient in some Ethiopia soils is based on results of

soils are deficient in S. Thus, further research is needed to be done to verify the existing claims that S limiting in Ethiopian soils in different soil types. In this regard, there is little or no information so far on the response of wheat to S application in Basona worena district of north Shewa, Ethiopia. Thus, experiment was conducted to determine effects of S application under balanced fertilization on the growth, yield components and yield of wheat and to

Basona werna District under two soil types of *Vertisols* and *Cambisols*.

## Materials and Methods

### *Description of the study areas*

The experiment was conducted for 3 consecutive years (2013/14-2015/16) cropping season on two locations at Goshebado (*Vertisols*) and Gudoberet (*Cambisols*) about 147 and 172km northwest, and East from the capital City of Ethiopia (Addis Ababa) respectively. Geographically, the field experiment was conducted at a range of $09^0$ $^0$

$^{0,}$ $^0$

Goshebado and $09^0$ $^0$ $^0$ o $039^0$

and an altitude of 2914 to 3043 m.a.s.l at Gudoberet. The study locations (soil types) and the district as a whole are characterized by having a uni-modal rainfall pattern and receives an average annual rainfall of 921.2 mm. *Vertisols* is the dominant soil type that the experiment conducted at Goshebado and *Cambisols* at Gudoberet. Major crops grown in both locations; wheat, Barley, lentil, faba bean, and chickpea, field pea and grass pea in decreasing orders of area cultivated under these crops.

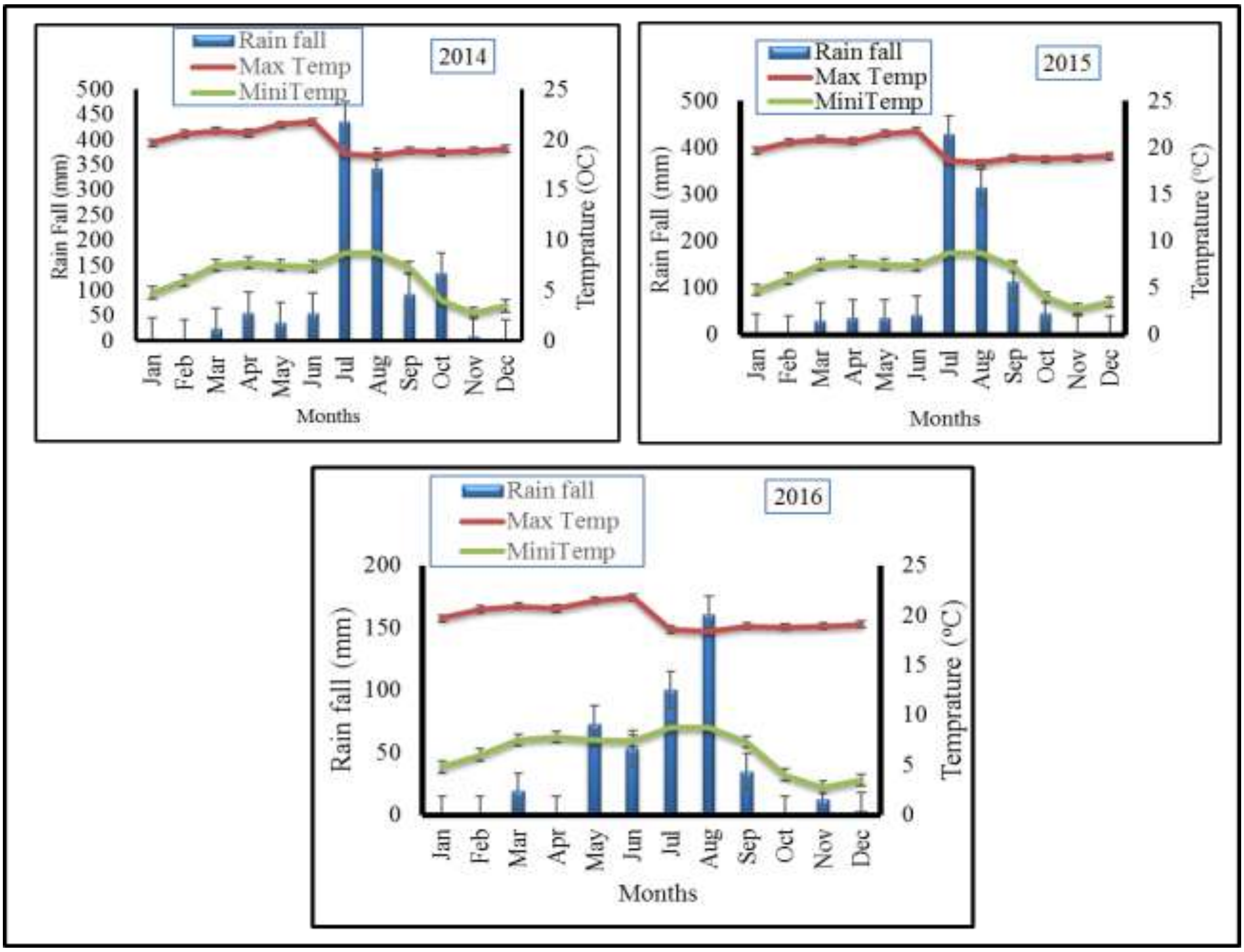


**Figure 1**. Monthly rain fall and average maximum and minimum temperatures in the three years of the study district

**Soil sampling and analyses**

After selecting the experimental sites, pre-planting soil samples were collected from each site for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0-20 cm using augur randomly from 15 spots by walking in a zigzag pattern. After thoroughly mixing the composite samples, 1 kg of sub-sample was taken and brought to Debre Birhan agricultural research Centre soil laboratory where it was air dried and grounded to pass 2 mm mesh sized sieve.

The processed samples were analysed for texture following by Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using pH-water method by making soil to water suspension of 1: 2.5 ratio and was measured using a pH meter. The soil OC content was determined by wet digestion method (Walkley and Black, 1934). Total nitrogen (TN) was determined by using the modified micro Kjeldhal method (Cottenie, ed

by Olsen *et al*. (1954).

**Treatments, design and experimental procedure**

The experiment consisting of six levels of S (0, 10, 20, 30, 40 and 50 kg ha$^{-1}$) accompanied by 69$P_20_5$,80$k_20$, 92N and micronutrients (2Zn, 0.5Cu and 0.5B kg ha$^{-1}$) and was laid out in RCB design with three replications. Gypsum (CaSO4*2H2O), Borax, Zinc Sulfate, Copper Salfate and Triple super phosphate (TSP) were used as S, B, Zn, Cu and P sources respectively. The test crop, wheat variety, Diglo was planted in a unit plot size of 3.6 x 3.4m with row spacing of 20 cm apart at a rate of 131.25 kg ha$^{-1}$. The whole doses of gypsum, KCl and TSP fertilizers were applied as basal in both sides of rows just before planting as per the treatment. The Urea-N was split in which one half of N was applied at planting and the remaining one half was applied one month after planting and after weeding. Micronutrients (Zn, B, and Cu) in the form of ZnS04, Borax and CuS04 respectively was applied foliar mode two times at tillers developments stage of the crops. All agronomic management of the trails were done as per the specific recommendation for the crop.

**Data analysis**

The collected data were subjected to statistical analysis of variance (ANOVA) and carried out using SAS software program using SAS version 9.3 (SAS institute Inc, 2011). Normality and homogeneity of variance were checked and Combined analysis for the 3 years were done by using the procedure of SAS software version 9.3 (SAS institute Inc, 2011). Mean comparisons were done by Least Significant Difference (LSD) according to gypsum fertilizer during planting of this experiment was collected from Debire Birhan town. Accordingly, price of gypsum was 1.2 Ethiopian birr (ETB) $kg^{-1}$. The field prices of grain and straw yield at the district local market around the study area was used. Accordingly, prices of grain and straw yield of wheat were 10.5 and 2.4 ETB $kg^{-1}$ respectively.

## Results and Discussion

### Soil physical and Chemical properties

Pre-planting soil analyses data of selected physicochemical properties of samples collected from experimental locations at Goshebado (*Vertisols*) and Gudoberet (*Cambisols*) are summarized in Table 1. The soils of Goshebado and Gudoberet was belonging to clay textural class. Goshebado soil has soil reaction is ranged from moderately acidic to neutral whereas the soil of Gudoberet is ranged from slightly acidic to neutral reaction (Murphy, 1968). The OC and TN content of both soil types are in low categories according to Tekalign (1991). The available P content of Gudoberet (*Cambisols*) is medium range while at Goshebado (*Vertisols*) is ranged from *very low* to *low* categories (Olsen *et al*., 1954). The available soil P value for crop production and yet it is far lower than the critical soil available P value established for some Ethiopian soils which is 8 mg $kg^{-1}$ (Tekalign and Haque, 1991).

**Table 1**. Soil physico-chemical properties of the study sites across years

| Parameters | *Cambisols* | | | *Vertisols* | | |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 |
| **pH (1:2.5) ratio** | 6.2 | 6.7 | 6.5 | 7.15 | 7.2 | 5.9 |
| **Av. P (ppm)** | 5.04 | 7.76 | 6.06 | 8.7 | 0.12 | 0.42 |
| **TN (%)** | 0.11 | 0.08 | 0.08 | 0.08 | 0.06 | 0.06 |
| **OC (%)** | 1.11 | 0.90 | 0.91 | 0.83 | 0.70 | 0.70 |
| **C: N** | 10.47 | 10.81 | 10.79 | 11.0 | 11.5 | 11.48 |
| **Sand (%)** | 12 | 16 | 30 | 8 | 12 | 16 |
| **Clay (%)** | 56 | 56 | 42 | 70 | 68 | 70 |
| **Silt (%)** | 32 | 28 | 28 | 22 | 20 | 14 |
| **Textural Class** | clay | clay | clay | clay | clay | clay |

**Table 2**. Mean squares for sources of variation

| Parameters | Mean squares for sources of variation with respective degrees of freedom in parenthesis | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | S (5) | Y (2) | SL (1) | Rep in SL (2) | S*Y (10) | S*SL (5) | S*Y*SL (20) | Error (70) |
| PH | $5.9^{ns}$ | $1267.7^{**}$ | $6198.6^{**}$ | 20.2 | $7.1^{ns}$ | $4.2^{ns}$ | $5.0^{ns}$ | 19.0 |
| SPL | $0.05^{ns}$ | $13.30^{**}$ | $32.34^{**}$ | 0.24 | $0.03^{ns}$ | $0.04^{ns}$ | 0.03ns | 0.24 |
| NT | $0.13^{ns}$ | $1.91^{**}$ | $97.28^{**}$ | 0.60 | $0.10^{ns}$ | $0.15^{ns}$ | 0.10ns | 0.26 |
| FT | $0.2^{ns}$ | $1.60^{**}$ | $124.8^{**}$ | 0.4 | $0.1^{ns}$ | $0.1^{ns}$ | 00.10ns | 0.23 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GY | 209145* | 10193262** | 50311170** | 101528 | 11803ns | 802 41ns | 120442ns | 779140 |
| STY | 515449* | 18621526** | 57295361** | 19410 | 62392ns | 42210ns | 48378ns | 2049051 |

PH =plant height (cm), SPL =spike length (cm), NT= number of total tillers, FT= fertile tillers, GY= grain yield, STY straw yield, S=Sulfur, Y=year, SL=Soil type.

## Effect on growth and yield components of Wheat

On soil types, growth and yield components of bread wheat
(Table 2). Data in table 3 showed that effects of S on mean growth and yield components of wheat at both Soils types

**Table 3**. Effect of S on growth and yield components of Wheat at Goshebado (*Vertisols*) and Gudoberet (*Cambisols*)

| S-rate (kg ha$^{-1}$) | *Cambisols* | | | | *Vertisols* | | | |
|---|---|---|---|---|---|---|---|---|
| | **PH** | **SPL** | **NT** | **FT** | **PH** | **SPL** | **NT** | **FT** |
| **0** | 88.4 | 6.3 | 4.9 | 4.8 | 73.5 | 5.4 | 2.9 | 2.7 |
| **10** | 90.6 | 6.4 | 5.1 | 5.0 | 74.4 | 5.4 | 2.9 | 2.6 |
| **20** | 88.8 | 6.5 | 4.7 | 4.7 | 74.5 | 5.3 | 2.9 | 2.6 |
| **30** | 89.2 | 6.5 | 4.9 | 5.0 | 75.4 | 5.4 | 3.1 | 2.8 |
| **40** | 90.0 | 6.4 | 4.8 | 4.8 | 74.0 | 5.2 | 3.0 | 2.8 |
| **50** | 90.1 | 6.5 | 4.9 | 4.9 | 74.5 | 5.4 | 3.2 | 2.9 |
| **CV (%)** | **4.3** | **3.5** | **9.2** | **9.7** | **1.8** | **4.1** | **7.4** | **9.1** |
| **LSD (<0.05)** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

*PH=plant height (cm), SPL=spike length (cm), NT=number of total tillers plant$^{-1}$, FT=fertile tillers plant$^{-1}$*

**Table 4.** Interaction effects of S with year on growth and yield components of wheat

| S-rate (kg ha$^{-1}$) | **2014** | | | | **2015** | | | | **2016** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PH** | **SPL** | **NT** | **FT** | **PH** | **SPL** | **NT** | **FT** | **PH** | **SPL** | **NT** | **FT** |
| **0** | 75.5 | 5.2 | 4.3 | 3.9 | 81.7 | 6.0 | 4.0 | 3.9 | 85.7 | 6.3 | 3.5 | 3.3 |
| **10** | 74.9 | 5.3 | 4.3 | 4.0 | 83.8 | 6.1 | 3.9 | 3.9 | 88.6 | 6.4 | 3.9 | 3.7 |
| **20** | 75.3 | 5.1 | 4.1 | 3.8 | 83.1 | 6.2 | 3.7 | 3.7 | 86.4 | 6.5 | 3.7 | 3.5 |
| **30** | 75.3 | 5.3 | 4.2 | 4.0 | 84.8 | 6.2 | 3.9 | 3.8 | 86.8 | 6.3 | 3.9 | 3.7 |
| **40** | 75.6 | 5.2 | 4.2 | 4.0 | 85.2 | 6.0 | 3.9 | 3.9 | 85.3 | 6.3 | 3.7 | 3.6 |
| **50** | 74.9 | 5.2 | 4.2 | 4.0 | 85.3 | 6.2 | 4.2 | 4.2 | 86.8 | 6.4 | 3.8 | 3.5 |
| **LSD (<0.05)** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** | **ns** |

*PH=plant height (cm), SPL=spike length (cm), NT=number of total tillers plant$^{-1}$, FT=fertile tillers plant$^{-1}$, S=Sulfur*

**Table 5**. Interaction effects of S with soil types and year on plant height and Spike length of Wheat

| Year | Soil Types | Plant height (cm) | | | | | | Spike Length (cm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S-rate kg ha$^{-1}$ | | | | | | S-rate kg ha$^{-1}$ | | | | | |
| | | 0 | 10 | 20 | 30 | 40 | 50 | 0 | 10 | 20 | 30 | 40 | 50 |
| 1 | ***Vertisols*** | 67.1 | 66.2 | 67.2 | 68.5 | 67.7 | 66.0 | 4.9 | 5.0 | 4.8 | 4.9 | 4.8 | 4.8 |
| | ***Cambisols*** | 83.9 | 83.7 | 83.4 | 82.1 | 83.5 | 83.8 | 5.5 | 5.7 | 5.5 | 5.6 | 5.6 | 5.7 |
| 2 | ***Vertisols*** | 71.8 | 74.1 | 73.7 | 73.9 | 73.7 | 74.8 | 5.0 | 5.0 | 5.1 | 5.2 | 4.9 | 5.2 |
| | ***Cambisols*** | 91.6 | 93.6 | 92.6 | 95.6 | 96.6 | 95.7 | 7.0 | 7.1 | 7.2 | 7.2 | 7.2 | 7.2 |
| 3 | ***Vertisols*** | 81.7 | 82.8 | 82.5 | 83.7 | 80.5 | 82.7 | 6.2 | 6.3 | 6.2 | 6.0 | 6.0 | 6.3 |
| | ***Cambisols*** | 89.7 | 94.3 | 90.3 | 90.0 | 90.0 | 90.9 | 6.4 | 6.6 | 6.8 | 6.6 | 6.5 | 6.6 |
| **LSD(<0.05)** | | **ns** | | | | | | **ns** | | | | | |

1=2014, 2=2015,3=2016

**Table 6.** Interaction effects of S with soil types and year on number of total and fertile tillers of wheat

| Year | Soil Types | Number of total tillers plant$^{-1}$ | | | | | | Number of fertile tillers plant$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S-rate (kg ha$^{-1}$) | | | | | | S-rate (kg ha$^{-1}$) | | | | | |
| | | **0** | **10** | **20** | **30** | **40** | **50** | **0** | **10** | **20** | **30** | **40** | **50** |
| 1 | ***Vertisols*** | 3.6 | 3.2 | 3.5 | 3.5 | 3.6 | 3.5 | 3.2 | 2.9 | 2.9 | 3.0 | 3.3 | 3.1 |
| | ***Cambisols*** | 5.0 | 5.3 | 4.7 | 4.8 | 4.7 | 4.9 | 4.7 | 5.1 | 4.7 | 5.0 | 4.7 | 4.9 |
| 2 | ***Vertisols*** | 2.4 | 2.4 | 2.4 | 2.5 | 2.5 | 3.1 | 2.3 | 2.4 | 2.3 | 2.4 | 2.5 | 3.0 |
| | ***Cambisols*** | 5.5 | 5.4 | 5.0 | 5.3 | 5.3 | 5.3 | 5.5 | 5.4 | 5.0 | 5.3 | 5.3 | 5.3 |
| 3 | ***Vertisols*** | 2.8 | 3.0 | 2.8 | 3.2 | 3.0 | 2.9 | 2.5 | 2.7 | 2.5 | 2.9 | 2.8 | 2.5 |
| | ***Cambisols*** | 4.2 | 4.7 | 4.6 | 4.6 | 4.5 | 4.6 | 4.1 | 4.7 | 4.6 | 4.6 | 4.5 | 4.5 |
| **LSD(<0.05)** | | **ns** | | | | | | **ns** | | | | | |

**1=2014, 2=2015,3=2016**

**Effect on yield of Wheat**

Both grain yield (GY) and straw yield (GY) of wheat were significantly affected by effects of S application in both *Cambisols* and *Vertisol*s (Table 2). Data in Table 7 showed that effects of S on mean Grain and Straw yield of wheat at both Soils types. On *Cambisols*, increase in S rate up to 30 kg S ha $^{1}$) had a positive effect on grain and Straw yield of wheat while above 30 kg S ha$^{-1}$, yield decreased numerically, but not significantly. Application of 20 and 30 kg ha$^{-1}$ S have significantly increased grain yield by 9.0 and 10.1 % over the control respectively and Straw yield by 10.4 and 10.5 % over control respectively. Similarly, on *Vertisols*, 30 and 40 rates have significantly increased grain yield by 8.0 and 10.0 % over control respectively and same treatments increased Straw yield by 10.6 and 9.0 % over control respectively. Generally, applications of S on both soil types improve grain and straw yield of bread wheat. These results are in agreement with the finding of Assefa Menna (2016) who studied the response of wheat to S application and reported that wheat significantly responded to S fertilizer application. In another study, Khan et al. 2015) reported that S applied at 20 kg ha$^{-1}$ at stem elongation stage significantly increased yield of wheat by 28.5 % over untreated control. According to DeRuiter and Martin 2001), wheat yield can be increased up to 42 % due to S fertilizer depending on the inherent S level in particular soils.

**Table 7.** Effect of S on mean yield of Wheat on *Vertisols* and *Cambisols*

| S-rate (kg ha$^{-1}$) | Grain yield (kg ha$^{-1}$) | | Straw yield (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | *Vertisols* | *Cambisols* | *Vertisols* | *Cambisols* |
| **0** | 2438.1c | 3635.9c | 3421.2b | 4771.9b |
| **10** | 2460.7c | 3961.6a | 3666.6a | 5270.2a |
| **20** | 2502.8bc | 3992.0a | 3734.1a | 5323.0a |
| **30** | 2649.2ab | 4062.6a | 3827.0a | 5333.9a |
| **40** | 2707.3a | 3929.6c | 3760.4a | 5101.7a |
| **50** | 2572.8abc | 3909.5c | 3726.0a | 5174.7a |
| **CV (%)** | **6.1** | **9.6** | **7.0** | **9.4** |
| **LSD (<0.05)** | **144.2** | **358.5** | **243** | **462.2** |

**Table 8.** Interaction effects of S with soil types and year on grain and straw yield of wheat

| Year | Soil Types | Grain yield kg ha$^{-1}$ | | | | | | Straw yield kg ha$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S-rate kg ha$^{-1}$ | | | | | | S-rate kg ha$^{-1}$ | | | | | |
| | | **0** | **10** | **20** | **30** | **40** | **50** | **0** | **10** | **20** | **30** | **40** | **50** |
| **1** | ***Vertisols*** | 2009.4 | 2047.1 | 2000.4 | 2208.1 | 2440.3 | 2062.6 | 2926.9 | 3139.4 | 3078.4 | 3241.3 | 3186.0 | 2938.7 |
| | ***Cambisols*** | 2938.5 | 3298.6 | 3766.6 | 3357.0 | 3142.4 | 3323.8 | 4745.0 | 5044.5 | 5286.2 | 5263.9 | 5151.4 | 5121.4 |
| **2** | ***Vertisols*** | 1651.3 | 1397.1 | 1539.6 | 1715.7 | 1602.3 | 1648.3 | 1771.9 | 1813.7 | 1900.7 | 2006.7 | 1844.4 | 1902.6 |
| | ***Cambisols*** | 4636.0 | 4560.7 | 4674.6 | 5162.4 | 4920.8 | 4981.6 | 5656.5 | 5900.8 | 6146.4 | 6276.6 | 5806.5 | 5981.0 |
| **3** | ***Vertisols*** | 3653.6 | 3937.9 | 4000.3 | 3933.8 | 4079.4 | 4007.4 | 5564.9 | 6046.6 | 6223.0 | 6233.0 | 6250.8 | 6336.6 |
| | ***Cambisols*** | 3333.3 | 4025.5 | 3534.6 | 3668.3 | 3725.5 | 3423.2 | 3914.1 | 4565.2 | 4537.1 | 4461.3 | 4347.2 | 4421.7 |
| **LSD(<0.05)** | | **ns** | | | | | | **ns** | | | | | |

1=2014, 2=2015,3=2016

## Effects of Soil and Years

Results of analyses of wheat response data to over all of the two soils and years are summarized in Table 9. Soils and years have significantly affected PH, SPL, NT, BY, GY and STY of wheat. Accordingly, significantly higher values of these parameters were obtained in *Cambisols* than *Vertisols*. *Cambisols*, GY and STY were higher by 34.9 and 28.3% over that produced than *Vertisols* irrespective of treatments. This could be possible due to better nutrient availability to crop in *Cambisol*s than *Vertisols*.

**Table 9**. Overall mean on growth, yield components and yield of wheat across soils and years

| Soil | PH | SPL | NT | FT | BY | GY | STY |
|---|---|---|---|---|---|---|---|
| ***Cambisols*** | 89.5a | 6.4a | 4.9a | 4.8a | 9061.1a | 3915.2a | 5145.9a |
| ***Vertisols*** | 74.4b | 5.3b | 3.0b | 2.7b | 6239.4b | 2550.2b | 3689.2b |
| **LSD (<0.05)** | 1.67 | 0.19 | 0.196 | 0.18 | 869.5 | 337.93 | 548.02 |
| **Year** | | | | | | | |
| **1** | 75.3c | 5.2c | 4.2a | 4.0a | 6807.2b | 2713.6c | 4093.6b |
| **2** | 84.0b | 6.1b | 3.9b | 3.9b | 7124.9b | 3207.5b | 3917.3b |
| **3** | 86.6a | 6.4a | 3.6c | 3.6c | 9018.7a | 3776.9a | 5241.8a |
| **LSD (<0.05)** | **2.0** | **0.2** | **0.2** | **0.2** | **1064.9** | **413.9** | **671.2** |

*PH = plant height (cm), SPL = spike length (cm), NT = number of total tillers plant$^{-1}$, FT = fertile tillers plant$^{-1}$, BY = biomass yield (kg ha$^{-1}$), GY = grain yield (kg ha$^{-1}$), STY = Straw yield (kg ha$^{-1}$), 1 = 2014, 2 = 2015, 3 = 2016.*

## Economic Analyses

The results of partial budget analyses data of S fertilizers across two soils are summarized in Table 10. Accordingly, all treatments produced higher and positive net benefit (NB) relative to the control treatment in both soil types, indicating that feasibility of S fertilizer application for wheat production in the study area. In general, NB from application of S fertilizer produced from *Cambisols* was higher than *Vertisols*. Consequently, the highest NB (42884.9 and 27074.7 ETB) was produced by application of S at 30 and 40 kg ha$^{-1}$ on *Cambisols* and *Vertisols* respectively. When it comes to the marginal rate of return (MRR), the highest value of MRR (4913.31 and 1277.24%) was produced by S at a rate of 10 and 30 kg ha$^{-1}$ from *Cambisols* and *Vertisols* respectively.

**Table 10**. Partial budget analysis of wheat to the study areas

| S-rate (kg ha$^{-1}$) | *Cambisols* | | | | | | |
|---|---|---|---|---|---|---|---|
| | AGY (kg ha$^{-1}$) | ASTY (kg ha$^{-1}$) | TGB | TVC | NB | MRR | MRR (%) |
| 0 | 3635.9 | 4771.9 | 44175.7 | 5334 | 38841.7 | - | - |
| 10 | 3961.6 | 5270.2 | 48302.9 | 5418 | 42884.9 | 49.13 | 4913.31 |
| 20 | 3992.0 | 5323.0 | 48703.2 | 5501 | 43202.2 | 27.11 | 2711.08 |
| 30 | 4062.6 | 5333.9 | 49364.8 | 5584 | 43780.8 | 20.76 | 2075.62 |
| 40 | 3929.6 | 5101.7 | 47610.5 | 5668 | 41942.5 | 10.28 | 1028.38 |
| 50 | 3909.5 | 5174.7 | 47604.8 | 5751 | 41853.8 | 8.22 | D |
| S-rate (kg ha$^{-1}$) | *Vertisols* | | | | | | |
| 0 | 2438.1 | 3421.2 | 30153.8 | 6016 | 24137.8 | - | - |
| 10 | 2460.7 | 3666.6 | 30946.1 | 6091 | 24855.1 | 10.56 | 1056.45 |
| 20 | 2502.8 | 3734.1 | 31487.0 | 6166 | 25321.0 | 8.89 | 888.83 |
| 30 | 2649.2 | 3827.0 | 33027.6 | 6241 | 26786.6 | 12.77 | 1277.24 |
| 40 | 2707.3 | 3760.4 | 33390.7 | 6316 | 27074.7 | 10.79 | 1078.95 |
| 50 | 2572.8 | 3726.0 | 32097.6 | 6391 | 25706.6 | 5.18 | D |

AGY=Adjusted grain yield, ASTY=adjusted straw yield, TGB=total growth benefit, TVC=total variable cost, NB=net benefit, MRR=marginal rate of return.

## Conclusion and Recommendation

The results of this experiment revealed that application of S fertilizer has significantly increased yield of bread wheat grown in *Cambisols* and *Vertisols* of the study district, northern Shewa, Ethiopia compared to that obtained from unfertilized control. Moreover, the current finding presents additional evidence to research claims that S is becoming a limiting nutrient in some Ethiopian soils which being reported. Maximum yield of wheat was obtained with treatment involving application of 30 kg S ha$^{-1}$ and 40 kg S ha$^{-1}$ from *Cambisols and Vertisols* respectively. While, partial budget analysis result revealed that, 10 and 30 kg S ha$^{-1}$ produced the highest MMR (4913.31 and 1277.24%) and thus, those treatments are found to be economically feasible treatments for bread wheat production in *Cambisols* and *Vertisols* of the district of Basona worena respectively.

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# II) Agricultural Water Management

# Evaluation of Furrow Irrigation Methods for Maize Production in Kobo GirranaValley, Ethiopia

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## Abstract

*The lack of irrigation water management techniques is a serious obstacle to the expansion of irrigation infrastructures in Kobo Girana valley. A new irrigation method for maize production was designed and tested for yield and water use efficiency (WUE). The objective of the experiment was to evaluate the effects of the furrow irrigation system under different water application levels and identify the furrow irrigation type which allows achieving optimum maize yield and water use efficiency. A field experiment was conducted in kobo Girrana valley and the experiment was carried out for 2 consecutive years (2011 and 2012). Irrigation water was applied to furrows using a siphon from a ditch at the head of the furrow lined with geomembrane plastic with an inflow rate of 0.17l/sec. Totally nine treatments were arranged in factorial RCBD design from three furrow irrigation techniques (alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI)) and three irrigation amounts (100%ETc, 75%ETc, and 50%ETc). The frequency of irrigation was fixed at 7 days interval. The resulting data were subjected to analysis and it was observed that treatment effects on most yield and yield-related parameters were significantly different. Both irrigation water levels and furrow types showed an interaction effect on almost all parameters except biomass yield which showed non-significant interaction. Maximum grain yield 3.32 ton ha$^{-1}$ was observed in the treatment combination of CFI-100ETc and lowest water productivity of 0.64kgm$^{-3}$. However, 3.17 ton ha$^{-1}$ grain yield and 1.23 kg.m$^{-3}$ water productivity was recorded due to AFI and 40mm depth of application. Compared to the other methods tested in this research, alternate furrow irrigation technique tends to increase water productivity. Moreover, alternate furrow irrigation could save 50% of water and reduces the labor required to carry out the irrigation compare to the conventional type.*

**Keywords**: Crop water requirement, water use efficiency, irrigation method, and alternate furrow

## Introduction

Irrigation is an age-old art perhaps as an old human population. Nevertheless, the increasing need for crop production due to the growing population in the world is necessitating a rapid expansion of irrigated agriculture throughout the world (Awulachew *et al.,* 2005). This situation is similar in Ethiopia. Much of an increase in the irrigated area had come because of the expansion of small-scale irrigation in the country. Yet, the existing irrigation development in Ethiopia, as compared to the resources the country has, is negligible (Mintesnot *et al*., 2005). Moreover, the effect of a global climatic change is worsening the scarcity of water for irrigation (Behera and Panda, 2009). The great challenge for the coming decades will therefore be the task of increasing food production per unit of water consumption, particularly in countries with limited water and land resources as well as inefficient water use (Kirda, 2002).

Increasing optimum water productivity, especially the value produced per unit of water, can be an important pathway for poverty alleviation (Perry *et al*., 2009). Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem. Irrigation water management implies the application of suitable water to crops in the right amount at the right time. The salient feature of an improved method of irrigation is the controlled application of the required amount of water at the desired time, which leads to minimization of range of variation of the moisture content in the root zone, thus reducing stress on the plants. Improvement of irrigation water management is portrayed as the key issue in copping up with crop irrigation needs and future water scarcity. One of the irrigation management practices which could result in water-saving is deficit irrigation (Eck *et al.,* 1987). One more option to increase water productivity through deficit level is an alternate and fixed furrow irrigation system.

Alternative furrow irrigation, some furrows are irrigated while adjacent furrows are not and water is saved mainly by reduced evaporation from the soil surface, as in the case of drip irrigation. The studies of Du *et.al*, (2010) improved by converting conventional furrow irrigation to alternate furrow irrigation (AFI) in order to increase water use efficiencies. According to Ghasemi and Sepaskhah (2003) reported, wide-spaced furrow irrigation and alternative furrow irrigation have been used as a means to improved water use efficiency (WUE). Alternate furrow irrigation (skipped furrow irrigation), which has a higher water use efficiency is one of the effective methods to minimize wastage of irrigation water (Halim, 2013). The economic and environmental benefits of using the alternative furrow irrigation methods are higher than all other irrigation methods because less water is applied and the economic return is higher (Nelson and Al-kaisi, 2011).

The hypothesis behind irrigating alternate furrows is that:

1. In alternate furrow irrigation, less surface water is wetted and less evaporation from the surface occurs.
2. More lateral roots are stimulated and a chemical signal is produced in drying roots to reduce the shoot water loss.
3. The amount of water needed (i.e., irrigation water use), time, and labor requirement for irrigation are decreased.
4. Water use efficiency (WUE) will be nearly doubled by using this method.

Thus, this study was initiated to evaluate efficiencies of different furrow irrigation methods and amount of water-on-water productivity and yield of maize.

## Materials and Methodology

*Description of Study Area*

The experiment was conducted in Kobo irrigation research station which is located about 50 kilometers from Woldia town to the North-East direction. The area is situated at $12.08^0$ N (latitude), at $39.28^0$ E longitudes, and at an altitude of 1470 m mean above sea level (Figure 1).

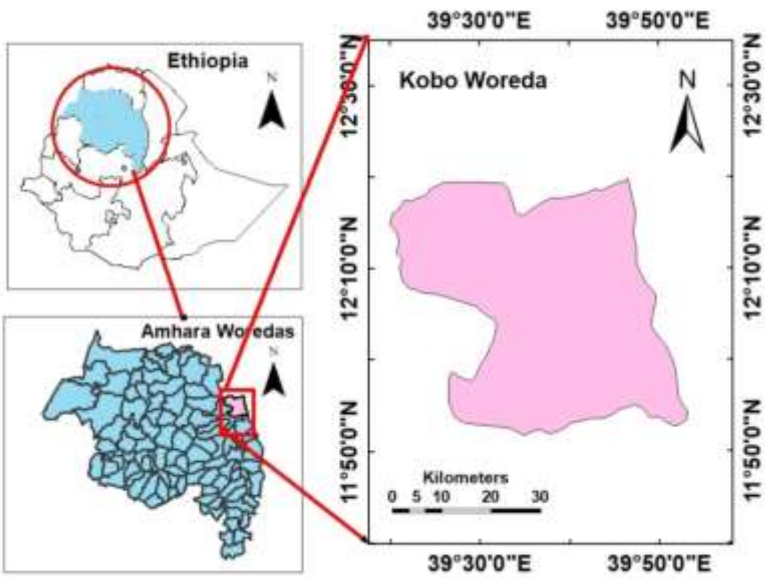


**Figure 1**. Location map of the study area

The 15 years mean annual rainfall is about 630 mm and the average daily reference evapotranspiration rate of 5.94 mm/day. The mean annual maximum and minimum temperature is 26.2 0C and 14.8oc, respectively. The soil type in the experimental site is silty clay loam with average FC and PWP of 17.57% and 12.3% on a volume basis accordingly. The site is characterized by an average infiltration rate of 8 mm/hr and a pH value of 7.8.

*Experimental Design and Treatment Arrangement*

Each treatment was replicated three times and the plot has lied following Factorial-RCBD. Totally nine treatments were composed of three furrow methods; Alternate furrow irrigation (AFI), Fixed furrow irrigation (FFI) & conventional furrow irrigation (CFI), and three Irrigation amounts; 50%ETc, 75%ETc, and 100%ETc of irrigation requirement (Table 1). The irrigation depth of application was determined by using CROPWAT version 8 software programs. The experiment was conducted for two consecutive years of 2011 and 2012.AFI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two neighboring furrows while CFI was the conventional way where every furrow was irrigated during each watering. With 100% ETc (full irrigation) implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of the CROPWAT program. 75% ETc, and 50% ETc means 75%, and 50% of full irrigation requirement, respectively. Each experimental plot was 3 m x 6 m with 1.5m free space between plots and 2m wide spacing between blocks.

**Table 1**. The treatment arrangement and seasonal water requirements of each treatment

| Treatment | Furrow type | Depth of application (mm) | Seasonal Irrigation Water Requirement(mm) |
|---|---|---|---|
| 1 | CFI | 100%ETc (40) | 560 |
| 2 | CFI | 75%ETc (30) | 420 |
| 3 | CFI | 50%ETc (20) | 280 |
| 4 | FFI | 100%ETc (40) | 280 |
| 5 | FFI | 75%ETc (30) | 210 |
| 6 | FFI | 50%ETc (20) | 140 |
| 7 | AFI | 100%ETc (40) | 286 |
| 8 | AFI | 75%ETc (30) | 210 |
| 9 | AFI | 50%ETc (20) | 140 |

***Planting and crop management***

Maize (*zea maize*) of variety in the 1$^{st}$ week of February and harvested around the middle of May with the length of growing period 90-100days. Two seeds were planted per hole with a plant spacing of 0.30 m. All plots were irrigated immediately after planting (planting irrigation). Prior to the third treatment irrigation; plants were thinned to one per stand for a population of 80 plants per plot. Blanket Fertilizer rates of 100 kg ha $^{-1}$ DAP and 100 kg ha $^{-1}$ UREA were applied. Nitrogen fertilizer was applied in two splits: two-thirds at planting and one-third at knee height. All other agricultural operations, including pesticide and hand weeding, were applied uniformly and simultaneously for all treatments. Maize was harvested by cutting the aboveground biomass and left for further drying before removing the cobs from the stalks. The crop was then threshed and grain yield (at 15% moisture content) was measured. Agronomic parameters grain yield, dry biomass yield, plant height, and water productivity were recorded. Finally, the collected data were subjected to Genstat 13th Edition for analysis.

### *Irrigation management*

The frequency of irrigation was fixed as 7 days interval, which is determined by the CROPWAT model at no yield penalty level. Totally all plots were irrigated 14 times throughout the growing season. Irrigation water was applied to furrows using siphon from a ditch at the head the furrow was lined with geomembrane plastic with an inflow rate of 0.17l/sec. Prior to planting all plots were irrigated with an equal amount of water up to the field capacity to initiate germination.

## Results and Discussion

### *Irrigation effects on maize yield and yield parameters*

From the ANOVA table (Table 2), it was observed that most of the yield and yield parameters showed a significant

types had a significant interaction effect on measured agronomic parameters except for dry biomass yield.

**Table 2**. ANOVA table showing the effect of furrow irrigation method and irrigation depth on yield and related components of maize crop

| Source of variation | Degree of freedom | Mean Square: Grain yield (ton/ha) | Biomass (ton/ha) | Plant height (cm) | Water productivity (kg/m$^3$) |
|---|---|---|---|---|---|
| Replication | 2 | 0.02363 | 38.37 | 5.54 | 0.00387 |
| Year | 1 | 0.00104 | 28.16 | 56.63 | 0.000017 |
| Rep/year | 2 | 0.0083 | 36.29 | 105.16 | 0.001677 |
| Irrigation level | 2 | 7.94147** | 39.15** | 880.06** | 0.014136* |
| Types of furrow | 2 | 4.35283** | 16.81** | 330.76* | 1.405746** |
| Irrigation Level/ furrow Types | 4 | 0.2958** | 41.49 | 146.68* | 0.025753** |
| Errors | 40 | 0.01147 | 38.23 | 41.27 | 0.002172 |

### *Grain yield and Yield Parameters*

In all furrow irrigation methods, the grain yield produced showed an increasing trend when the amount of water added increased. The highest GY was in the CFI-100%ETc treatment with 3.16 t $ha^{-1}$, whereas FFI-50%ETc exhibited the lowest GY with 1.218 t $ha^{-1}$ (Table 3). Grain yields under conventional furrow irrigation (CFI) were significantly higher than those under alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI); due to the higher amount of applied water and crop evapotranspiration. This finding is similar to results obtained by Sepakhah and Khajehabdollahi (2005) evaluated the alternate furrow irrigation with different irrigation intervals for maize. Sepaskhah and Parand (2006) effect of alternate furrow irrigation with supplemental every furrow irrigation at the different stages on the yield of maize also reported alternate furrow irrigation resulted in a significant reduction of maize yield compared with every furrow irrigation due to water stress.

Decreasing applied water by 25% and 50% of ETc led to decreasing in grain yield of maize by 24% and 50%, respectively due to the small amount of applied irrigation water, which did not much full maize water requirements, caused water stress and consequently reduced crop yield. This result similar to reported by Abd EI-Halim (2013) impact of alternate furrow irrigation with different irrigation intervals on the yield of corn. Similarly, Seghatoleslami *et al.* (2005) reported water stress reduced seed yield in foxtail millet. On the other hand, AFI with different irrigation levels proved to be superior by increasing plant height than CFI and FFI based on a two-season mean. Even though the treatment combination of CFI-100ETc gave a maximum grain yield of 3.316 t. $ha^{-1}$ and optimum grain yield 3.17 ton $ha^{-1}$ obtained due to AFI-100ETc. This might be attributed to the better availability of soil moisture during the irrigation cycle for AFI (Table 3), which enhanced water and nutrient uptake and doubtless reflected on the final GY. This result confirms the results found by Abdel-Maksoud *et al.* (2002), Sepaskhah and Khajehabdollahi (2005). Additionally, alternate furrows gave a significant difference in each irrigation level. To take advantage of this type of plant response, Kang *et al.* (1997) suggested that irrigation might be designed so that part of the root system is exposed to drying soil while the rest is in wet soil. Such a design could lead to reduced stomata opening without leaf water deficit.

### *Water productivity (WP)*

Irrigation water productivity (WP) was significantly affected by furrow irrigation type and irrigation level. The highest WP values were 1.29 kg $m^{-3}$ recorded for the AFI-75%ETc treatment followed by 1.24 kg m$^{-3}$ obtained for AFI-100%ETc, whereas the lowest values reached 0.644 kg m$^{-3}$ for CFI-100ETc (Table 3). There were significant statistical differences recorded for WP between AFI and the CFI treatment. These results indicated that AFI is appropriate to increase WP because they allow applying less irrigation water for maize production. The high WP values for AFI could be due to the small amount of applied water for AFI as compared with the CFI treatment. Sepaskhah and Hosseini (2008) reported similar results. In addition, Nouri and Nasab (2011) concluded that the AFI system generally increases sugar cane yield and field WUE.

**Table 3**. Effect of furrow type and irrigation level on agronomic parameters and water productivity

| Furrow type With Irrigation levels | Plant height (cm) | Grain yield (t ha$^{-1}$) | Water productivity (kg m$^{-3}$) |
|---|---|---|---|
| AFI-50%ETc | 186.4a | 1.496f | 1.1635c |
| AFI-75%ETc | 181.1ab | 2.395c | 1.2901a |
| AFI-100%ETc | 179.1ab | 3.174b | 1.2348b |
| CFI-50%ETc | 172.9bc | 1.849e | 0.7195g |
| CFI-75%ETc | 172.9bc | 2.503c | 0.6743gh |
| CFI-100%ETc | 169.5c | 3.316a | 0.6449h |
| FFI-50ETc | 168.7c | 1.218g | 0.9475d |
| FFI-75%ETc | 167.9cd | 1.59f | 0.8564e |
| FFI-100%ETc | 160.3d | 2.058d | 0.8005f |
| CV (%) | 7.7 | 8.9 | 5.0 |
| LSD(0.05) | 7.496* | 2232.3** | 0.05439** |

*Note: Means followed by the same letter (s) are not significantly different at the 5% level of probability.*

### *Dry Biomass Yield*

Compared to conventional watering or watering fixed parts of the root system, alternate furrow irrigation reduced water consumption by 50% with a total biomass reduction of 10%. Low irrigation levels also significantly reduced the total dry biomass yield. The conventional irrigation method produced maximum dry biomass yield (Table 4). The two years data showed that if the AFI method uses less irrigation than the conventional irrigation method with no or minimal yield loss. Generally, results show that alternative drying of part of the root system is better than the drying of the fixed part of the root zone. Finally, it can be concluded that the AFI system can substantially save agricultural water use for irrigation.

Table 4: Mean effects of furrow types and irrigation levels on dry biomass yield

| Water levels | Dry biomass yield (t ha$^{-1}$) | Furrow types | Dry biomass yield (t ha$^{-1}$) |
|---|---|---|---|
| 100%ETc | 8.14a | CCF | 7.94a |
| 75%ETc | 6.94b | AFI | 7.16b |
| 50%ETc | 6.55c | FFI | 6.53c |
| CV (%) | 10.0 | CV (%) | 10.0 |
| LSD (0.05) | 0.5036 | LSD (0.05) | 0.5036 |

## Conclusions and Recommendation

Irrigation techniques and irrigation levels had shown a highly significant difference in grain yield, plant height, dry biomass, and water productivity. The interaction effect of irrigation techniques and irrigation levels

effect of irrigation techniques and irrigation levels was not shown significantly different on biomass. Results obtained from this study was shown that the AFI 100% system lead to lesser water input and yet was still able to generate comparable maize yield with CFI 100%.

Alternate furrow irrigation with appropriate irrigation levels can be used as an efficient method for maize production in rainfall stress areas like kobo woreda. From this experiment, it could be concluded that the alternative furrow irrigation treatment controlled stress irrigation without the risk of reduced grain yield of maize increase production and productivity of the society. Moreover, it increased the water use efficiency and saved irrigation water. Besides it also saves the energy and time for farmers to irrigate the whole land in turn it saves the cost for a water of irrigation. Therefore, it is recommended that using an alternative furrow irrigation system in areas where there is water scarcity as well as labor expensiveness like to the study area, AFI is the best option to increase the production of maize and other vegetables.

As intensive irrigation practice is already common in the study area, giving a training and advisory service for communities as to how to use crop water requirement based irrigation system is basic, as over application and high-frequency irrigation causes water logging, aggravate soil salinity, water losses as runoff or tailwater, increases the cost of labor and time to irrigate farms. An alternative furrow irrigation system is the best technology among the tested technologies to be recommended for the communities of the study area, because of its high-water productivity, in addition to time, labor and irrigation cost saving. Further research work is needed to give the appropriate irrigation interval with an alternative furrow irrigation system.

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# Determination of Crop Water Requirements and Irrigation Scheduling of Wheat at Koga and Rib irrigation Schemes, Ethiopia

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## Abstract

*In counties where water resources are limiting factors; there is a need to improve water resource management, determine water requirement and scheduling which are key parameters for precise irrigation management. This study was conducted to determine the crop water requirements (CWR) and irrigation scheduling of wheat at two locations under different weather and soil condition, North West Ethiopia. CROPWAT 8.0 model was used to determine the crop water requirement. The Penman-Monteith method was applied to calculate the reference evapotranspiration (ET0) and the United States Department of Agriculture (USDA) soil conservation service method was used to estimate the effective rainfall. Crop coefficients (kc), rooting depth, depletion level, and other agronomic parameters were adopted from FAO guidelines. Field data including; field capacity (FC), permanent wilting point (PWP), initial soil moisture depletion (%), available water holding capacity (mm/meter), infiltration rates (mm/day), and local climate data were determined in the study area. Five levels of irrigation water depth (50%, 75%, 100%, 125%, and 150%) and two irrigation intervals (14 and 21 days) were arranged in a randomized completely block design with three replications. The result was analyzed using SAS version 9.0 statistical software. The results showed that the irrigation regime had an impact on yield and water productivity. At Koga, irrigating 75% CWR (12 mm, 22 mm, 51 mm, and 48 mm) at initial, development, middle and late-stage respectively within 14 days irrigation interval gave 3.36 t/ha wheat yield and 1.07 kg/m$^3$ water productivity. While at Rib, irrigating 75 % CWR (0 mm,21 mm, 76 mm, and 78 mm) at initial, development, middle, late-stage) respectively within 21-day irrigation interval gave 3.73 - 4.77 t/ha yield and 1.07-2.5 kg/m$^3$ water productivity. Therefore, to attain an optimum yield and water use efficiency at Koga and Rib, wheat could be irrigated with an average irrigation application depth of 33 mm and 44 mm every 14 and 21 days irrigation interval respectively.*

**Keywords:** *Irrigation scheduling; Crop Water Requirement; wheat; Koga; Rib*

## Introduction

Irrigation is the means to optimize plant water use and increase crop production. Implementing comprehensive irrigation water management practices is essential to improve excessive irrigation and eliminate the associated problems (Al-Kaisi et al., 1997). The relation between yield and crop water consumption has been investigated and the result water resources (Allen et al., 1998). Therefore, the objective of this study was to determining crop water requirements and irrigation scheduling using the CROPWAT model for better resource allocation and crop productivity.

## Materials and Methods

### *Site Description*

Koga irrigation scheme is located in the Northwest of Ethiopia at Mecha district, 41 km to the West of Bahir Dar city and 543 km to the North of the capital city, Addis Ababa at 37°7'29.72" Easting and 11°20'57.85" Northing and at an altitude of 1953 m a.s.l. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperatures are 26.8 0C and 9.7 0C respectively. Rib irrigation site is located in Fogera district Northwest of Ethiopia, 60 kilometres to the East of Bahir Dar city and 644 km North of the capital city, Addis Ababa at 37°25' to 37°58' Easting and 11°44' to 12°03' Northing and an altitude of 1794 m a.s.l. It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the study area was 30°c and 11.5°c. The area is characterized as mild altitude agroecology. The trial was conducted in 2013 and 2014 at the

field at Rib irrigation scheme, Western Amhara, Ethiopia (Figure 1). The field capacity (FC) and permanent wilting point (PWP) of Koga and Rib are (32 % and 59 %) and (18 % and 21 %) respectively. In Figure 2, the Koga Effective rainfall, Average rainfall, dependable rainfall, and $ET_0$.

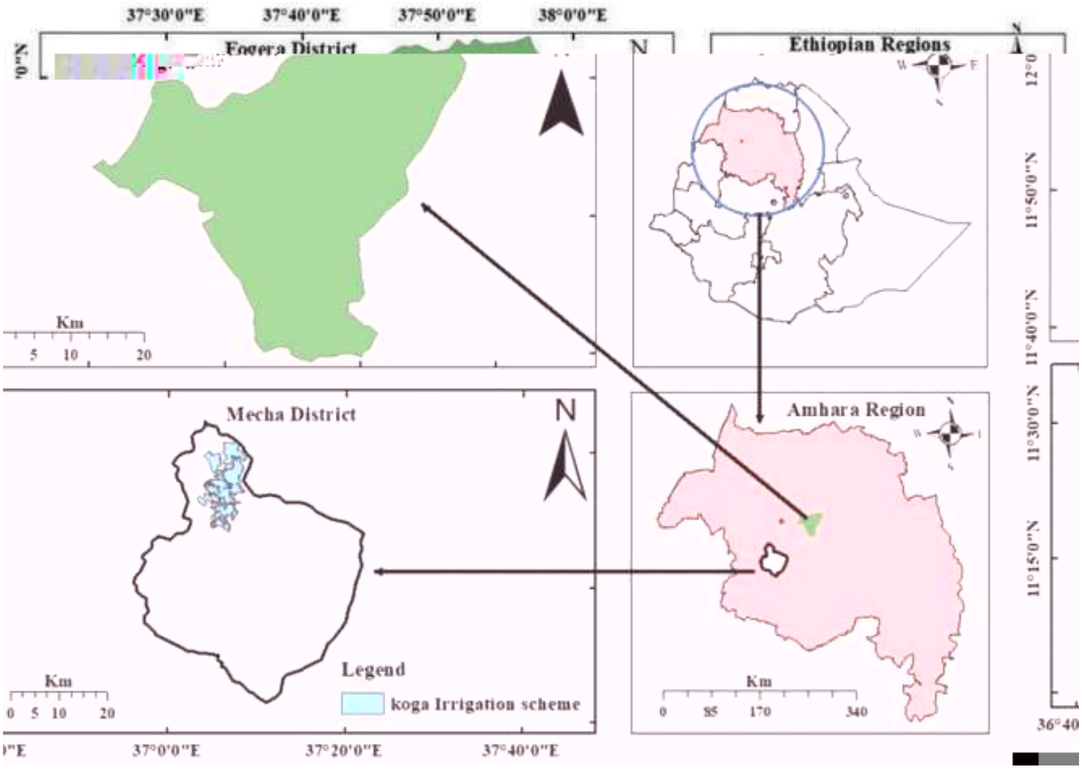


**Figure 1**. The location map of the study areas

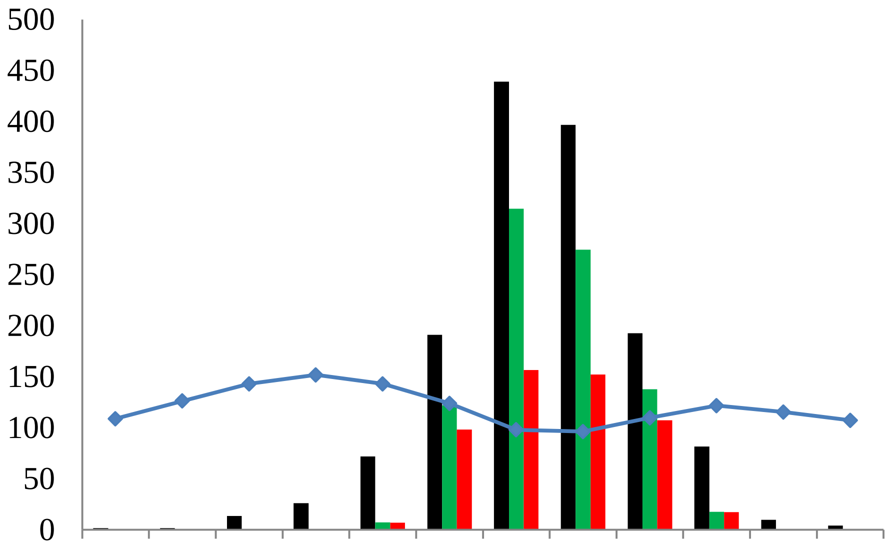


**Figure 2.** Koga Effective rainfall, Average rainfall, dependable rainfall, and $ET_0$

**Methods**

The field experiments were conducted in a randomized complete block design (RCBD) with three replications. The crop wheat; a variety of TAY was used and planted on 0.2 m spacing between row and by drilling 125 kg $ha^{-1}$ seed. DAP was applied at a rate of 100 kg $ha^{-1}$ at planting and 138 kg $ha^{-1}$ Urea; half at planting and a half at 45 days after planting was applied. All the agronomic practices were equally treated for each treatment. Reference evapotranspiration (ETo) and the crop evapotranspiration (ETc) were estimated using Doorenbos and Pruitt (1977) FAO penman-Monteith method; Equations 1 and 2 respectively. Crop and irrigation water requirement was computed using the CROPWAT 8.0 software. Data of initial soil moisture, soil texture, and water holding capacity of the soil were collected before planting. Local rainfall data was used for estimation of effective rainfall and it was generated based on 80 percent dependable rainfall. USDA Soil Conservation Service method was used for the estimation of effective rainfall.

Where: ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ $m^{-2}$ $day^{-1}$], G = soil heat flux density [MJ $m^{-2}$ $day^{-1}$], T = mean daily air temperature [°C], U2 = wind speed at 2 m height [m $s^{-1}$], es = saturation vapour pressure [kPa], ea = actual vapour pressure [kPa], es-ea = saturation vapour pressure deficit [kPa], slope vapour pressure curve [kPa $°C^{-1}$], $^{-1}$]

Where:

ETc = Crop Evapotranspiration

ETo = Reference Crop Evapotranspiration

Kc = Crop coefficient

*Treatment Setup*

The on-farm trial was conducted in the dry season with ten (10) treatments. The two factors of irrigation depth and frequency were factorially arranged and laid out in RCBD. The Two irrigation intervals of 14 and 21 days and five irrigation depths (50, 75, 100, 125, and 150 % of CWR) at four growth stages were selected from the output of the CROPWAT 8.0 model (Figure 3). The gross irrigation water requirement was determined using 70 % application efficiency for both locations. To verify the CROPWAT generated depth, field experiments were carried out for two consecutive years at both locations.

**Table 1**. The on-farm trail treatment combination

| Treatment | Depth and Interval | Treatment | Depth and Interval |
|---|---|---|---|
| T1 | 50% CWR at 14 days | T6 | 50% CWR at 21 days |
| T2 | 75% CWR at 14 days | T7 | 75% CWR at 21 days |
| T3 | 100% CWR at 14 days | T8 | 100% CWR at 21 days |
| T4 | 125% CWR at 14 days | T9 | 125% CWR at 21 days |
| T5 | 150% CWR at 14 days | T10 | 150% CWR at 21 days |

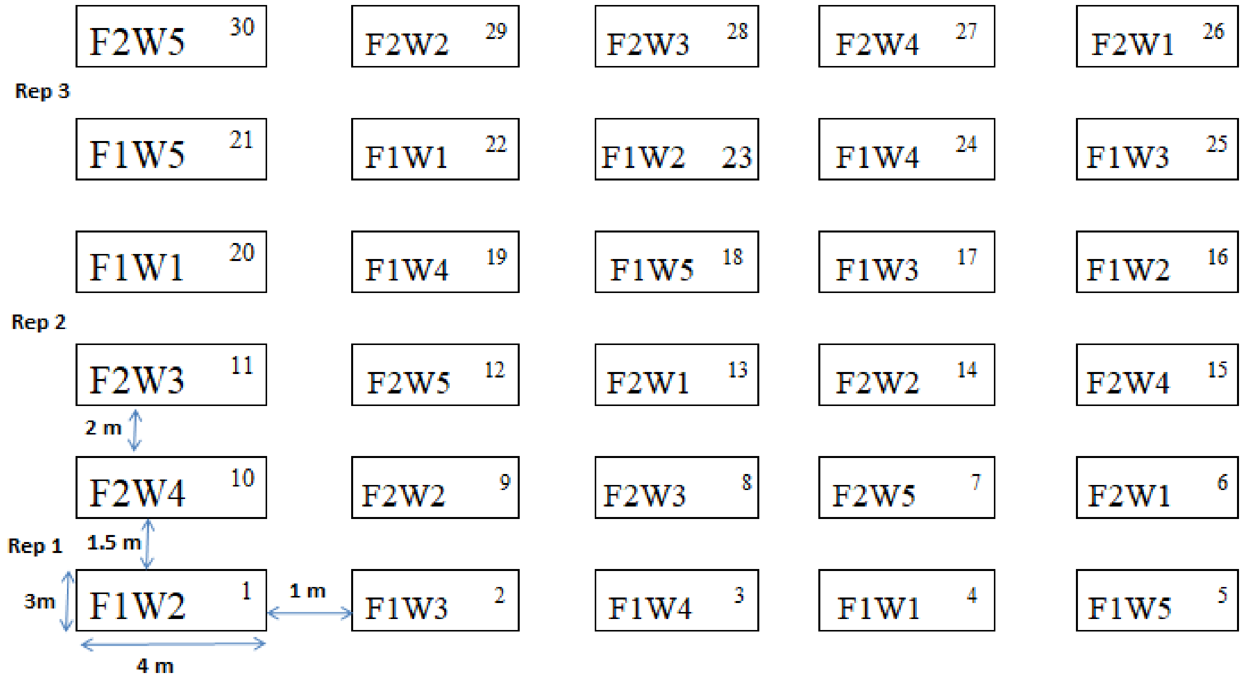


**Figure 3**. Field Layout of the experiment (where: W1 = 150 % CWR, W2 = 125% CWR, W3 = 100% CWR, W4 = 75% CWR, W5 = 50% CWR while F1 and F2 are 14 day and 21day irrigation frequency respectively).

## Results and Discussion

The soil sample was taken before planting of wheat takes place and analysis using laboratory procedure. The field capacity (FC), permanent wilting point (PWP), and available water (AW) was done at Adet Agricultural Research Center soil laboratory using the gravimetric method. The result as shown in the table the soil texture was varied in the study site. The result of the soil sample analysis at the Koga site shown that (Table 1) the soil textural classification lay under the clay soil texture according to (Hazelton & Murphy, 2016), and the other physical characteristics were also similar with (Abiyu & Alamirew, 2015). The soil analysis at Rib has shown that the soil is a light clay classification and has high alluvial deposited soil that comes from the upstream mountainous area of the Rib River. Meanwhile, the net irrigation depth of the study area is depicted in Table 2.

**Table 1.** Soil characteristics of the study area

| Site | FC (%) | PWP (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|
| Koga | 30.8±1.7 | 18.9±1.2 | 20.2±4.8 | 22.4±2.7 | 57.3±4.5 |
| Rib | 59.0±1.3 | 21.0±1.4 | 24.0±2.4 | 36.0±3.5 | 40.0±5.2 |

### *Effect of crop water requirement and irrigation scheduling on wheat*

Effect of different irrigation scheduling treatments on crop growth parameters, yield, and water productivity at Koga and Ribb irrigation scheme was presented in tables below. The ANOVA table showed that yield and water productivity were not significant differences over the year (Y), year by frequency (F), and year by depth (D) for both locations (Table 3).

**Table 2**. The net irrigation depth of the study area

| Treatment | Location | |
|---|---|---|
| | Koga | Rib |
| | Net irrigation depth (mm) | Net irrigation depth (mm) |
| 14D x 50% CWR | 223 | 219 |
| 14D x 75% CWR | 334 | 328 |
| 14D x 100% CWR | 445 | 437 |
| 14D x 125% CWR | 557 | 547 |
| 14D x 150% CWR | 668 | 656 |
| 21D x 50% CWR | 234 | 232 |
| 21D x 75% CWR | 345 | 349 |
| 21D x 100% CWR | 456 | 465 |
| 21D x 125% CWR | 567 | 581 |
| 21D x 150% CWR | 679 | 697 |

*Note: 14D=14 days irrigation interval, 21D=21 days irrigation interval*

### *Wheat Water productivity*

The water productivity at Koga irrigation frequency, irrigation depth, and their interaction showed a highly significant difference in the water productivity of wheat (Table 3 and 4). The lowest (0.33 kg/m3) and the highest (1.07 kg/m3) water productivity were obtained for 150 and 75 % CWR at 21-day irrigation intervals respectively. The 14-day results are in close agreement with Kebede (2003) and (Bekele and Tilahun, 2007) who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture could be compensated for by water use efficiency. The water productivity at Rib showed that irrigation frequency and depth were a highly significant difference (Table 5 and 6). The lowest (0.70 kg/m$^3$) and the highest (2.38 kg/m$^3$) water productivity were obtained for 150 % CWR and 50 % CWR irrigation depth within 14 and 21day intervals respectively. However, their 0.05). These results are also in close agreement with Kebede (2003) and (Bekele and Tilahun, 2007) who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture could be compensated for by water use efficiency.

### *Wheat yield*

The statistical analysis at Koga showed that irrigation frequency, irrigation depth, and their interaction have a highly significant difference in the grain yield of wheat (Table 3). The lowest (2.06 t ha$^{-1}$) and the highest (3.6 t ha$^{-1}$) grain yield of wheat were obtained for 50 and 125 % CWR at 14-day irrigation intervals respectively. The yield showed an increasing trend with the increase of water level up to 125 and 75 % CWR at 14 and 21day irrigation interval respectively. However, a further increase in irrigation level hurt the grain yield of wheat. The production was low compared to other productive areas of northwestern Amhara; this might be due to the soil condition (acidic soil) of the Koga command area since wheat is very sensitive to soil acidity. Besides, the soil at Koga has very low organic matter content and available phosphorus content according to the category by (Choudhury and Kumar, 1980). This result is in line with the finding of Ali and Yasin (1991), who reported that a high yielding wheat variety demands, adequate nutrient supply and optimum water to achieve maximum grain yield.

**Table 3**. ANOVA for yield and water productivity at Koga

| Parameter | Degree of Freedom (DF) | Mean square Yield (t/ha) | Water Productivity (kg/m$^3$) | 1000 Seed weight (g) |
|---|---|---|---|---|
| Year (Y) | 1 | 0.15 ns | 0.005 ns | ns |
| Replication (R) | 2 | 0.02 ns | 0.0008 ns | ns |
| Frequency (F) | 1 | 1.71 ** | 0.02 * | ns |
| Depth (D) | 4 | 1.76 ** | 0.62 ** | ns |
| Y*F*D | 4 | 0.55 ** | 0.48 ** | ns |
| R*F | 2 | 0.09 ns | 0.006 ns | ns |
| F*D | 4 | 1.95 ** | 0.14 ** | ns |
| Error | 28 | 0.07 | 0.004 | 0.089 |

*Note: ns is not significant, * significant and ** highly significant.*

**Table 4**. Mean yield and water productivity analysis result of Koga

| Frequency (day) | Depth (%CWR) | Yield (t/ha) | water productivity (kg/m$^3$) |
|---|---|---|---|
| 14 | 50% | $2.06^{bc}$ | 0.92 |
| 14 | 75% | $3.36^{a}$ | 1.07 |
| 14 | 100% | $3.04^{ab}$ | 0.66 |
| 14 | 125% | $2.61^{b}$ | 0.64 |
| 14 | 150% | $2.33^{bc}$ | 0.62 |
| 21 | 50% | $1.94^{bc}$ | 1.02 |
| 21 | 75% | $1.36^{e}$ | 1.07 |
| 21 | 100% | $2.87^{b}$ | 0.68 |
| 21 | 125% | $2.95^{ab}$ | 0.96 |
| 21 | 150% | $2.09^{bc}$ | 0.33 |
| CV (%) | | 8.9 | 8.03 |

The statistical analysis of mean wheat yield at Rib showed that irrigation frequency, irrigation depth, and their interaction have a highly significant difference (Table 5 and 6). The lowest (3.96 t ha-1) and the highest (4.54 t ha-1) grain yield of wheat were obtained for 150 and 125 % CWR at 21 14 day irrigation intervals respectively. The result reveals that an increasing trend with the increase in water level up to 125 and 100 % CWR at 14 and 21day irrigation interval respectively. The total grain yield of wheat at Fogera plain (Rib) was much larger than the Koga irrigation scheme this is due to the condition of the soil at Fogera is fluvisols which are deposited from upper catchments and have good nutrient content. The combined effect of fertilizer and irrigation water can improve the wheat yield. This finding also similar to Ali and Yasin (1991), who reported high yielding wheat variety demands adequate nutrient supply to maximum grain yield.

**Table 5**. ANOVA for yield and water productivity at Ribb

| | | Mean Square | | |
|---|---|---|---|---|
| Source | DF | 1000 seed weight(g) | yield(t/ha) | Water productivity (kg/m$^3$) |
| Year (Y) | 1 | 2224 ** | 12325861.8 ** | 10.4 ** |
| Replication (R) | 2 | 2.99 ns | 348861.79 ** | 0.04 ** |
| Frequency (F) | 1 | 3.9 ns | 25030.8 ns | 1.17 ** |
| Depth (D) | 4 | 4.85 * | 471892.6 ** | 3.56 ** |
| Y*F*D | 4 | 2.9 ns | 471240.4 ** | 0.1 ** |
| R*F | 2 | 1.3 ns | 10015.06 ns | 0.006 ns |
| F*D | 4 | 0.37 ns | 501773.9 ** | 0.09 ** |
| Error | 28 | 1.73 | 50381 | 0.005 |
| CV (%) | | 4.2 | 5.4 | 5.6 |

*Note: DF Degree of freedom, ns not significant * significant and ** highly significant*

**Table 6**. Mean yield and water productivity analysis result of Ribb

| Frequency (Day) | Depth (%CWR) | Yield (t/ha) | WP (kg/m$^3$) |
|---|---|---|---|
| 14 | 50 | 3.67$^{c}$ | 1.88$^{b}$ |
| 14 | 75 | 4.25$^{ab}$ | 1.48$^{c}$ |
| 14 | 100 | 3.99$^{bc}$ | 1.03$^{d}$ |
| 14 | 125 | 4.54$^{a}$ | 0.93$^{de}$ |
| 14 | 150 | 4.13$^{ab}$ | 0.70$^{e}$ |
| 21 | 50 | 3.98$^{bc}$ | 2.38$^{a}$ |
| 21 | 75 | 4.27$^{ab}$ | 1.81$^{b}$ |
| 21 | 100 | 4.14$^{abc}$ | 1.36$^{c}$ |
| 21 | 125 | 4.03$^{bc}$ | 0.96$^{d}$ |
| 21 | 150 | 3.96$^{bc}$ | 0.90$^{de}$ |
| CV (%) | | 2.2 | 1.79 |

*Note: WP Water Productivity, CWR- Crop Water Requirement*

## Conclusion and Recommendations

The effects of the irrigation regime were assessed by examining the effects on yield and water productivity of wheat at the Koga and Rib irrigation scheme. The study revealed that the irrigation regime (interaction effect of irrigation frequency and depth) affected the yield and water productivity of wheat at Koga and Rib irrigation schemes. At Koga, irrigating wheat within a 14-day interval using 75 % CWR irrigation depth gave 3.36 t/ha yield and 1.07 kg/m$^3$ water productivity. At Rib irrigation scheme, irrigating wheat within 21 days using 75% CWR irrigation depth has a high yield advantage gives 4.27 t/ha and 1.81 kg/m$^3$ optimal grain yield and water productivity respectively. Therefore, at the Koga irrigation scheme, irrigating 75% CWR (12 mm, 22 mm, 51 mm, and 48 mm) at initial, development, middle and late-stage respectively within 14 days irrigation interval could be applied to achieve optimal wheat yield and water productivity. While at Rib irrigation scheme, irrigating 75 % CWR (0 mm, 21 mm, 76 mm and 78 mm) at initial, development, middle, late-stage) respectively within 21-day irrigation interval could be applied to achieve optimal wheat yield and water productivity. However, to attain maximum wheat yield and water productivity further study is crucial in the area of fertilizer and irrigation water interaction.

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# Determination of Optimal Bed Width of furrow irrigated wheat at Koga and Rib Irrigation schemes, North West, Ethiopia

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## Abstract

*Water scarcity and irrigation methods are the major factors limiting the production of crops in agricultural irrigation farming. Improving effective water utilization is a serious challenge for water management experts. Field experiments were conducted to determine an optimal bed width of furrow irrigated wheat at Koga and Rib irrigation scheme within Lake Tana Sub-basin in Amhara regional state. The schemes represent silt clay soil at Koga and clay loam alluvial deposited soil at Rib. The experiments were conducted during the 2016/17-2017/18 irrigation seasons. The experiment was arranged in Randomized Complete Block Design (RCBD) having seven-bed widths of 40, 60, 80, 100, 120, 140, and 160 cm. It was found that bed width managed in different soil textures had significantly affected yield and water productivity of wheat. The results revealed that under silt clay soil (Koga), the 80 cm optimal bed width gave 26 % grain yield advantage and consumes 25% less water compared to the farmer practice. Similarly, Plant height has a significant difference but the panicle length and 1000 seed weight of wheat have no significant difference. The optimum bed width under alluvial deposited soil (Rib) was 120 cm which gave 27 % yield and 27 % water productivity advantage relative to the farmer practice. In addition, the plant height showed a significant difference but panicle length and 1000 seed weight of wheat have no significant difference. Therefore, we recommend optimum raised bed width of 80 cm and 120 cm for Koga (silt clay texture) and Rib (clay loam alluvial deposit soil) irrigation schemes for better yield and water productivity respectively.*

**Keywords:** *Furrow irrigation, Koga, Optimal Bed width, Rib, wheat,*

## Introduction

Irrigation is an essential agricultural practice for food, pasture, and fiber production in semiarid and arid areas (Koech and Langat, 2018). Farmers use surface irrigation systems to irrigate wheat through furrow, border strip, and basin techniques. However, the efficiency of surface irrigation is lower and farmers may lose up to 50 % of water delivery by deep percolation and runoff (Tadesse et al., 2016). This method is the most common technique being practiced throughout the world, implying that the water distribution is uncontrolled and inefficient (Bilibio et al., 2011). When water demand is increasing in irrigated agriculture, the need to increase water productivity is crucial. Therefore, it required prior consideration for implementing water management practices. Generally, wheat is sown in the traditional method on flat land, which often endangers the crop by excess irrigation. While in raised bed, wheat are plant on the bed which is practiced by dividing the field into narrow strips of raised beds separated by furrows (Soomro et al., 2017). In raised bed irrigation system, the plants are grown on the beds which use irrigation water efficiently and ensure better crop growth under heavy rains (Berkout et al., 1997). Wheat is an important staple food crop in Ethiopia. Today, wheat is among the most important crops grown both as a source of food for consumers and as a source of income for farmers (Minot et al., 2019). Wheat production has grown significantly to drive agricultural growth and food security; set it as one of the fourth most important food grains in Ethiopia (Gebreselassie et al., 2017). However, wheat production in Ethiopia is relatively small by global standards due to poor utilization of modern technology including improved seed, fertilizer, chemicals, irrigation, and mechanization (Minot et al., 2019).

Conventional flatbed planting and flood irrigation are commonly used for growing wheat production. However, it leads to the ineffective use of applied nitrogen, poor aeration and leaching, crop lodging, lower water use efficiency, and crusting of the soil surface (Majeed et al., 2015). On the other hand, the raised bed planting system improves the method of weed control and facilitates mechanical cultivation during the crop growing season. It also provides an opportunity for easy field entry resulting from row orientation on the beds, and irrigation water management is more efficient, less labor required with the use of furrows than conventional flood irrigation (Sayre and Moreno Ramos, 1997, Fischer et al., 2005). The furrow bed irrigation method permits more efficient use of irrigation water as compared to the basin or border irrigation (Hassan et al., 2005). Raised bed irrigation in wheat production, save more than 30-35% of irrigation water, 13.4% higher grain yield than the flat border irrigation method (Ahmad et al., 2010, Hussain et al., 2018). Similarly, the average irrigation duration decreased by 35.6 % in the case of bed and furrow irrigation method (Hassan et al., 2005, Ahmad and Mahmood, 2005) and improves 15% higher fertilizer use efficiency (Majeed et al., 2015). Kalwij et al. (1999) found that 30.6 % decrease in time spent on irrigation water application in bed and furrow irrigation method for cotton production. When water is applied to a furrow, it moves vertically under the influence of gravity and laterally by capillarity. Clay soils have more lateral movement of water than sandy soils which favors capillary action (Watson et al., 1995).

Wheat is the most dominantly cultivated cereal crop under irrigation in the Koga irrigation scheme and the newly introduced Rib irrigation scheme by farmers. In the traditional system, farmers cultivate wheat using their traditional know-how, the tools, and resources available. Farmers cultivate wheat using the flat panting technique, flooding irrigation method, and irrigate a series of the furrow with narrow bed (two rows with furrow irrigation). This leads to the application of excess water, which results in a water shortage problem at the scheme. Therefore, the aims of this study were to introduce the production of wheat using a raised bed method and determine optimal bed width in clay and loam soil structure.

## Materials and Methods

### *Description of the study area*

The experiment was conducted at Koga and Rib irrigation schemes in Lake Tana basin, Ethiopia, for two years, 2016/17 and 2017/18. The soil characteristics of the Koga and Rib experimental field are silt clay and clay loam soil textures respectively (Table 1). Koga irrigation scheme is located in the Northwest of Ethiopia at Mecha district, 41 km to the West of Bahir Dar city and 543 km to the North of the capital city, Addis Ababa at 37°7'29.72" latitude and 11°20'57.85" longitude and an altitude of 1953 m a.s.l. The average annual rainfall of the area is about 1438 mm. The mean maximum and minimum temperatures are 26.8 $^{0}$C and 9.7 $^{0}$C respectively. Rib irrigation site is located in Fogera district Northwest of Ethiopia, 60 kilometers to the East of Bahir Dar city and 644 km North of the capital city, Addis Ababa at 37°25' to 37°58' Easting and 11°44' to 12°03' Northing and an altitude of 1794 m a.s.l (Figure 1). It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the study area was 30°c and 11.5°c. The area is characterized as mild altitude agroecology. In both locations, farmers use flooding, furrow, and border irrigation system to cultivate field crops.

**Table 1**. Soil characteristics of the study area

| Site | FC (%) | WP (%) | CEC | N (%) | P (ppm) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|---|---|
| Koga | 30.8±1.7 | 18.9±1.2 | 20.1±2.7 | 0.2±0.03 | 18.4±10.7 | 20.2±4.8 | 22.4±2.7 | 57.3±4.5 |
| Rib | 59.0±1.3 | 21.0±1.4 | 33.0±3.4 | - | 34.7±2.4 | 24.0±2.4 | 36.0±3.5 | 40.0±5.2 |

***Experimental setup***

The irrigation method consisted of bed and furrow irrigation techniques having seven treatments using different bed widths with a furrow width of 40 cm. The treatments were arranged in a randomized complete block design with three replications. The raised beds and furrows were made manually and the height of the beds was 10 cm. The irrigation water applied was measured using a flume. The seed rate used for the experiment was 150 kg ha$^{-1}$ and the spacing between rows was 20 cm applied by drilling. In both locations, the recommended variety of TAY was used. A fertilizer rate of 121.1 kg ha$^{-1}$ NPS at planting and 150.13 kg ha$^{-}$1 Urea (50.13 kg ha$^{-1}$ at planting and 100 kg ha$^{-1}$ at the tillering stage) were applied equally for all treatments. All agronomic practices (weeding, pesticide, and insecticide) were done in accordance with the recommendation made for the area. The experimental trial was conducted in the dry season (November to March) and the optimum recommended depth of 33 mm and 44 mm every 14 and 21 days at Koga and Rib were applied respectively.

Table 2. Treatment setup

| Treatment | Bed width | No of Rows | Treatment | Bed width | No of Rows |
|---|---|---|---|---|---|
| T1 | 40 cm | 2 | T5 | 120 cm | 6 |
| T2 | 60 cm | 3 | T6 | 140 cm | 7 |
| T3 | 80 cm | 4 | T7 | 160 cm | 8 |
| T4 | 100 cm | 5 | | | |

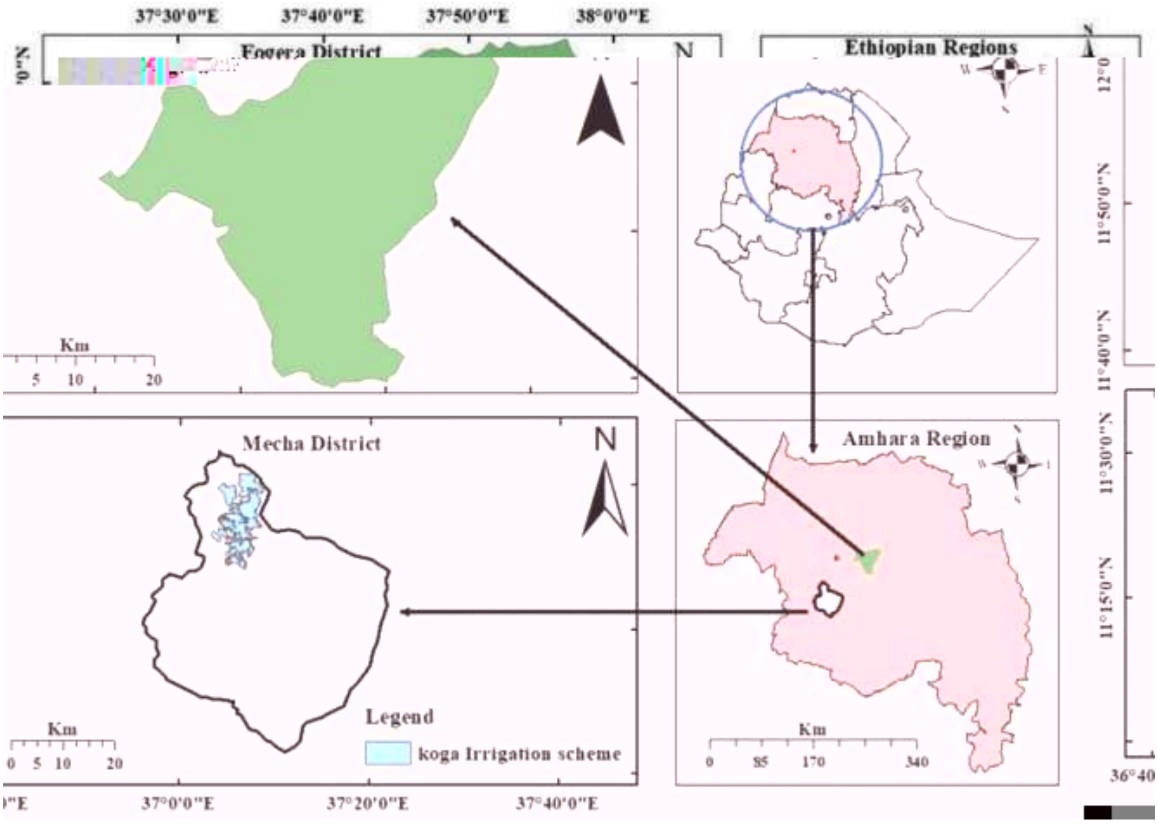


**Figure 1**. The location map of the study areas

The water application method was surface irrigation technique that applies through furrow and a siphon hose was used for measuring the amount of water we applied using a constant head. The flow rate of the irrigated water was measured and calculated using the volumetric method of discharge determination. This had done by collecting water in a container of known volume.

Q = V/t where, V = volume of container ($m^3$), t = time taken (hr) and Q = discharge of irrigation water ($m^3$ hr $^{1}$) for both experimental sites (Gore & Banning, 2017). The field layout of the experiment is illustrated in Figure 2.

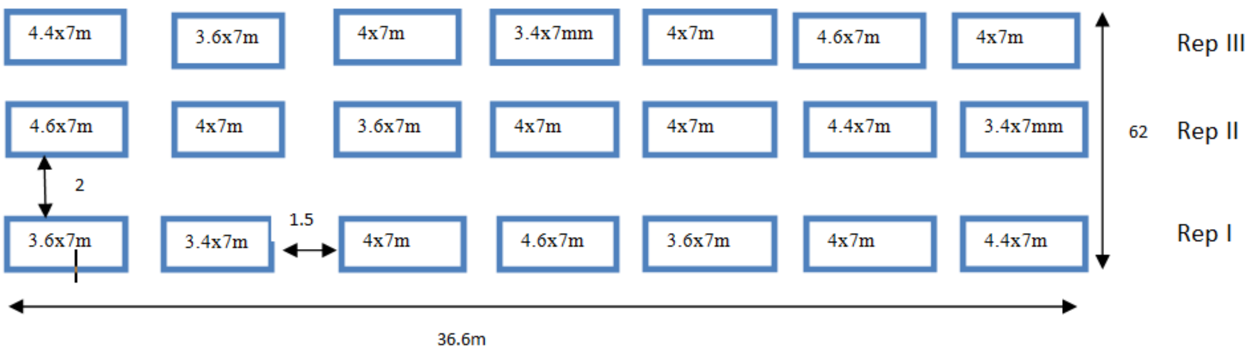


**Figure 2**. Field layout of the experiment

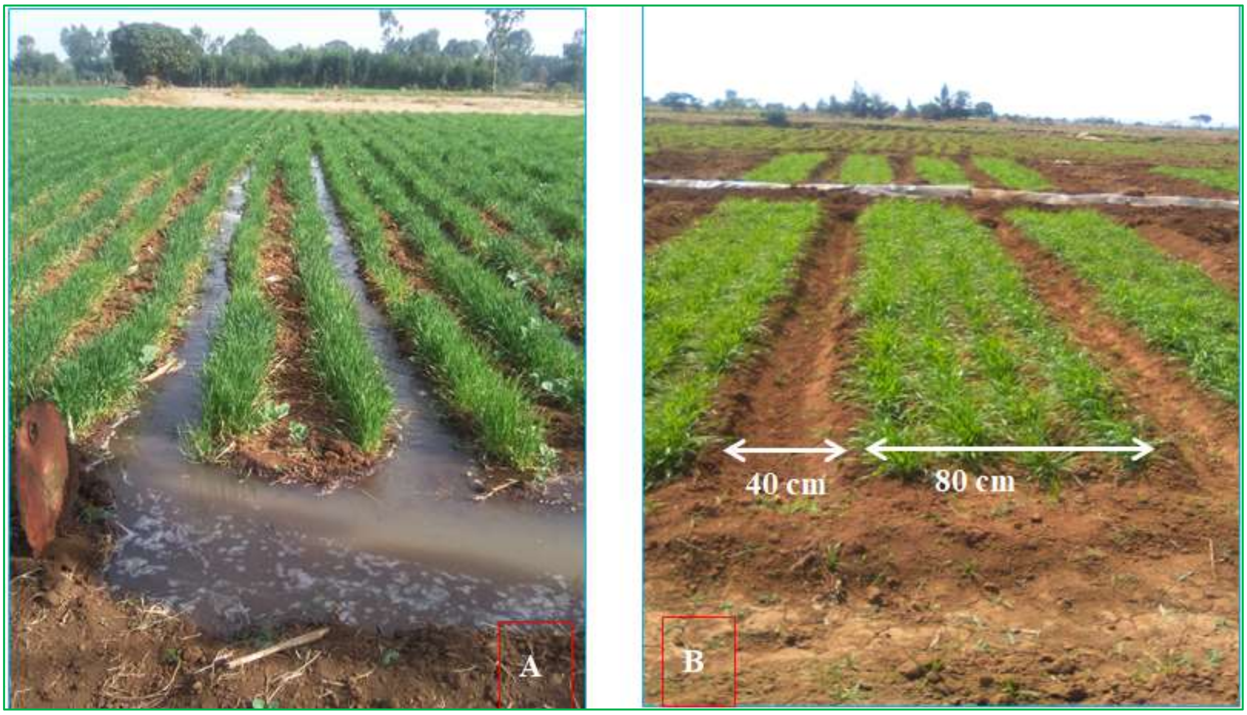

**Figure 3**. The farmer irrigation practice (A) and raised bed irrigation (B) at the site

## Results and Discussion

### *Wheat yield*

The study had conducted at silt clay soil (Koga) and loamy/alluvial deposited soil (Rib) to determine optimum bed width planted mid-November under irrigation. The results show that a significant difference between different bed widths has been observed on both sites (Table 3). The highest grain yield of 2.85 ton ha$^{-1}$ at silt clay soil was obtained using 80 cm bed width at Koga while the lowest yield 2.26 ton ha$^{-1}$ was obtained by using 40 cm bed width. On the other hand, in the alluvial deposited soil, a maximum of 4.99 ton ha$^{-1}$ and a minimum 3.39 ton ha$^{-1}$ grain yield, as shown in (Table 3) was obtained using 120 cm and 40 cm bed widths respectively. The production of wheat at the Koga scheme was too low due to strong acidic problems in the scheme. This result reveals that lateral movement in the Rib irrigation scheme (alluvial soil) was higher than in the Koga irrigation scheme. The panicle length and 1000 seed weight had not shown a significant difference among the different bed widths while plant height had a significant difference between bed widths at both locations. Generally, the results implied that the production of wheat under optimal raised bed width provided a 26 % yield advantage at Koga and 27 % at the Rib irrigation scheme as compared to the farmer practice. The farmer irrigation practice and raised bed irrigation at the study area is presented in Figure 3.

Our result is well agreed with the findings of Soomro et al. (2017), as they reported that the wheat crop produced a 24.65 % yield advantage. Similarly, Razaq et al. (2019) reported a 13.0 % higher grain yield under optimal raised-bed irrigation compared to the conventional irrigation system. Mollah et al. (2009) also reported wheat planting using 70 cm wide beds with two and three plant rows had 21 and 20 % yield increments respectively over the conventional method. The obvious reason for higher yield production under optimal bed width is due to effective utilization of land by reducing the number of furrows and lateral movement of the water. However, in Ethiopia, raised bed irrigation technique has not introduced until the study period.

**Table 3**. wheat yield and yield components

| Bed Width (cm) | Yield (ton ha$^{-1}$) | | Plant height (cm) | | Panicle length (cm) | | 1000 Seed Weight (g.) | |
|---|---|---|---|---|---|---|---|---|
| | Koga | Rib | Koga | Rib | Koga | Rib | Koga | Rib |
| 40 | 2.26$^{c}$ | 3.93$^{c}$ | 85.2$^{ab}$ | 91.4$^{b}$ | 8.6 | 9.1 | 34 | 30.5 |
| 60 | 2.67$^{ab}$ | 4.51$^{ab}$ | 89.1$^{a}$ | 94.1$^{ab}$ | 9.3 | 9.5 | 33.6 | 29.4 |
| 80 | 2.85$^{a}$ | 4.45$^{b}$ | 86.6$^{ab}$ | 97.3$^{a}$ | 8.9 | 8.9 | 34 | 30.1 |
| 100 | 2.63$^{ab}$ | 4.54$^{ab}$ | 87.7$^{ab}$ | 94.6$^{ab}$ | 8.5 | 9.0 | 34 | 29.7 |
| 120 | 2.54$^{b}$ | 4.99$^{a}$ | 83.4$^{ab}$ | 94.3$^{ab}$ | 8.5 | 9.3 | 34.3 | 30.1 |
| 140 | 2.63$^{ab}$ | 4.64$^{ab}$ | 79.5$^{b}$ | 96.8$^{ab}$ | 8.0 | 9.5 | 33.6 | 30.6 |
| 160 | 2.52$^{b}$ | 4.31$^{bc}$ | 81.8$^{ab}$ | 94.3$^{ab}$ | 8.0 | 9.5 | 33.3 | 28.2 |
| CV | 6.9 | 8.6 | 7.6 | 4.6 | 7.6 | 11.2 | 2.8 | 10.4 |
| LSD | ** | ** | * | * | ns | ns | ns | ns |

*Note: The (*) indicate significantly and (**) indicate highly significant at 5% and 1% level of confidence respectively*

*Wheat Water Productivity*

Wheat cultivation on raised beds enhanced water productivity, crop grain yield, and yield components as compared to the traditional flat sowing method (Razaq et al., 2019). The results revealed that water productivity was significantly affected by soil characteristics and the width of the raised bed (Table 4). The optimal raised bed width produced 25 % in clay soil (0.82 kg m$^{-3}$) and 27 % in clay loam soil (1.57 kg m$^{-3}$) higher water productivity as compared to farmer practice (40 cm bed width), which was a similar finding with the report of Razaq et al. (2019) in Pakistan. The area and number of furrows per hectare in the wider beds (better land productivity) is lower than the narrow beds resulting in received a lower amount of irrigation water. Savings of irrigation water by bed planting of wheat ranged from 18%-50% as reported by scientists (Gupta et al., 2002, CHOUDHARY et al.). The evident reason for higher water productivity under optimal bed width is due to effective utilization of land by reducing the number of the furrow.

**Table 4**. Water productivity of wheat affected by bed width

| Bed Width (cm) | Site | 40 | 60 | 80 | 100 | 120 | 140 | 160 | CV | LSD (5%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Water productivity (kg m$^{-3}$) | Koga | 0.74$^{c}$ | 0.87$^{ab}$ | 0.93$^{a}$ | 0.82$^{ab}$ | 0.78$^{b}$ | 0.81$^{ab}$ | 0.74$^{b}$ | 6.9 | ** |
| | Rib | 1.22$^{c}$ | 1.40$^{ab}$ | 1.39$^{b}$ | 1.41$^{ab}$ | 1.56$^{a}$ | 1.45$^{ab}$ | 1.35$^{bc}$ | 8.6 | ** |

## Conclusions

In the study areas, wheat was growing using surface irrigation and a series of furrows with narrow beds leads to poor production and waste of water. The optimal raised bed width of wheat at Koga (clay soil) was 80 cm bed width while at Rib (loam soil) was 120 cm bed width which gave 26 % and 27 % grain yield advantage respectively as compared to farmer irrigation practice. In addition, using the optimal bed width, the water amount of saved water has increased by 25 % in clay soil and 28 % on loamy soil as compared to farmer irrigation practice. This result revealed that using the saved water, up to 25% to 28% additional land could be irrigated. The lateral movement of water in loamy soil was higher than clay soil which results in a possibility of production of wheat in a wider bed at Rib irrigation scheme. Generally, the cultivation of wheat using optimal raised bed width enhanced water productivity, crop yield, and its components as compared to the traditional flatbed sowing and a series of furrows with a narrow bed method.

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# Determination of irrigation regime for watermelon at Koga and Rib irrigation schemes in Amhara Region, Ethiopia

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## Abstract

*Determining the optimum crop water requirements is considered one of the most important factors affecting plant productions. Excessive application of water can damage watermelon and face fruit quality problems, leading to a reduction of the melon fruit yield, lower fruit quality characteristics, and plant disease. Therefore, the main objective of this study was to determine the crop water requirement of watermelon in a field experiment using the CROPWAT model at Koga and Rib irrigation schemes. The experiment was conducted from 2016 to 2018 irrigation seasons for two years in the Amhara region, Ethiopia. The experiment was (RCBD) in a factorial arrangement having 12 treatments; three irrigation intervals (14, 21, and 28 days) and the model generated depth of 50 %, 75 %, 100 %, and 125 %. The results indicated that 75 % depth of water applied within 14 days intervals at the Koga irrigation scheme gave a total of 40.2 t $ha^{-1}$ yield with water productivity of 0.29 kg $m^{-3}$. In the case of Rib, 75 % of irrigation depth showed that better yield production within 21 days irrigation interval and produced 67.9 t $ha^{-1}$ fruit yield with water productivity 0.94 kg $m^{-3}$. In both locations, the fruit diameter and fruit length were not statistically significant among treatments. Generally, this research showed that an appropriate regime of irrigation had significantly increased crop water use and yield production.*

**Keywords**: *Irrigation scheduling, Koga, Rib, Watermelon, Water productivity*

## Introduction

To maintain self-sufficiency in the food supply, one viable option is to raise the production and productivity per unit of land through irrigation (Clark et al., 2011; Tchangani, Dambrine, & Richard, 1998). Irrigation scheduling is planning when and how much water to apply in order to maintain healthy plant growth during the growing season. Irrigation scheduling methods are based on two approaches, that is soil measurements and crop monitoring (Hoffman & Martin, 1993). Irrigation scheduling based on crop water status should be more advantageous for science crops to respond to both the soil and the aerial environment (Yazar, Howell, Dusek, & Copeland, 1999). Excessive application of water can damage watermelon and face fruit quality problems, leading to a reduction of the melon fruit yield, lower fruit quality characteristics and plant disease (Sensoy, Ertek, Gedik, & Kucukyumuk, 2007). The major watermelon producers in the world are; China, Turkey, Iran, Brazil, United States, Egypt, and the Russian Federation (Fao & Isric, 2010) while this fruit in Ethiopia is newly introduced. The importance of this fruit is for the production of juices, nectars, and fruit cocktails (Wani, Sreedevi, Reddy, Venkateswarlu, & Prasad, 2008). Timely management of plant pests, weeds, and proper water application is essential during the production period of watermelon. Generally, excess application of water causes leaching of nutrients, reduction of yield which results in a reduction of water use efficiency (Refai, Mostafa, Hefzy, & Zahran, 2019). The application of appropriate water for crops can improve nutrient availability, soil erosion, aeration, and water productivity (Gaafer & Refaie, 2006). Optimum supply of water and nutrient has a better water use efficiency, good moisture content of the fruit, survival rate, and better fruit test (Raviv & Blom, 2001).

CROPWAT software model is a computer program used for irrigation planning and management developed by FAO and the model is widely used to estimate reference evapotranspiration (ET0) and crop evapotranspiration (ETc) (Abdalla, Zhang, Ishag, & Gamareldawla, 2010). It allows us for the development of recommendations, improved irrigation practices, the planning of irrigation schedules, and the assessment of production under rainfed conditions or deficit irrigation (Clarke, Smith, & El-Askari, 2001). Proper amount and timing of water applications is a crucial decision for a farm manager to meet the water needs of the crop, to prevent yield loss, and maximize the irrigation water use efficiency resulting in beneficial use and conserve water resources (Allen, Pereira, Raes, & Smith, 1998). However, crop water requirements and irrigation schedules of watermelon were not done in the study site (Koga and Rib) irrigation scheme. Therefore, the objectives of this study were to determine the crop water requirement and irrigation schedule of watermelon using the CROPWAT model.

## Materials and methods

*Description of the study area*

The Koga watershed is located in the headwaters of the Blue Nile basin, Ethiopia has a total area of 266 $km^2$

(Gebrehiwot, Taye, & Bishop, 2010). The soil type of the experimental site is Nitisols with the dominant texture of clay and the soil has strongly acidic characteristics. The Rib watershed is located in the South of

latitude with an altitude of 1774 m above sea level. The soil type of the Rib irrigation site is Fluvisols with the texture of clay and has neutral reaction soil properties. This woreda is located at a higher elevation of the region than the Mecha woreda. Both Koga and Rib irrigation schemes were located in west Amhara and belong to the modern large-scale irrigation schemes in Ethiopia as well as in the Amhara region (Figure 1). The climatic characteristics and the physical soil properties of the study area is displayed in Table 1 and 2.

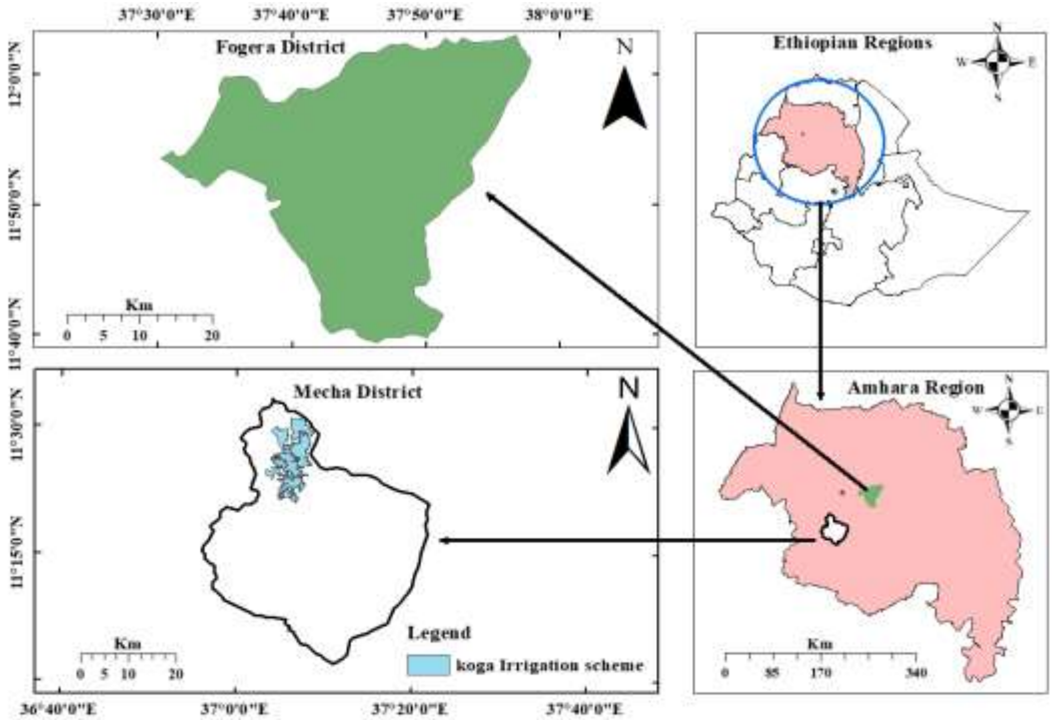



**Figure 1**. Map of the study areas

**Table 1**. Climatic characteristics of experimental sites

| Parameters | Koga | Rib |
|---|---|---|
| Minimum temperature (ºc) | 9.7 | 11.5 |
| Maximum temperature (ºc) | 26.8 | 30 |
| Mean annual rainfall (mm) | 1118 | 1400 |
| Relative humidity (%) | 68 | 70 |
| Wind speed (m/sec) | 2.0 | 1.5 |
| Sunshine hour (hr) | 10.4 | 7.9 |

***Experimental Design***

The design of this experiment was a factorial randomized complete block design (RCBD) having 12 treatments and consists of three irrigation intervals and four levels of irrigation depth. The irrigation intervals were 14, 21, 28 days and the levels of irrigation were 50 %, 75 %, 100 %, and 125 % of evapotranspiration (ETC) or crop water requirement for both locations. The treatments were replicated three times for each site and uniformly managed during the time of conducting the trial. The spacing between rows and plants was 1.8 m and 0.9 m respectively.

The CROPWAT computer model version 8.0 was used to calculate ETC. Then, ETC was calculated as the product of reference evapotranspiration (ETo) and crop coefficient (Kc). The amount of fertilizer applied based on the blanket recommendation was 100 kg ha$^{-1}$ NPS which means fertilizer formed from a combination of nitrogen, phosphorus, sulfur and used instead of diammonium phosphate (DAP) and 100 kg ha$^{-1}$ Urea fertilizer. Split application of Urea was practiced, which is half at planting and half at 45 days after planting. The variety of the test crop was Crimson and all agronomic practices were carried out uniformly for each treatment and years at both locations. The soil moisture status and soil properties were monitored in order to use schedule both the timing of irrigations and the volume of water applied. Irrigation was practiced in order to study the behavior of the crop and the amount of water required at each phase of the growth stage and over the growth period.

**Table 2**. Physicochemical properties of soil for the experimental sites

| Parameters | Koga | Rib |
|---|---|---|
| Filed capacity (%) | 32.0 | 59.25 |
| Permanent wilting point (%) | 18.0 | 21.0 |
| Total nitrogen (%) | 0.21 | 0.003 |
| Available phosphorus (ppm) | 19.67 | 36.71 |
| Cations exchange capacity (%) | 20.06 | 33.0 |
| Organic matter (%) | 0.37 | N.A |
| Power of hydrogen ((PH $H_2O$ (1:2.5)) | 4.75 | 6.70 |
| Electric conductivity (mmhoscm$^{-1}$) | 1.01 | N.A |

*Note: N.A = data not available*

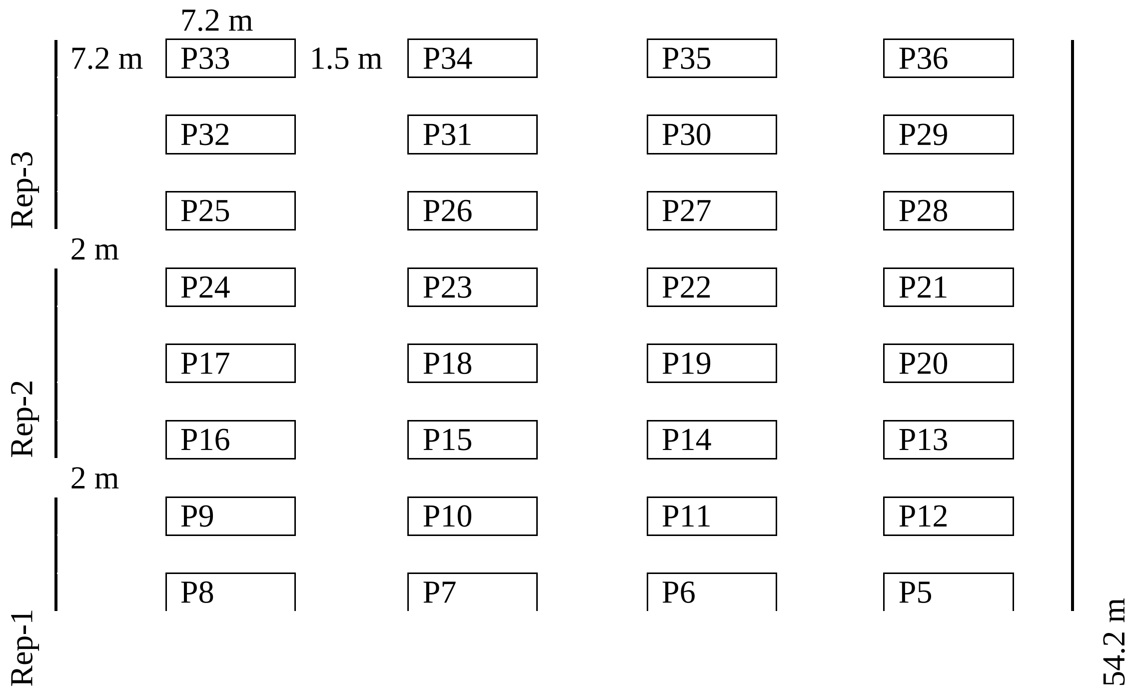
**Table 3**. Treatment combination of the experiment

| Treatment | Irrigation depth | Irrigation interval | Treatment Combinations |
|---|---|---|---|
| T1 | 50% ETC | 14 Day intervals | 50% ETC and 14 Day intervals |
| T2 | 75% ETC | 14 Day intervals | 75% ETC and 14 Day intervals |
| T3 | 100% ETC | 14 Day intervals | 100% ETC and 14 Day intervals |
| T4 | 125% ETC | 14 Day intervals | 125% ETC and 14 Day intervals |
| T5 | 50% ETC | 21 Day intervals | 50% ETC and 21 Day intervals |
| T6 | 75% ETC | 21 Day intervals | 75% ETC and 21 Day intervals |
| T7 | 100% ETC | 21 Day intervals | 100% ETC and 21 Day intervals |
| T8 | 125% ETC | 21 Day intervals | 125% ETC and 21 Day intervals |
| T9 | 50% ETC | 28 Day intervals | 50% ETC and 28 Day intervals |
| T10 | 75% ETC | 28 Day intervals | 75% ETC and 28 Day intervals |
| T11 | 100% ETC | 28 Day intervals | 100% ETC and 28 Day intervals |
| T12 | 125% ETC | 28 Day intervals | 125% ETC and 28 Day intervals |

*Note: ETC=Evapotranspiration of the crop, T=treatments*

The water application method was a surface irrigation technique that applies through furrow and a siphon hose was used for measuring the amount of water applied using a constant head. The flow rate of the irrigated water was measured and calculated using the volumetric method of discharge determination. This can be done by collecting water in a container of known volume. Q = V/t where, V = volume of container ($m^3$), t = time taken (hr) and Q = discharge of irrigation water ($m^3\ hr^{-1}$) for both experimental sites (Gore & Banning, 2017).

Watermelon fruits were harvested at marketable maturity and were then counted, individually weighed and harvest plot yields calculated. The harvestable plot area was 25.92 $m^2$ at Koga and 19.4 $m^2$ at Rib. The area of the harvestable plot varies due to the land limitation in the case of Rib irrigation scheme. The watermelon should be harvested before vines become withered, and by understanding the maturity indicator of the fruit (Paltrinieri & Staff, 2014). The overall maturity of the melon sometimes happens which is characterized by flesh mealy in texture and reddish-orange in color. The circumference and the length of the watermelon were measured by the plastic meter and weighted by sensitive balance. In this finding, the furrow irrigation method was used by keeping specific irrigation time.


7.2 m
7.2 m
1.5 m
P33
P34
P35
P36
P32
P31
P30
P29
P25
P26
P27
P28
Rep-3
2 m
P24
P23
P22
P21
P17
P18
P19
P20
P16
P15
P14
P13
Rep-2
2 m
P9
P10
P11
P12
P8
P7
P6
P5
Rep-1
54.2 m

is because of the variation of soil properties between the two experimental sites and the two sites have climatic and agroecological differences. Since the water holding capacity of the soil at Rib (Table 2
soil. Since watermelon is deep-rooted it could tolerate water stress except for peak production due to the requirement of irrigation application timely. Regardless of irrigation technique care must be taken at the field to minimize wetting of the bed tops and reduced fruit contact with moist soil to develop unsightly ground spots and fruit rots. The quality yield of watermelon was produced with adequate irrigation depth. The soil properties were the inputs for calculating ETC using the CROPWAT model and had a great influence on the amount of water required.

**Table 4**. Mean yield and irrigation depth of watermelon for each treatment

| Treatments | Experimental sites | | | |
|---|---|---|---|---|
| | Koga | | Rib | |
| | Irrigation depth (mm) | Mean yield(t/ha) | Irrigation depth (mm) | Mean yield(t/ha) |
| 14D50% | 302.2 | 27.787 | 119.3 | 43.152 |
| 14D75% | 453.3 | 40.164 | 179.0 | 50.751 |
| 14D100% | 604.4 | 33.578 | 238.6 | 49.028 |
| 14D125% | 755.5 | 37.58 | 298.3 | 44.132 |
| 21D50% | 280.1 | 31.712 | 78.45 | 63.304 |
| 21D75% | 420.1 | 23.237 | 117.7 | 67.889 |
| 21D100% | 560.1 | 17.301 | 156.9 | 51.112 |
| 21D125% | 700.1 | 17.891 | 196.1 | 57.131 |
| 28D50% | 298.7 | 22.479 | 65.25 | 60.461 |
| 28D75% | 448.0 | 23.407 | 97.88 | 46.068 |
| 28D100% | 597.3 | 29.434 | 130.5 | 52.538 |
| 28D125% | 746.6 | 25.696 | 163.1 | 53.391 |

*Note: Treatments=14 days irrigation interval with 50 %, 75 %, and 125 % of 100 % $ET_C$, 21 days irrigation interval with 50 %, 75 %, and 125 % of 100 % ETC and 28 days irrigation interval with 50 %, 75 %, and 125 % of 100 % $ET_C$, $ET_C$=Evapotranspiration of the crop determined from the CROPWAT model.*

As shown in Table 4, the seasonal water requirement of watermelon varies from 302.2 mm to 755.5 mm in the case of the Koga irrigation scheme and 65.25 mm to 298.3 mm for the Rib irrigation site. This variation depends on the climate and the total length of the growing period, as well as the soil characteristics of the test sites. The range of the amount of water required for watermelon in this research was lower than the other findings by Erdem & Yuksel, (2003); ;
(2009); Bastos, Silva, Rodrigues, Andrade Jr, and Ibiapina (2012), which varied from 460 mm to 600 mm under different climate and soil scenarios.

### *Effect of irrigation regimes on watermelon*

*Yield and water productivity*

The results showed that treatments have a significant effect on the yield and water productivity of watermelon for both irrigation schemes (Table 5 and 6). The maximum yield was produced for treatment two (40.2 t $ha^{-1}$) in the case of Koga and 67.9 t $ha^{-1}$ yields were produced in the case of the Rib irrigation scheme (T6). According to Ajao and Oladimeji (2017) report, the potential yield of this fruit ranges from 7.39 t $ha^{-1}$ to 58.49 t $ha^{-1}$. The yield production of watermelon at the Koga irrigation scheme was too low due to strongly acidic problems in the scheme (Tewabe, Abebe, Enyew, & Tsige, 2020). The water productivity of watermelon was calculated as the ratio of total yield obtained and the amount of water applied for each treatment. The maximum water productivity of watermelon was obtained at treatment nine which gave 0.34 kg $m^{-3}$ and 1.15 kg $m^{-3}$ at Koga and Rib respectively. This finding was somehow agreed with (Rashidi & Gholami, 2008) they reported that the water productivity of watermelon was ranged from 2.7 kg $m^{-3}$ to 14.33 kg $m^{-3}$. For both locations, the yield produced had a significant response to the amount of irrigation water applied at different application depths. Therefore, irrigating watermelon with 14 days irrigation interval at Koga and 21 days irrigation interval at Rib (75 % CWR) generated depth gave maximum yield and water productivity of watermelon.

**Table 5**. Combined ANOVA for the effect of irrigation regime on the yield and yield components of watermelon at Koga

| Source of variation | DF | Mean squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yield (t $ha^{-1}$) | Pr >F | WP (kg $m^{-3}$) | Pr > F | Diameter (cm) | Pr > F | Fruit length (cm) | Pr > F |
| Rep | 2 | 14.44 | | 9.76 | | 9.78 | | 1.81 | |
| Trt | 11 | 316.6 | <0.001 | 67.2 | 0.033 | 4.46 | 0.393 | 1.29 | 0.98 |
| Year | 1 | 5173 | <0.001 | 794.8 | <0.001 | 60151 | <0.001 | 2941.3 | <0.001 |
| Trt XYr | 11 | 253.9 | <0.001 | 37.21 | 0.314 | 3.5 | 0.58 | 2.714 | 0.78 |
| Residual | 46 | 66.99 | | 31.00 | | 4.1 | | 4.216 | |
| Total | 71 | | | | | | | | |

**Table 6**. Combined ANOVA for the effect of irrigation regime on the yield and yield components of watermelon at Rib

| Source of variation | DF | Mean squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yield (t $ha^{-1}$) | Pr >F | WP (kg $m^{-3}$) | Pr > F | Diameter (cm) | Pr > F | Fruit length (cm) | Pr > F |
| Rep | 2 | 45.59 | | 0.003 | | 0.367 | | 0.475 | |
| Trt | 11 | 353.61 | <0.001 | 0.393 | <0.001 | 1.73 | 0.54 | 4.890 | 0.727 |
| Year | 1 | 6460.3 | <0.001 | 1.073 | <0.001 | 30.34 | <0.001 | 106.77 | <0.001 |
| Trt XYr | 11 | 68.11 | 0.71 | 0.022 | 0.14 | 2.64 | 0.234 | 6.98 | 0.454 |
| Residual | 46 | 0.72 | | 0.014 | | 1.97 | | 6.93 | |
| Total | 71 | | | | | | | | |

### *Diameter and fruit length*

The diameter and fruit length of watermelon were not statistically significant among treatments for both experimental sites. But the mean fruit length and diameter of watermelon were closely related between the irrigation schemes. Even though the analysis indicated that no significant difference among the treatments in the fruit diameter and the fruit length but relatively large fruit diameter and the length were observed for some treatments at both experimental sites (Table 7 and 8) below.  In the report of (Ramos & Ramos, 2009) different water depths had no significant effect on the fruit length of the fruit. Application of agronomic practices with the collaboration of irrigation water management may significantly vary among treatments. The yield variations between the two locations were sought because of the features of soil, water and climatic condition, and source of water.

*Yield and Irrigation depth*

The fruit yield of watermelon has a significant variation among the arranged treatments for Koga and Rib irrigation schemes (Figures 3 and 4). As indicated below the figure the yield of the watermelon decreased along with the treatments when the amount of irrigation water depth declines. Relatively with the safe management of irrigation water (T2) gave the optimal yield at the Koga irrigation scheme and treatment (T9) generated sufficient yield in the case of the Rib irrigation scheme. The trend line showed that the yield of watermelon had positively correlated with the irrigation depth for both irrigation schemes. But the correlation coefficient ($R^2$) indicated below (Figures 3 and 4) describes weak positive relations between the amount of irrigation water applied and the yield produced at each irrigation scheme.

**Table 7**. Analysis of yield and water productivity of watermelon at Koga

| Treatment | fruit length (cm) | Diameter (cm) | Yield (t ha$^{-1}$) | WP (kg m$^{-3}$) |
|---|---|---|---|---|
| 14D50% | 28.15[a] | 38.68[a] | 27.8[ab] | 0.23[ab] |
| 14D75% | 27.62[a] | 38.86[a] | 40.2[a] | 0.29[ab] |
| 14D100% | 27.10[a] | 38.08[a] | 33.6[ab] | 0.21[ab] |
| 14D125% | 26.98[a] | 36.87[a] | 37.6[a] | 0.20[ab] |
| 21D50% | 27.57[a] | 37.24[a] | 31.7[ab] | 0.32[ab] |
| 21D75% | 26.79[a] | 38.52[a] | 23.2[ab] | 0.25[ab] |
| 21D100% | 27.86[a] | 38.99[a] | 17.3[b] | 0.15[b] |
| 21D125% | 26.80[a] | 37.71[a] | 17.9[b] | 0.15[b] |
| 28D50% | 27.17[a] | 36.65[a] | 22.5[ab] | 0.34[a] |
| 28D75% | 27.37[a] | 38.70[a] | 23.4[ab] | 0.31[ab] |
| 28D100% | 28.02[a] | 39.31[a] | 29.4[ab] | 0.32[ab] |
| 28D125% | 27.11[a] | 38.07[a] | 25.7[ab] | 0.25[ab] |
| Mean | 27.38 | 38.14 | 27.5 | 0.25 |
| CV (%) | 7.6 | 7.3 | 15.9 | 11.6 |
| LSD (5%) | ns | ns | 9.5 | 0.08 |

*Note: Numbers followed by the different letters indicate statically significant between treatments at a level of 5 % and ns = non-significant*

**Table 8**. Analysis of yield and water productivity of watermelon at Rib

| Treatment | Length (cm) | Diameter (cm) | Yield (t ha$^{-1}$) | WP (kg m$^{-3}$) |
|---|---|---|---|---|
| 14D50% | 22.99[a] | 39.18[a] | 43.2[c] | 0.45[ef] |
| 14D75% | 22.09[a] | 37.03[a] | 50.8[abc] | 0.46[ef] |
| 14D100% | 22.07[a] | 37.34[a] | 49.0[abc] | 0.40[f] |
| 14D125% | 22.83[a] | 38.87[a] | 44.1b[c] | 0.32[f] |
| 21D50% | 23.07[a] | 39.27[a] | 63.3[ab] | 1.00[ab] |
| 21D75% | 23.29[a] | 38.88[a] | 67.9[a] | 0.94[abc] |
| 21D100% | 22.85[a] | 38.18[a] | 51.1[abc] | 0.63[de] |
| 21D125% | 22.74[a] | 38.54[a] | 57.1[abc] | 0.64[de] |
| 28D50% | 21.96[a] | 37.32[a] | 60.5[abc] | 1.15[a] |
| 28D75% | 22.56[a] | 38.01[a] | 46.1b[c] | 0.77[bcd] |
| 28D100% | 22.00[a] | 36.46[a] | 52.5[abc] | 0.78[bcd] |
| 28D125% | 23.57[a] | 39.18[a] | 53.4[abc] | 0.72[cd] |
| Mean | 22.6 | 38.1 | 53.2 | 0.68 |
| CV (%) | 11.7 | 7.7 | 26.5 | 26.8 |
| LSD (5%) | ns | ns | 0.21 | 1.63 |

*Note: Numbers followed by the different letters indicate statically significant between treatments at a level of 5% and ns = non-significant*

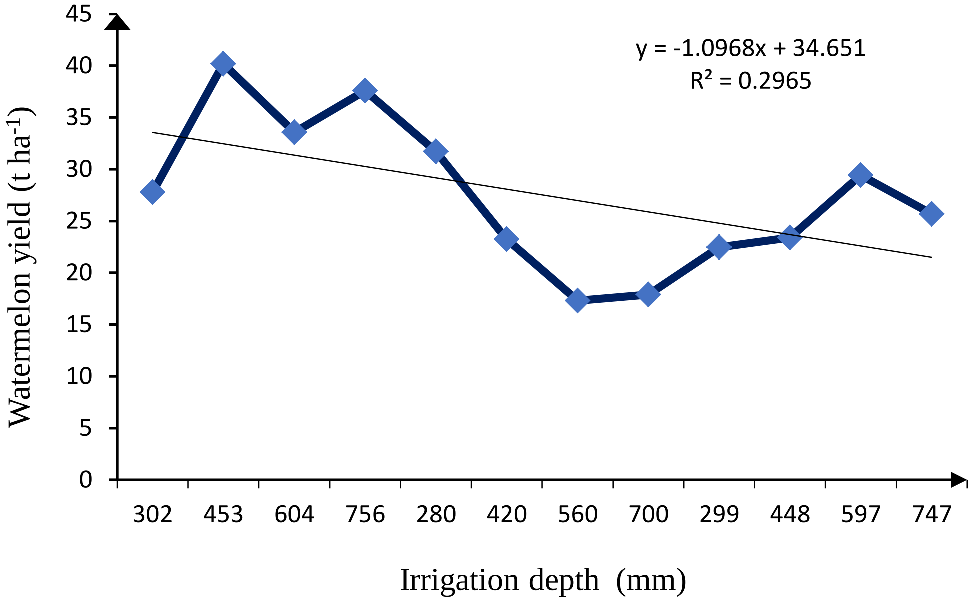



**Figure 3**. Trend of yield and irrigation depth interaction at Koga irrigation scheme

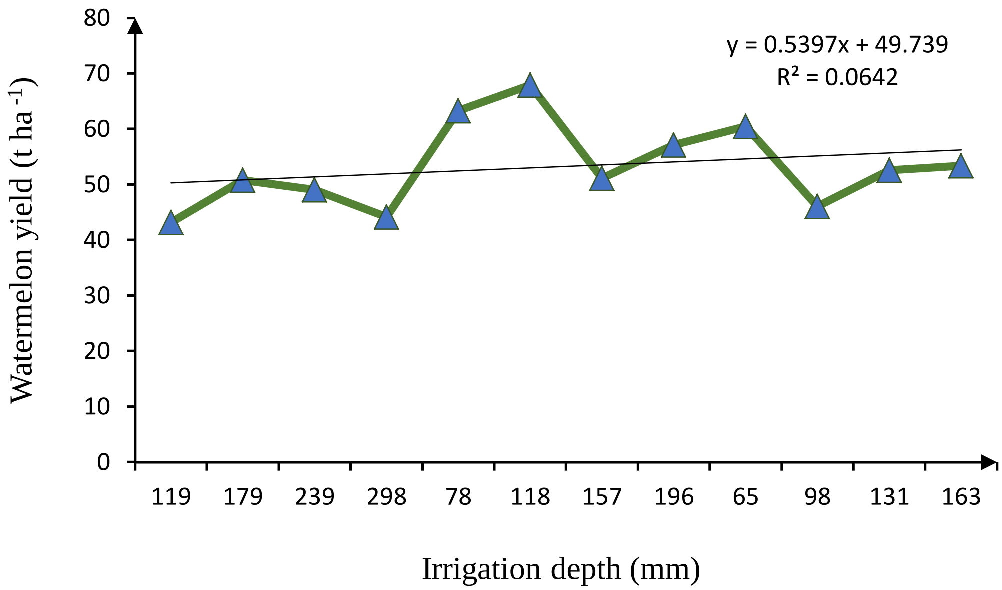



**Figure 4**. Trend of yield and irrigation depth interaction at Rib irrigation scheme

According to Amaral et al. (2016), the productivity and final quality of the watermelon crop were related to several factors, which acted during all phases of its growth and development. In this study similar acts of growth and development determinant factors related to irrigation, the amount was observed during the period of the experiment at both locations.

## Conclusions and recommendations

The amount of irrigation depth and scheduling had a significant effect on the yield and water productivity of crops. Spatial and temporal variation had also its impact on the amount and depth of irrigation water applied. This research indicated that the interaction of irrigation scheduling and depth across locations had a significant effect on the yield and water productivity of watermelon at Koga and Rib irrigation schemes. The result showed that 40.2 t $ha^{-1}$ yield within 14 days intervals and 67.9 t $ha^{-1}$ yield within 21 days intervals at Koga and Rib irrigation scheme. The result also showed that 0.34 kg $m^{-3}$ and 1.15 kg $m^{-3}$ water productivity was achieved with appropriate depth and scheduling at Koga and Rib respectively. Generally, this study revealed that the total depth of water produced the maximum yield of watermelon was 453 mm and 117 mm over the growing period at Koga and Rib irrigation schemes respectively. Irrigation significantly increased crop water use and therefore watermelon yield. Therefore, the determination of appropriate depth and irrigation scheduling can improve the yield and water productivity of watermelon.

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# Determination of irrigation water Requirement and Frequency for Tomato in Efratanagidm District, North Shewa

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## ABSTRACT

*Information on crop water requirement and frequency of crops is vital for irrigation water planning. Irrigation scheduling is planning when and how much water to apply in order to maintain healthy plant growth during the growing season. It is an essential daily management practice for farmers growing irrigated crops. However, irrigation practice in terms of the amount of water to be used and frequency of application has lacked proper knowledge. The purpose of this study is therefore to deliver the preliminary information on seasonal water requirement of tomato based on the widely used FAO cropwat model. The experiment was conducted at north Shewa Amhara region Efratanagidim District yimilo irrigation site. The experiment was conducted in randomly completed block design with 15 treatments and three replications. Statistically the total depth of water during growth period of tomato at Ataye and the same agroecology was 4431.94m$^3$/ha to get 48.95t/ha tomato yield gave an additional irrigation land without high yield penalty.*

**Key words**: Tomato, Efratanagidiem, water amount

## INTRODUCTION

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increasing in food demand. Food security is a major concern in many parts of the world including east Africa, Rift valley of Ethiopia where rainfall is unpredictable and unreliable (Tesfaye, 2008). To maintain self-sufficiency in food supply, one viable option is to raise the unit yield. A favorable method for raising yield per unit area is through irrigation.

Reported showed that the crop water requirement of crops correlated with the temperature and irrigation water demand (Kijne, 2010; Surendran et al., 2014). In the future, food and livelihood security may be challenged due to global environmental changes, particularly global climatic changes that evidence has gradually shown to be appearing (Aggarwal and Singh, 2010). Developments in irrigation are often instrumental in achieving high rates of agricultural goals but proper water management must be given due weightage in order to effectively manage water resources. the proper management of existing irrigated areas is important for fulfilling of food security in order to increasing population (Hari Prasad et al., 1996).

Irrigation water management is a crucial component of any irrigation project. Wise use of water resources is becoming the important element in agriculture as the demand for the resource is dramatically increasing because of population pressure and hence feeding the world is a priority issue. Knowledge of crop water requirements is therefore quite helpful for planning a sound irrigation scheduling where water can be used efficiently and effectively.

Operational applications of ET estimates yet heavily rely on the FAO-56 model because of minimum requirement of phonological and standard meteorological inputs (Evett et al., 1995; Kite and Droogers, 2000; Allen, 2000; Eitzinger et al., 2002). In FAO-56 approach, actual ET is calculated by combining reference evapotranspiration (ETo) and Kc. The Food and Agriculture of the United Nations has been extensively working on models that are capable of estimating crop water requirement and exercising irrigation scheduling of crops for any irrigation project for the last thirty years. The models have been widely used in the research, academia and developments sectors.

Understanding crop water needs is essential for irrigation scheduling and water efficient use in an arid region (Parry et al., 2005). Further, with increasing scarcity and growing competition for water, judicious use of water in agricultural sector will be necessary (Ali, 2010). Predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. In our study area consistent information on irrigation water use is still lacking. CROPWA is a FAO model for irrigation management designed by Smith (1991) which integrates data on climate, crop and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc) and irrigation water requirements

The CROPWAT model a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for determination of crop evapotranspiration (FAO, 1998) and yield responses to water (Doorenbos and Kassam, 1979).

In Ethiopia, the major portion of irrigation water management is traditional where farmers are irrigating as long as the water is available, without considering whether it is above or below the optimum of the crop water requirement. For large dams, the information of crop water requirement of the proposed crops is usually used for design purposes and it is not exercised on the real duty of irrigation operation, however. Moreover, in areas where, farmers are cultivating on small scale, the same information is critically limiting and more water is believed to be wasted (Roth G. 2014).

Irrigation scheduling is planning when and how much water to apply in order to maintain healthy plant growth during the growing season. It is an essential daily management practice for a farm manager growing irrigated crops. Proper timing of irrigation water applications is a crucial decision for a farm manager to: 1) meet the water needs of the crop to prevent yield loss due to water stress; 2) maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources; and 3) minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater.

Effective irrigation is possible only with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Applying too much water will result in extra pumping costs, wasted water, and increased risk for leaching valuable agrichemicals below the rooting zone and possibly into the groundwater.

Irrigation criteria, in terms of frequency of irrigation and amount of application per irrigation, seasonal net irrigation requirement and gross irrigation requirement for most of the lowland crops that are grown in the Middle Awash region of Ethiopia have been quantified by Melka Werer Research Centre. However, there was little effort undertaken in the highlands of Ethiopia especially in Amhara region. Crop water use studies which was conducted in some other area are not adopted because it highly location specific.

In North Shewa as such there is no an attempt to determine crop water requirements of irrigated crops except study conducted at Shewarobit for onion and pepper and at Bakelo for wheat and potato to estimate crop water requirements. The aim of this research was therefore to estimate the net irrigation requirement of tomato (Lycopersicon*esculentum) and* estimate the irrigation schedules of tomato using CROPWAT computer model in Ataye.

## MATERIALS AND METHODS

### Description of the Study Area

The experiment was conducted at the Amhara region north Shewa Efratanagidim District a yimilo irrigation site. The site is located 154 km from Debreberehan town and 9 km from Ataye town. The geographic location of the experimental site is $39^0$

1514 m.a.sl. The area has two major seasons; rainy and dry season. The rainy season lasts from the beginning of June to the end of September with mean annual rainfall of 822 mm, while the dry season lasts mainly from October to the end of May. The hottest months, February, April and May with mean monthly maximum temperature of 27.7°C, while the coldest months are November and December with mean minimum temperature of 11.5°C.

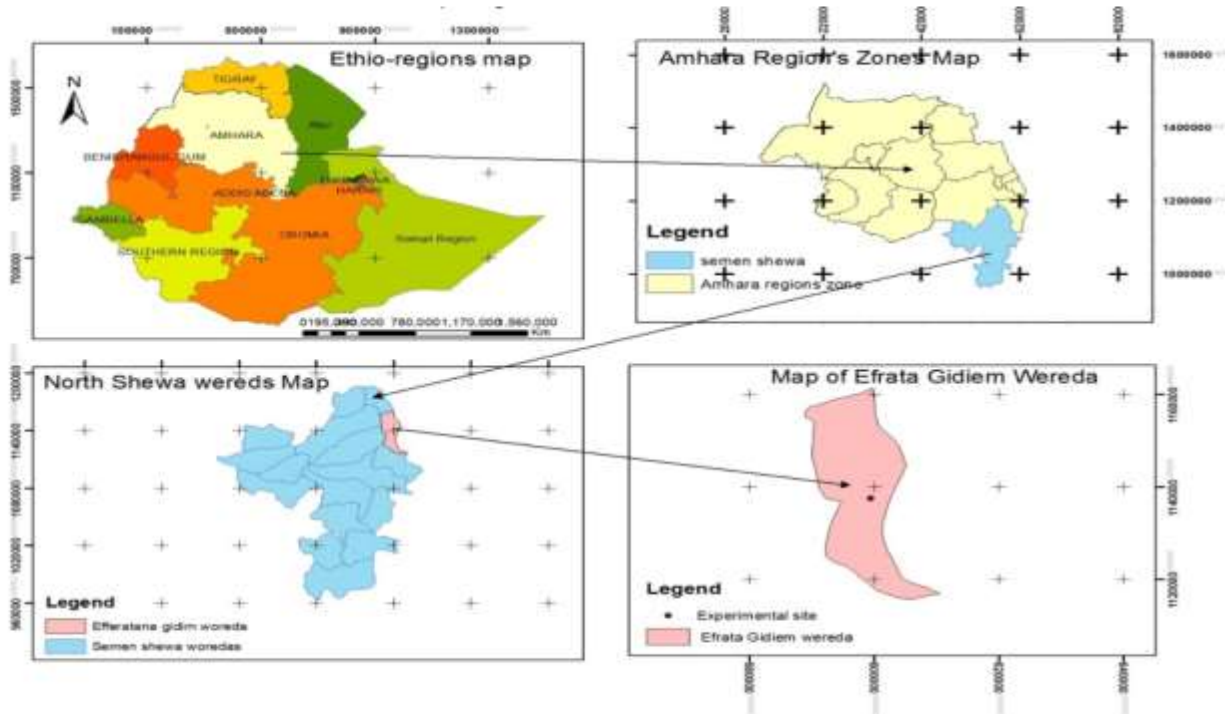


Figure 2. location map of experimental area

### Field Layout and Experimental Design

The experiment was conducted in random complete block design with 15 treatments set up and 3 replications. The unit plot size was 2.1m * 4m ($8.4m^2$). Treatments were assigned to each experimental plot by using SAS Software to randomize within a replication. The space between plant, row, plot and replication is 30cm, 75cm, 1m and 2m respectively.

Table 1 Treatments and applied water levels

| Treatments | Applied water level |
|---|---|
| T1 | 50% ETC |
| T2 | 75% ETC |
| T3 | 100% ETC |
| T4 | 125% ETC |
| T5 | 150% ETC |
| T6 | 50% ETC before 3-day interval |
| T7 | 75% ETC before 3-day interval |
| T8 | 100% ETC before 3-day interval |
| T9 | 125% ETC before 3-day interval |
| T10 | 150% ETC before 3-day interval |
| T11 | 50% ETC after 3-day interval |
| T12 | 75% ETC after 3-day interval |
| T13 | 100% ETC after 3-day interval |
| T14 | 125% ETC after 3-day interval |
| T15 | 150% ETC after 3-day interval |

The reference evapor-transpiration value (ETo) for the site was calculated from the long-term meteorological variables (Monthly Minimum and Maximum temperature, wind speed, sunshine hours and relative humidity) using the cropwat version 8.0, based on the Pen man-Moeinth formula. The Kc values have been adopted from the FAO cropwat computer model. FAO cropwat computer model has finally been employed to obtain the crop water requirements of the crop and exercising irrigation scheduling for the site.

**Experimental Field Management**

conventional plowing practice (plowing was done twice before sowing the test tomato crop traditional plow called *Maresha*, drawn by a pair of oxen). Stubbles, weeds etc. were removed from the field. The experimental field was divided into three main blocks (Replicates) and each block was divided into fifteen plots which received different treatment combinations All agronomic practices were applied equally for each treatment according to the recommendation of the area (starting from sawing to harvesting recommended package of practices were followed). Disease, insect pest and weeding management were carried out as required.

**Soil Sampling and Analysis**

Soil samples were taken from experimental field at 0-20cm depth using an auger before sowing. The composite soil samples were prepared by quartering and air-drying at room temperature, ground using a pestle and a mortar and allow passing through a 2mm sieve. Working samples were obtained from bulk sample and was analyzed to determine the soil physico-chemical properties like, soil texture, organic matter, and soil pH, and CEC and bulk density.

Table 2 method to determine chemical and physical properties of soil

| Parameters | Properties of the soil | | method |
|---|---|---|---|
| | Chemical | Physical | |
| $P^H$<br>EC<br>OC<br>OM<br>Soil texture<br>Bulk density | | | $P^H$ meter or electrometer<br>EC-meter or electrometer<br>Walkley and black ,1934<br>1.724*OC, Broadbent, 1953<br>Hydrometer, Bouyoucous, 1962<br>Volumetric meter |

**Field Operations and yield harvesting**

The tomato (Woino) variety was raised on a plot of land adjacent to the experiment plot for a period of thirty days in accordance with recommendation of Anonymous, (1976) before being transplanted. Recommendation rate of phosphorus, and nitrogen as a source of NPS and Urea fertilizer was applied at the rate of 240 Kg/ha and 100kg/ha respectively to the field.

Tomatoes harvested were estimated into marketable and non-marketable yields. Marketable yields were those crops harvested and transported to the market with market prevailing price. Non-marketable yields were those crops obtained from the experimental site as damaged tomatoes and/or those that could not be sold.

**Water use Efficiency**

According to Majumdar (2004), water use efficiency can be determined as the ratio of the amount of marketing yield crop yield to the amount of water required for growing the crops.

It can be calculated as; $Eu = \frac{Y}{WR}$

Where; Eu = field water use efficiency (t/ha-mm)

Y = crop yield (t/ha)

WR = Water requirement of the crop (ha-mm)

**Data Collection and Measurements**

The dada taken from the experimental site for analysis were growth parameters (plant height, fruit diameter and number of fruit), yield parameter (fruit yield) in both marketable and unmarketable yield amount of water and frequency (interval) during application period.

**Data analysis**

The collected data were subjected to analysis of variance (ANOVA) using SAS 9.0. Where ever the treatment effect was significant, mean separation were made using the least significance difference (LSD) test at 5% level of probability. Correlation analyses of selected parameters were also performed using Pearson correlation.

## RESULTS AND DISCUSSION

### Physico-chemical Properties of Soil before Planting

Some of the physicochemical properties of soils of the study sites before planting are summarized in Table 3. Accordingly, the soils of location belong to clay textural class based on soil textural class determination triangle of International Soil Science Society (ISSS) system (Rowell, 1994).

Table 3 Soil physical and chemical properties at Ataye

| parameter | Value | parameter | Value |
|---|---|---|---|
| Sand (%) | 28 | OC | 1.8 |
| Clay (%) | 38 | OM (%) | 3.04 |
| Silt (%) | 34 | BD | 1.37 |
| pH | 7.8 | PW | 23.4 |
| EC (ds/mm) | 0.23 | FC | 6.95 |

*OC=organic carbon, OM=organic matter, BD=bulk density, PW =permanent wilting point, FC = field capacity EC =electric conductivity*

### Reference evapotranspiration of the experimental site

The simulated result of the metrological data for reference evaporation of the study site summarized with respect to each month and average ETO in table 4.how ever, using 10

Table 4 the reference evapotranspiration (ETo) values at Ataye

| Month | Min Temp | Max Temp | Humidity | Wind | Radiation | ETo |
|---|---|---|---|---|---|---|
| | °C | °C | % | km/day | MJ/m²/day | mm/day |
| January | 12.1 | 25.7 | 60 | 156 | 18.2 | 3.9 |
| February | 12.8 | 27 | 60 | 173 | 21.1 | 4.59 |
| March | 13.6 | 26.7 | 59 | 173 | 18.5 | 4.4 |
| April | 13.6 | 27.7 | 69 | 156 | 19.9 | 4.45 |
| May | 14 | 27.2 | 62 | 173 | 21.2 | 4.75 |
| June | 13.8 | 26.1 | 76 | 104 | 18.1 | 3.73 |
| July | 11.8 | 21.1 | 88 | 104 | 15 | 2.82 |
| August | 12 | 20.8 | 90 | 104 | 14.9 | 2.77 |
| September | 12.8 | 22.5 | 83 | 112 | 16.9 | 3.24 |
| October | 12.6 | 24.6 | 64 | 190 | 19.8 | 4.23 |
| November | 11.3 | 25 | 62 | 190 | 21.1 | 4.3 |
| December | 11.5 | 25.2 | 60 | 173 | 18.9 | 3.97 |
| Average | 12.7 | 25 | 69 | 150 | 18.6 | 3.93 |

As mentioned in table 2, the highest monthly ET0 for the site was observed in May (4.74 mm/day), while the lowest was detected was observed in August 2.65 mm/day. The result indicated that ETo was higher during the dry season and lower in the rainy season

The probable irrigation season for Ataye may start as early as November where the evapotranspiration rates are relatively low until the crops will have full maturity and hence planting during those periods will have two advantages; using the soil moisture reserve that could have been stored from that recedes in late September or early October. Secondly, planting crops at times of low evapotranspiration is implicated that the demand of the crops for water is also low. Therefore, irrigation water saving is more practical for early planning. To determine the amount of water needed and when to apply it, calculate the ETc (crop water use) between irrigations with the following equation, where Kc is the crop coefficient and ETo is the reference crop evapotranspiration: ETc = Kc x ETo**.** Doorenbos and Pruitt (1977) divided the kc curve into four stages: initial, crop development, mid and late-season stages. The Initial growth stage occurs from sowing to about 10% ground cover, the crop development stage from about 10% to70% ground cover. The Mid-season stage includes flowering and yield formation, while the Late-season includes ripening and harvesting.

Crops have different water requirements depending upon the place, climate, soil type, cultivation method, etc., and the total water required for crop growth is not equally distributed over its whole life span over its whole life span (Some, et al).

The trend of average crop evapotranspiration (ETc) and reference evapotranspiration (ET0) for tomato was illustrated for the whole growing season in Fig. (3). The ETc values were clearly less than ET0 in the early developmental stages, but the ETc increased with time due to canopy growth until it exceeded ET0 near the end of the crop season. Low ETc rate occurred during the first Days or the month of Jan, when only few leaves contributed to the evapotranspiration and most ETc was evaporation from the soil. Water consumption increased from Feb to Mar, mainly due to water use by the plants during the vegetative stage. Maximum water requirements occurred during the flowering stage or the month of April (mid stage) and water use decreased from last day April (fruit set stage). Daily ET crop varied from <2.41 mm/day at crop establishment to 2.92 mm/day at early vegetative growth and 4.33 mm/day at late vegetative growth and achieved a peak of 5.05 mm/day at flowering. ET crop then declined to a value of 4.35 mm/day during the ripening stage (late stage). The performance of the various depth of water applied were based on tomato yield.

Table 5 Crop water requirement for tomato

| Month | Decade | Stage | Kc coeff | ETcrop mm/day | ETcrop mm/dec | Ir. Req. mm/day | Ir. Req. mm/dec |
|---|---|---|---|---|---|---|---|
| Jan | 2 | Init | 0.6 | 2.34 | 11.7 | 2.34 | 11.7 |
| Jan | 3 | Init | 0.6 | 2.48 | 27.3 | 2.48 | 27.3 |
| Feb | 1 | In/De | 0.61 | 2.65 | 26.5 | 2.65 | 26.5 |
| Feb | 2 | Dev.t | 0.69 | 3.18 | 31.8 | 3.18 | 31.8 |
| Feb | 3 | Dev.t | 0.84 | 3.78 | 30.2 | 3.78 | 30.2 |
| Mar | 1 | Dev.t | 0.98 | 4.36 | 43.6 | 4.36 | 43.6 |
| Mar | 2 | De/Mi | 1.1 | 4.85 | 48.5 | 4.85 | 48.5 |
| Mar | 3 | Mid | 1.15 | 5.08 | 55.8 | 5.08 | 55.8 |
| Apr | 1 | Mid | 1.15 | 5.1 | 51 | 5.1 | 51 |
| Apr | 2 | Mi/Lt | 1.11 | 4.96 | 49.6 | 4.96 | 49.6 |
| Apr | 3 | Late | 1.01 | 4.6 | 46 | 4.6 | 46 |
| May | 1 | Late | 0.87 | 4.1 | 41 | 4.1 | 41 |
| Totals | | | | | 463 | 463 | |

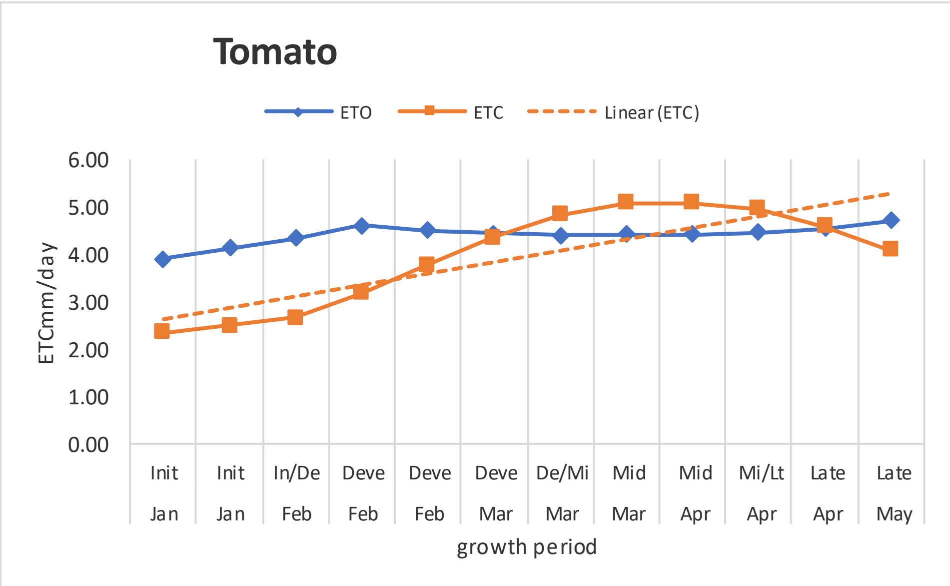


Figure 3 Temporal Crop evapotranspiration (ETc) and Reference crop Evapotranspiration (ET0) of Tomato

**Tomato yield and yield parameter**

The trend of PH ,NMF and NUMF growth  yield parameter in first year and second year  for tomato was illustrated for the application of different amount level of water depth  in table (6).in first year the maximum values of PH,NMF and NUMF in the treatment of 125% ETc before 3-day interval, 125% ETc and 100% ETc before 3-day interval and the minimum values parameters 50% ETc before 3-day interval, 50% ETc after 3-day interval and 150% ETc before 3-day interval respectively. in the second year the maximum values of the parameters 125% ETc   after 3-day interval, 50% ETc and 50% ETc and the minimum values also 75% ETc before 3-day interval, 150% ETc before 3-day interval and 50% ETc before 3-

day interval respectively the difference occurs due to the application level of water and the days of interval. But statistically shows that the analysis of variance of the tomato crop growth yield distribution for treatments, which indicated that there was highly significant

significance and there was no significant difference among number of marketable fruit at 5 % level of significance in first year while there was no significant difference among plant height, number of marketable fruit and number of unmarketable fruit at 5 % level of significance in second year.

Table 6. The response of plant height, number of marketable fruits, non marketable fruit, on the application of different amount of water in two years

| | First year | | | second year | | |
|---|---|---|---|---|---|---|
| Treatment | Ph cm | NMf /ha | NUMf /ha | Ph cm | NMf/ha | NUMf /ha |
| 50% ETc | 63$^{fgh}$ | 479369 | 96428.57 | 84.33 | 338892.9 | 47226.19 |
| 75% ETc | 65$^{efgh}$ | 478179 | 99607.14 | 75.87 | 267059.5 | 35714.29 |
| 100% ETc | 77$^{ab}$ | 537702 | 106345.2 | 80.27 | 194440.5 | 25000 |
| 125% ETc | 70$^{cdef}$ | 525000 | 142857.1 | 89.2 | 244440.5 | 34916.67 |
| 150% ETc | 62$^{gh}$ | 490083 | 95238.1 | 85.6 | 319047.6 | 36511.9 |
| 50% ETc before 3-day interval | 60$^{h}$ | 448809 | 67464.29 | 85.47 | 233726.2 | 22226.19 |
| 75% ETc before 3-day interval | 64$^{efgh}$ | 489678 | 99202.38 | 74.93 | 304369 | 41666.67 |
| 100% ETc before 3-day interval | 76$^{ab}$ | 475797 | 130559.5 | 78.07 | 216666.7 | 26988.1 |
| 125% ETc before 3-day interval | 82$^{a}$ | 494845 | 130321.4 | 84 | 196273.8 | 36904.76 |
| 150% ETc before 3-day interval | 72$^{bcd}$ | 416512 | 74607.14 | 83.47 | 188571.4 | 28571.43 |
| 50% ETc after 3-day interval | 74$^{bcd}$ | 399202 | 85714.29 | 85.2 | 278964.3 | 36107.14 |
| 75% Etc after 3-day interval | 70$^{cdef}$ | 525000 | 85321.43 | 83.93 | 297619 | 36511.9 |
| 100% ETc after 3-day interval | 67$^{defg}$ | 402143 | 109916.7 | 67.67 | 244845.2 | 39678.57 |
| 125% ETc after 3-day interval | 65$^{efgh}$ | 473417 | 84607.14 | 95.2 | 311904.8 | 33726.19 |
| 150% ETc after 3-day interval | 68$^{defg}$ | 473012 | 86904.76 | 76.07 | 263488.1 | 32535.71 |
| CV (%) | 5.41 | 10.55 | 17.51 | 16.1 | 30.34 | 28.6 |
| Mean | 69 | 473917 | 99673.01 | 81.95 | 260021.2 | 34285.71 |
| LSD (0.05) | 2.79 | NS | 10.96 | NS | NS | NS |

The response of MYF, UNMYF and TYF yield parameter and total application water application and water use efficiency for tomato was illustrated with the respect to each treatment in Table (7). The maximum values of MYF, UNMYF and TYF were in the

. And the minimum value of the yield parameters was in the

Statically the analysis of variance of the tomato crop yield distribution for treatments, which indicated that there was significant difference among the marketable yield, total yield and water productivity of crop at 5 % level of significance and there was no significant difference among total number of fruits, unmarketable fruit yield at 1% level of significance. The highest yield was 54.49 t/ha while the lowest was 37.89 t/ha. Statically 48.5 t/ha yield in the amount of irrigation water 376.71 mm depth with the water use efficiency 10.79 kg/m$^3$ safe 3127.33m$^3$ water from one hectare and get 0.59 ha additional irrigation land.

Table 7. The response of marketable fruit yield t/ha, unmarketable fruit yield t/ha, and total fruit yield on the Application of different amount of water

| Treatment | MYF t/ha | UNMYF t/ha | TYF t/ha | WUE kg/m$^3$ | TW m$^3$/ha |
|---|---|---|---|---|---|
| 50% ETc | 31.11$^{f}$ | 6.78 | 37.89$^{e}$ | 9.42$^{bc}$ | 3931.81 |
| 75% ETc | 39.39$^{bcde}$ | 5.79 | 45.19$^{bcde}$ | 8.46$^{cd}$ | 5244.2 |
| 100% ETc | 43.00$^{abcd}$ | 6.04 | 49.04$^{abcd}$ | 7.39$^{de}$ | 6546.25 |
| 125% ETc | 47.62$^{a}$ | 6.88 | 54.49$^{a}$ | 7.24$^{de}$ | 7559.27 |
| 150% ETc | 44.84$^{ab}$ | 6.69 | 51.53$^{ab}$ | 5.87$^{e}$ | 9227.11 |
| 50% ETc before 3-day interval | 33.56$^{f}$ | 4.97 | 38.52$^{e}$ | 11.28$^{a}$ | 3389.96 |
| 75% ETc before 3-day interval | 41.66$^{abcde}$ | 7.29 | 48.95$^{abcd}$ | 10.79$^{ab}$ | 4431.94 |
| 100% ETc before 3-day interval | 38.65$^{bcdef}$ | 7.01 | 45.66$^{bcde}$ | 8.10$^{cd}$ | 5465.34 |
| 125% ETc before 3-day interval | 39.00$^{bcdef}$ | 7.04 | 46.05$^{abcde}$ | 6.97$^{de}$ | 6505.11 |
| 150% ETc before 3-day interval | 37.38$^{bcdfe}$ | 6.18 | 43.56$^{de}$ | 5.99$^{e}$ | 7460.39 |
| 50% ETc after 3-day interval | 35.98$^{cdf}$ | 6.26 | 42.25$^{de}$ | 9.27$^{bc}$ | 4473.65 |
| 75%ETc after 3-day interval | 42.78$^{abcd}$ | 6.50 | 49.29$^{abcd}$ | 8.52$^{cd}$ | 5641.17 |
| 100 ETc% after 3-day interval | 39.36$^{bcde}$ | 7.06 | 46.42$^{abcde}$ | 6.31$^{e}$ | 7624.39 |
| 125% ETc after 3-day interval | 43.57$^{abc}$ | 6.56 | 50.13$^{abc}$ | 5.73$^{e}$ | 9254.32 |
| 150% ETc after 3-day interval | 35.20$^{def}$ | 6.06 | 41.26$^{cde}$ | 3.72$^{f}$ | 10970.1 |
| CV (%) | 15.37 | 26.58 | 14.14 | 17.79 | |
| mean | 39.44 | 6.43 | 45.87 | 7.68 | |
| LSD (0.05) | 2564.1 | NS | 2743 | 0.58 | |

The yield and land opportunity which got from saving water in the application of water through time interval illustrated in figure 4. The highest land and yield got from treatment six which saving 4169.31m$^3$of water and 0.81 ha additional irrigation land to get the 31.4 t/ha

Table 8. Correlation: number of marketable yield, number of unmarketable yield, marketable yield (Kg)/ha, unmarketable yield (Kg)/ha, total yield (Kg)/ha, water amount m3/ha

| | NMY | NUMY | M Y (Kg)/ha | UNMY (Kg)/ha | TY (Kg)/ha | water amount m3/ha |
|---|---|---|---|---|---|---|
| NMY | 1 | | | | | |
| NUMY | 0.809 | 1 | | | | |
| M Y (Kg)/ha | 0.835 | 0.798 | 1 | | | |
| UNMY (Kg)/ha | 0.772 | 0.894 | 0.729 | 1 | | |
| TY (Kg)/ha | 0.862 | 0.859 | 0.988 | 0.826 | 1 | |
| water amountm3/h | 0.489 | 0.509 | 0.562 | 0.511 | 0.578 | 1 |

## CONCLUSIONS AND RECOMMENDATION

The crop yield increase with increase in depth of water applied up to an optimum value beyond which it tends to reduce crop yield in the experimental area which is predominantly clay loam in texture. Statistically the total depth of water during growth period of tomato at Ataye and the same agroecology was to get 48.95t/ha tomato yield gave an additional irrigation land without high yield penalty. The application of water in each stage were initial 33.64 mm with 5 days interval, development1 60.54 mm with 9 days interval, development-2 94.18 mm with 14 days interval, mid 94.18 mm with 14 days interval and late 94.18 mm with 14 days interval water application used. This research result could be verified for confirmation and it works should be carried out using different tomato variety and irrigation method.

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# III) Soil and Water Conservation

# Evaluation of soil drainage methods for the productivity of Waterlogged Vertisols in Jama district Eastern Amhara region, Ethiopia

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## Abstract

*Vertisols are important agricultural soils in the Ethiopian highlands. The highland part of Jama district is one of which Vertisols have huge coverage and are underutilized due to waterlogging. Such a potential Vertisols areas needs to be put under wise cultivation. Thus, a study was conducted to investigate the effects of soil drainage methods on surface runoff, soil loss and yield of wheat crop as indicators of productivity improvement of typical Vertisols in Jama district of Amhara Region, Ethiopia during the rainy season of 2017/18. The treatments were three soil drainage methods (BBF-120cm*40cm, BBF-80cm*40cm and RF-40cm*40cm) arranged in a randomized complete block design with three replications on standard runoff plots. Statistical Analysis System, version 9.0 was used to perform analysis of variance and mean separation of the collected data on yield, soil loss and runoff. The result indicated that the effect of BBF-120cm*40cm brought significantly (P 0.05) higher difference on surface runoff, yield and biomass of wheat over RF-40cm*40cm. The rainfall of about 55.04%, 51.44 %, and 48.08% was lost as runoff from BBF-120cm*40cm, BBF-80cm*40cm and RF-40cm*40cm respectively. The drainage method, BBF-120cm*40cm gave 53% and 20.9% of grain yield advantage over the drainage methods of BBF-80cm*40cm and RF-40cm*40cm respectively. Whereas, Soil loss was not significantly (p >0.05) changed among all treatments and it is found in the range of soil loss tolerance in Ethiopia. As enhanced drainage is a requirement for successful crop production on Vertisols areas BBF-120cm*40cm is recommended for draining excess runoff and consequently maximizing the yield of wheat in the study area and others with similar farming system and agro-ecologies.*

**Keywords:** *drainage, grain yield, runoff, soil loss, Vertisols,*

## Introduction

In Ethiopia, about 12.6 million ha of land is reported as Vertisol; it accounts the portion about 10% of the total area of the country and is almost constrained by waterlogging problem due to the excess rainfall during the main growing seasons (Jutzi, 1989; Asamenew *et al*., 1993; Debele and Deressa, 2016). The highland location where rainfall is plenty coupled with relatively noble inherent fertility status enables these soils to have great potential for crop. Vertisols are some of the most productive soils for rainfed agriculture. Their high water holding capacity allows them to compensate better than most other soils for the low and erratic rainfall. On the other hand, due to the integral physical characteristics of these soils together with high rainfall of which is concentrated on months from June to September, the yield is low mainly due to waterlogging. An old data showed that out of the 7.6 million hectares of Vertisols found in the highlands only 26% of this area was under cultivation mainly due to waterlogging, the difficulty of land preparation, and soil erosion (Tekalign and Haque, 1988; Haque, 1992; Asamenew *et al*., 1993). Vertisols take a significant share of productive agricultural soils in the Ethiopian highlands but challenging to achieve the expected level of production due to their poor internal drainage and subsequent waterlogging (Jutzi and Abebe, 1987).

The highland part of Jama district is one of which Vertisols have huge coverage and are underutilized due to waterlogging. It is long established that waterlogging results in poor aeration, lower soil microbial activities, loss and unavailability of plant nutrients, and poor workability; in turn, causes Vertisols in Ethiopia are underutilized. In swamplands, the soil pores inside the root zone of crops are saturated and air circulation is taken closed. Waterlogging, therefore, precludes the free circulation of air within the root zone. Thus, water work adversely affects the chemical processes and also the bacterial activities that are essential for the correct growth of a plant (Cook and Veseth, 1991 cited by Assen *et al*., 2000; Mekonen *et al*., 2013). McDonald and Gardner, 1987 reported that the water table reaches near the root zones of the crops as a result of waterlogging will cause the soil pores to become fully saturated and the normal circulation of air in the root zones of the crops has stopped and the growth of the crops decreased.

The root tips, where most water, air, and nutrient uptake takes place, are the first to suffer from waterlogging mainly due to lack of oxygen reducing the seminal root growth in particular. Consequently, the crop root zone is poorly aerated and nutrient uptake for growth and development will be impaired (van Ginkel *et al*., 1991). To overcome the waterlogging stress, farmers in the highlands of eastern Amhara adopt a drainage technology called broad bed and furrow (BBF). But using this technology they Plant late in the season around the end of August up to mid-September when the excess water naturally drained away so that the crops grow on residual moisture, however, planting late in the season has yield disadvantage as the crop would be exposed to terminal moisture stress and frost damage (Jutzi and Abebe, 1987; Teklu *et al*., 2005). In good years (if the rain extends to September and October), the harvest may be very good if no frost. However, as this often fails, the consequence can range from substantial yield reduction to total crop failure (Debele and Deressa, 2016). In high rainfall areas, it is common to

40 to 60 cm. In this traditional ridge and furrow system, the furrows take up 40-50% of the crop area (Astatke *et al*., 2001).

Crop production and livestock feeding have been pushed by an increasing population pressure to steep slopes in the way of causing serious de-vegetation and soil erosion while Vertisols remain underutilized. There is a big opportunity to meet the demand for food doubling population if management strategies could be implemented towards the novel Vertisols of which with large moisture-holding capacity and relatively high fertility (Wubie, 2015). In Ethiopia where the people are suffering from food scarcity, removing production constraints in Vertisol areas is significantly an important alternative (Tekalign *et al*., 1993). Vertisol which covers an enormous landmass of the country needs to be put under cultivation with excess water draining innovations to achieve food security in Ethiopia. Furthermore, it has been reported that the removal of excess water from Vertisol significantly enhances nutrient uptake in crops (Asnakew *et al*., 1991). It is also proved that substantial increases in crop yield could be obtained on Vertisols if excess surface soil water is drained off and if appropriate cropping practices are used (Wubie, 2015). Therefore, this study was conducted to investigate the effects of soil drainage technologies on (i) enhancing surface drainage as an indicator of improved productivity through making effective ridge and furrow system, (ii) soil loss as indicators of the extent of soil degradation, and (iii) runoff generation for further discoveries related with water management to improve the productivity of typical Vertisol in the highland area.

## Materials and Methods

### *Description of the study area*

The experiment was conducted during the main rainy seasons from 2017 to 2018, in Jama district of south Wollo administrative zone of the Amhara national regional state in the northeastern highland vertisol area of Ethiopia at the research station of sirinka agricultural research center (Figure 1); which is 362 km northeast from Addis Ababa. Geographically the district is located between 10º 06´ 24" to 10º 35´ 45" N latitude and 39º 04´ 04" to 39º 23´ 03" E longitude with an altitude of 2850 masl at the specific area of a research station.

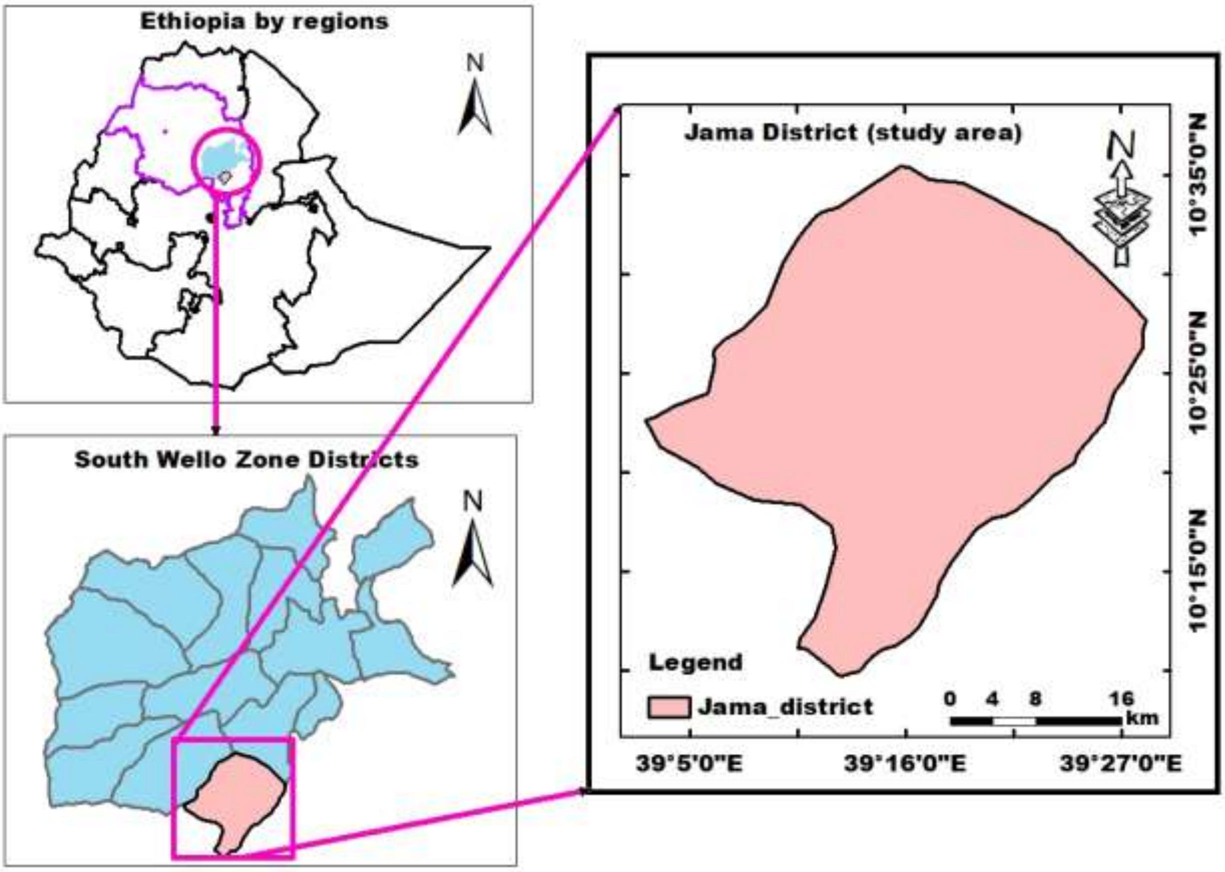


**Figure 1**. Location of the study area at Jama district in northeastern Ethiopian highlands

Based on 10 years (2008-2018) climatic data, the area receives an average annual rainfall of 1012.0 mm of which 74.6% is received during the main rain season (June to September) and the highland plateau of Jama has a very cold temperature which ranges from 0 to 20 $^{o}$c. The dominant soil in Jama is vertisol which is a black to gray clay with high swelling and shrinking character. It is poorly drained when wet and cracking when dry. The land use is mostly cultivated field crops: wheat (*Triticum aestivum L.*), teff (*eragrostis tef*), and fabbabean (*Vicia faba L.*) In rotation, while the marginal lands along the roadsides and communal pasture lands purposely left for feed sources are the major grazing grounds (Getaw, 2000).

### *Treatments and experimental design*

Treatments of three soil drainage techniques/planting beds (Table 1) were arranged in a randomized complete block design, with three replications on plots having a size of 4.8 m width and 10 m length dimension of measurable runoff producing area (Figure 2).

**Table 1**. Treatment description

| **Treatment name** | **Remark** |
|---|---|
| BBF-120 cm*40 cm ($T_1$) | |
| BBF-80 cm*40 cm ($T_2$) | |
| RF-40 cm*40 cm ($T_3$) | |

*NB: $T_1$=treatment one; $T_2$=treatment two; $T_3$=treatment three: Use this table for further identification of treatments in all sections of the paper*

*BBF-120 cm*40 cm (T1):* This system was constructed manually by scooping the soil from two sides of the furrows and distribute evenly on the upper part of the bed after the land is plowed by a traditional ox-drawn tine-plow implement having 40 cm width. The effective growing area is 120 cm wide and 20 cm high, separated by 40 cm wide furrows, to facilitate surface drainage between the beds. The crops are sown at the beginning of July, depending on the onset of rain and the type of crop to be grown.

*BBF-80 cm*40 cm (T1):* this was made with an effective bed width of 80 cm and 40 cm wide and 20 cm deep drainage furrows. This land preparation method is a recommended surface drainage system for Vertisol areas like Inewarie.

*RF-40 cm*40 cm (T3):* This is a traditional soil drainage method in the study area and neighbor districts of Northeastern highland Vertisol of Ethiopia for crops susceptible to waterlogging. It is constructed with the traditional tine plow after the seed is broadcast with an effective bed width of 40 cm and 40 cm wide and 20 cm deep drainage furrows, so that the crops grow on the ridges, allowing the excess water to drain out of the field through the furrows. In the case of our experiment, we adopted the method with its standard as of its conventional applicability while planting techniques and inputs were applied based on the recommended packages for the area.

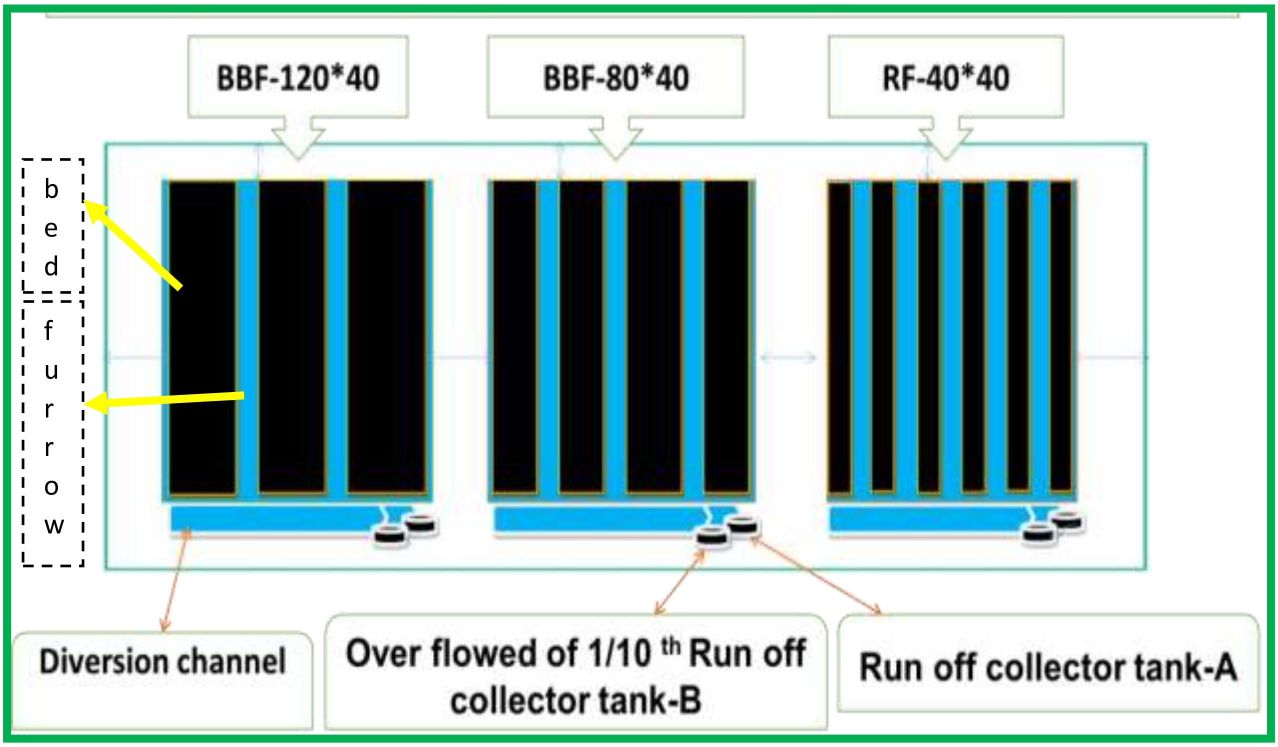


**Figure 2.** Experimental layout of the treatments

***Runoff and soil loss measurements***

Nine hydrologically isolated runoff plots of 10 m long and 4.8 m wide (48 $m^2$) were delineated on uniform land and the beds and furrows were graded along the slope to facilitate surface drainage through the furrows between the beds so that the crops grown on the drained beds. Plots were bounded by a galvanized metal sheet of 50 cm depth, of which 25 cm was inserted into the ground to prevent the lateral flow of runoff and the rest above the ground to block overland flow from entering the experimental plot. At the lower side of each plot, a water collector channel was constructed to collect the water drained from the furrows and beds (Figure 2). This water collector channel was also integrated with a small sediment trap (micro-pond) excavated at the outlet on which a barrel-like cylindrical tube was installed to measure the amount of runoff generated and soil removed from each drainage techniques/treatments. The rain gauge was installed near the experimental plots to record daily rainfall of the area.

Runoff was measured through using multi-slot divisors in the way that surface runoff was collected in the first tank, which when full overflowed into a second tank via a nine-slot divisor. The amount of runoff in each tank was measured daily (at 9:00 AM), and then the total daily and annual runoff amount for all the rainy days in a year per treatment for the main rainy season (Kiremit) was calculated as a ratio of runoff volume ($m^3$) to the area of runoff plot (48 $m^2$) and then converted to equivalent rate in a hectare of land. Similarly, the runoff coefficient was

calculated as the percentage of daily runoff (mm) to daily rainfall (mm). The total amount of eroded soil was determined through filtration (paper type *Whatman-597*, a pore size of 4-
of composite samples collected from both tanks after thoroughly mixing the collected runoff and sediment (Figure 3). After filtration the remained sediment was oven-dried at 105 $^oC$ for 24 hours and then weighed and compared with the weight of another filtration paper of the same size as a control to estimate the daily average soil loss from each replicated treatment as per the respective total runoff measured in the area (Adimassu *et al*., 2014).

**Figure 3**. Land preparation, water sample collection, and sediment filtration process

***Agronomic practices and data collection***

Tillage practices were applied 3 times a year on this area. The first plowing was done during the short rainy season, from March to May; and the secondary and tertiary tillage operations were undertaken at the mid of June to end June respectively. All beds and ridges were prepared in the first week of July at the first rain shower when the soil becomes moist for the ease of cultivation because the soil at this time is not bulky (not heavy) for bed preparation. Wheat (*Triticum aestivum L*.) was used as a test crop to evaluate the effect of soil drainage methods on runoff, soil loss and wheat yield. The seeding rate of wheat (variety *sora*) at a rate of 150 kg ha$^{-1}$ was applied in row. Recommended fertilizer rate for the area (115 kg/ha N and 69 kg/ha $P_2O_5$) was

as Plant height, biomass and grain yield was taken from the respective experimental plots by excluding border effects.

*Data analysis*

The data from each of the two years separately and altogether were statistically analyzed to understand the effect of drainage methods on runoff, soil loss, and wheat yield. Microsoft Office Excel 2010 and SAS version 9.2 (SAS, 2008) were used to analyze the data. Analysis of Variance (ANOVA) was performed to test whether the changes in runoff, soil loss, and wheat yield induced by treatments were statistically significant. Mean values were compared with the LSD test at $P<0.05$.

## Results and Discussion

*The effect of soil drainage methods on surface runoff*

The total and average rainfall amount in the growing periods (in the year 2017 and 2018) is illustrated in Figure 4. The total rainfall received during the rainy seasons of 2017 and 2018, 54.08 % and 55.90 % was lost as runoff from trt-1 (BBF-120 cm*40) respectively compared with 52.50 % and 50.49 % from trt-2 (BBF-80 cm*40) and the lowest runoff coefficient (47.53% and 48.58%) for the years 2017 and 2018 respectively were recorded from trt-3 (RF-40 cm*40). This might be attributed to the reduced speed of runoff from ridge and furrow system due to flat and uniform slope, which have resulted in higher opportunity time for infiltration or evaporation from depression storage on created furrows (Guzha, 2004). Total seasonal rainfall transformed to runoff from all treatments was not significantly vary in years in this study. As shown in Figure 7 below, there have been statistically significant differences ($P<0.05$) among the treatments in terms of surface runoff. In 2017, surface runoff was highest in BBF-120 cm*40 cm (272.27 mm) and BBF-80 cm* 40 cm (264.29 mm), however the lowest (239.29 mm) runoff was recorded from RF-40 cm*40 cm. In 2018, alike in 2017, the highest surface runoff (312.37 mm) was obtained from BBF-120 cm*40 cm, the lowest from BBF-80 cm* 40 cm (282.10 mm) and RF- 40 cm*40 cm (271.40 mm). The two-year average surface runoff was significantly highest (292.32 mm) in BBF-120 cm*40 cm and the lowest (255.34 mm) from RF-40 cm*40 cm. the research finding is in contrast with Mekonen *et al*., (2013) that showed RF was draining the excess water out of the field due to a large number of furrows constructed on the land of which can drain better with simple facilitation of furrows. Although the drainage density is relatively higher in treatment three (RF-40 cm*40 cm), increased volume of runoff was shown from BBF- 120 cm*40 cm. This situation could be attributed to reduced surface storage capacity from the experimental plots of treatment one (BBF-120 cm*40 cm) because the surface was relatively smooth and flat that facilitates the water to be retained rather than being transformed into a runoff.

Traditionally, surface roughness is created through tillage /ridge and furrow system/, which forms micro depressions in which excess water is stored (Govers *et al.*, 2000*;* Lipiec *et al*., 2006; Lindstrom *et al*., 1984). Unlike the case of Mekonen *et al*., (2013) these large numbers of created micro depressions by RF method coupled with flat slope allows water to be stored along the channel instead of drained out. On the other hand, BBF with a large bed size and a small number of furrows could significantly enable the runoff to be drained from relatively large catchment to furrows of which widely spaced and it gets the energy to flow out of the plot through powerful concentration on the channels. The runoff coefficient for all the treatments, and particularly for BBF-120 cm*40 cm was substantial. Our finding is in line with other studies that BBF induced more surface runoff than RF at flatlands in the highlands of Ethiopia (Erkossa *et al*, 2005). To solve the problem of crop failure due to moisture stress and to avoid losses of soil and nutrients changing this water resource into production through supplementary irrigation and other purposive techniques needs to be explored.

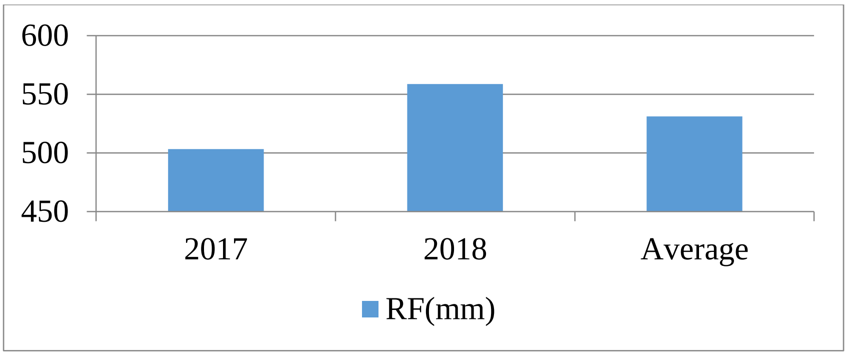


**Figure 4**. The total and average rainfall amount in the growing periods (in the year 2017 and 2018)

***The effect of soil drainage methods on soil loss***

The effect of drainage methods on soil loss for two consecutive years (2017 and 2018) is presented in Figure 5 and Figure 6. Soil loss was not significantly varying ($P > .05$) between treatments in both years. The finding indicated that soil loss showed an increment tendency corresponding to the runoff in both 2017 and 2018 growing seasons for all treatments. Though, unlike the runoff, the effects of the treatments on soil loss were not statistically significant in all years ($p \geq 0.05$) between each treatment but numerically highest soil loss (9.12 t ha $^{1}$) was recorded in BBF-120 cm*40 cm and the lowest (7.45 t ha $^{1}$) from RF-40 cm*40 cm (Figure 7) on average basis. The soil amount eroded from all treatments in 2018 is relatively higher compared with the year 2017 due to the highest proportional extent of runoff generated in 2018 as well. Two years combined analysis result of soil loss from all drainage methods (trt-1: 9.12 t ha $^{1}$ yr $^{1}$, trt-2: 8.64 t ha $^{1}$ yr $^{1}$ and trt-3: 7.45 t ha $^{1}$ yr $^{1}$) is in the range of soil loss tolerance in

Ethiopia (2  10 t ha$^{1}$ yr$^{1}$) (Hurni, 1993). This eludes the fear of soil erosion and suggests the possibility to use drainage methods that can drain excess water with better crop yield.

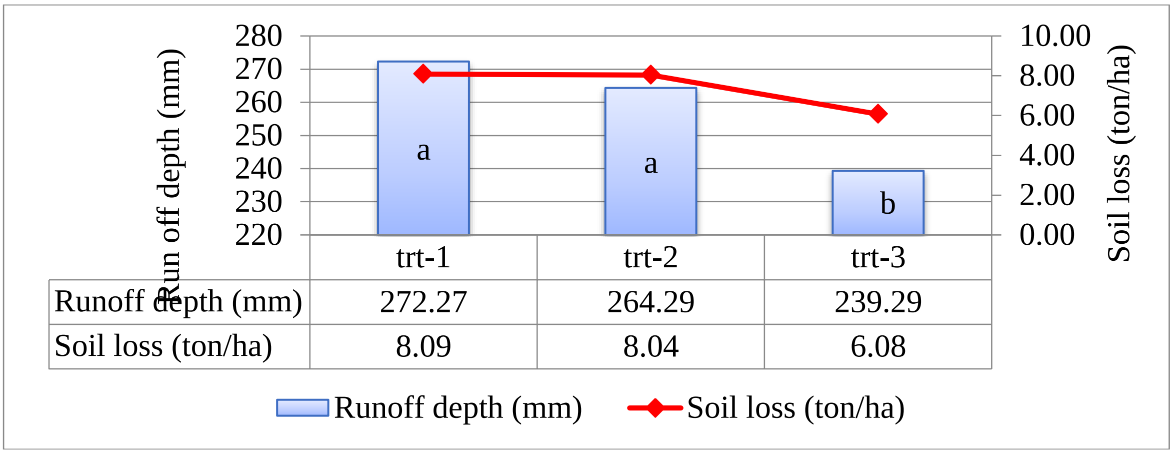


**Figure 5**. Runoff depth and soil loss amount in the year 2017 growing seasons (*Note: trt, treatment; different superscript letters in the same column represents significant differences (P<0.05)*).

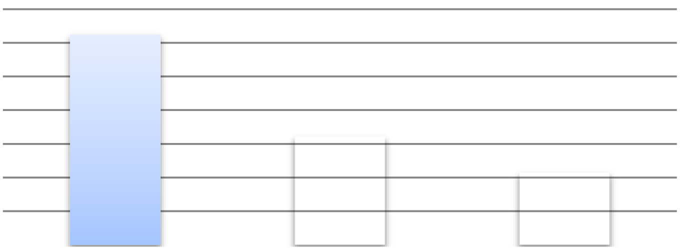

**Figure 6**. Runoff depth and soil loss amount in the year 2018 growing seasons (*Note: trt, treatment; different superscript letters in the same column represents significant differences (P<0.05*), *Means followed by the same letter in the same column are not significantly different at P = 0.05.*)

***The effect of soil drainage methods on soil moisture content***

Moisture data was taken from mid-august onward at the depth of 0-20 cm to observe if there is a difference in water content of the soil for different drainage methods corresponding to the amount of runoff drained out. The highest soil moisture content that (50.7%) was recorded in the RF-40 cm*40 cm drainage method and the lowest (45.5%) was also from the BBF-120 cm*40 cm land preparation technique for soil drainage. The reduced moisture from BBF-120 cm*40 cm in the above case could be attributed to reduced surface storage capacity because the surface was relatively smooth and then excess runoff was drained. A real difference in soil moisture content was observed among the treatments during the periods when there was optimum rainfall that enables runoff to occur. On an average basis, treatment three (RF-40 cm*40 cm) have retained higher moisture content up to 20 cm soil depth (29%) than treatment one (BBF-120 cm*40 cm) which retains 27.4%. This situation might be due to higher infiltration and lower loss of rainwater through runoff in treatment three (RF-40 cm*40 cm) than treatment one (BBF-120 cm*40 cm). The lower the capacity of drainage methods to drain excess water, the more opportunity for water to be stored on created micro depressions of the treatment with higher drainage density (Zhao *et al.*, 2014). After the period that rainfall declined, no more excess water is occurring then accordingly the difference in moisture content of the soil for each treatment gone insignificant. The lowest moisture content and highest runoff in the high rainy period from BBF-120 cm*40 cm indicated that this method enhanced surface drainage by removing more excess rainfall than BBF-80 cm*40 cm and RF-40 cm*40cm. Soil moisture content (MC) of each drainage methods at different dates of the growing season is shown in Figure 8.

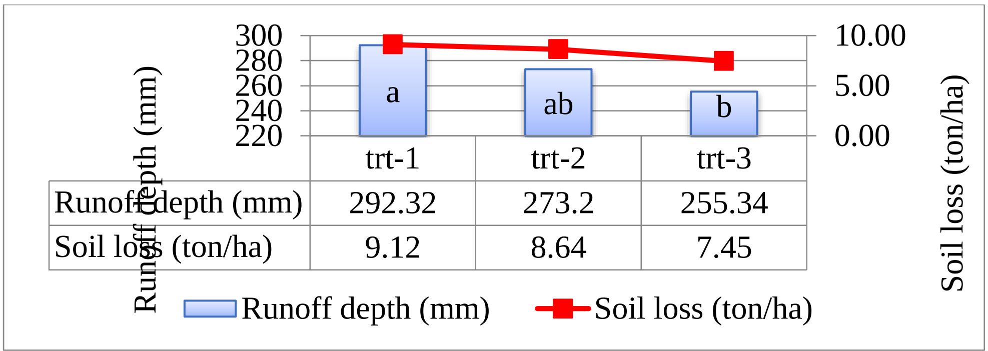


**Figure 7**. the two years average of runoff depth and soil loss amount (*Note: trt, treatment; different superscript letters in the same column represents significant differences (P<0.05)*).

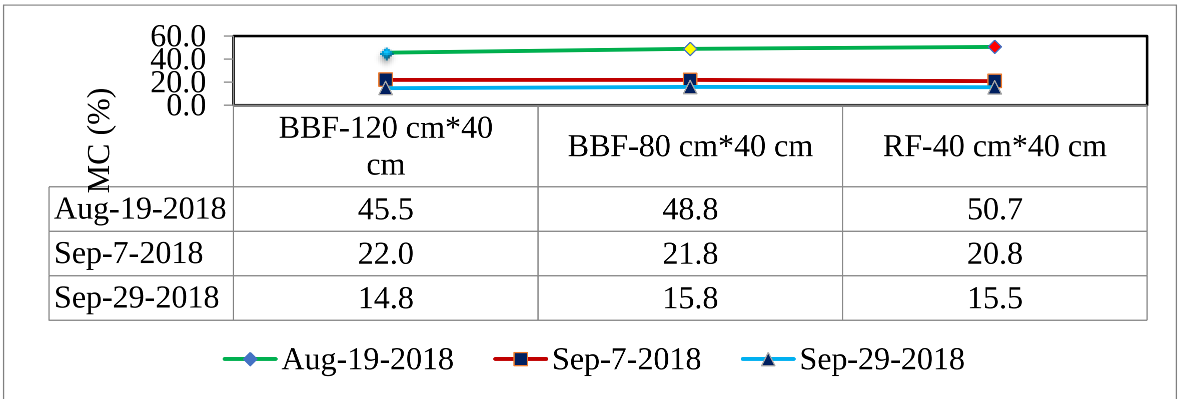


**Figure 8**. Soil moisture content (MC) of each drainage methods at different dates of the growing season

### *The effect of soil drainage methods on crop yield*

As shown in Table 2, The two years (2017 and 2018) and combined analysis of grain and biomass yields of wheat were significantly affected (P<0.05) by the land preparation methods.

The grain yield of wheat ranged from 1744 to 2669 kg ha $^{1}$ while the biomass yield ranged from 4544 to 6704 kg ha $^{1}$. BBF-120 cm*40 cm treatment gave the highest mean grain yield and biomass of wheat (2669.0 kg ha$^{-1}$, 6704 kg ha$^{-1}$) followed by BBF-80 cm*40 cm (2207.5 kg ha$^{-1}$, 5847 kg ha$^{-1}$) while RF-40 cm*40 cm gave the lowest grain yield (1744.30 kg ha$^{-1}$, 4544 kg ha$^{-1}$) respectively. The relatively low wheat biomass and grain yield performance from treatment three (RF-40 cm*40 cm) could attributed to size of productive area that is lost for drainage purpose (Table 3) and the capacity of the method to drain excess water. The more facilitation of BBF-120 cm*40 cm to drain excess water and advantage of limiting number of furrows gave an opportunity of saving more land on which crops were grown. Consequently,

m grain yield of wheat recorded from trt-1 (BBF-120 cm*40 cm) than trt-3 three (RF-40 cm*40 cm) over the two experimental years.

**Table 2**. Grain yield (kg/ha), Biomass (kg/ha), and Plant height (cm) of 2017/18 and combined results

| | | | |
|---|---|---|---|
| - | **2734** | **2604** | ***2669*** |
| - | **2032** | **2383** | |
| - | | | |

Although significantly different biomass and grain yield was observed among treatments, the

(result not shown). The reason for the situation is due to that variety trials on wheat in this area are not tracked in a similar technique of data collection. In this experiment the beds were different in size, so taking a sample only on selected beds was impossible, then whole plot (48m$^2$) was harvested for agronomic data analysis. Unlike we did to take harvested data, breeders in that area took a sample on the small size (0.6m$^2$~0.8m$^2$) or one bed for each treatment during their study with same test crop. In this case, the exaggerated yield performance might be reported when converted from small size to a hectare of land; on the other hand, taking whole plot for data analysis tells the

field but yield looks lower when compared with a data taken from small plot size (Jearakongman *et al.*, 2003). As shown in Table 2, Treatment one (BBF-120 cm*40 cm) showed 17.3% and 34.6% grain yield advantage of wheat over Treatment two (BBF-80 cm*40 cm) and Treatment three (RF-40 cm*40 cm) respectively. As enhanced drainage is a requirement for successful crop production on Vertisol, these methods might improve crop productivity as well.

As shown in Table 3,
crops were not growing on rather used to drain excess water was varied in a range from 18.2% to 45.5% of the total cropland. When using BBF-120 cm*40 cm much more land (81.8%) is occupied by beds of which crops were grow than the area (18.2%) used to construct furrows for drainage purposes. The land lost due to furrows coupled with the capacity of land preparation methods to drain excess water on flatlands has resulted in lowest grain yield from BBF-40 cm*40 cm followed by BBF-80 cm*40 cm but the highest mean grain yield and biomass was observed from BBF-120 cm*40 cm. It is contributed to the unintended saving of more land to raise crops on the land treated with BBF-120 cm*40 cm which allows better advantage of draining excess rainfall. It further indicates BBF 120cm*40cm enables to grow crops on additional 27.3% (Table 3) land when compared with BBF 40cm*40cm that causes significant land loss due to much area engagement by furrows.

**Table 3**. Land proportion occupied by crops and furrows for different soil drainage methods

| | Harvestable area | Area lost by furrows (%) |
|---|---|---|
| BBF-120cm*40cm | 44 | |
| BBF-80cm*40cm | 44 | |
| RF-40cm*40cm | 44 | |

**Conclusions and Recommendation**

The rainfall of about 55.04%, 51.44 %, and 48.08% was converted to runoff from BBF-120 cm*40 cm, BBF-80 cm*40 and RF-40 cm*40 cm respectively. So, the runoff coefficient was accounted for more than 50% of the seasonal rainfall for the first two drainage methods. This indicates the capacity to drain excess water and feasibility of water harvesting systems for irrigation purpose during early harvesting periods. The treatments resulted in significantly different runoff volumes, trt-1 (BBF-120 cm*40 cm), and trt-2 (BBF-80 cm*40 cm) can save more land on which crops can grow well and induced more excess water to enhance surface drainage than trt-3 (RF-40 cm*40 cm). This contributed to the significant increase in grain and biomass yield of wheat grown using these methods. On the other hand, it was observed that all drainage methods showed a tolerable tendency to cause soil loss in the study area.

The finding in general revealed that trt-1 (BBF-120 cm*40 cm) gave the highest mean grain yield and biomass of wheat; and it could potentially drain excess rainfall without causing significant soil loss. The capacity of draining more runoff is desirable to tackle the major problem of the study area which is surface waterlogging. So, trt-1 (BBF-120 cm*40 cm) is the best option for draining excess runoff and accordingly maximizing crop yields of wheat. Besides, further study is required on water harvesting systems to enhance vertisol productivity through using the drained water for irrigation in the study area and other eastern Amhara highland areas with similar farming system and agro-ecologies.

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