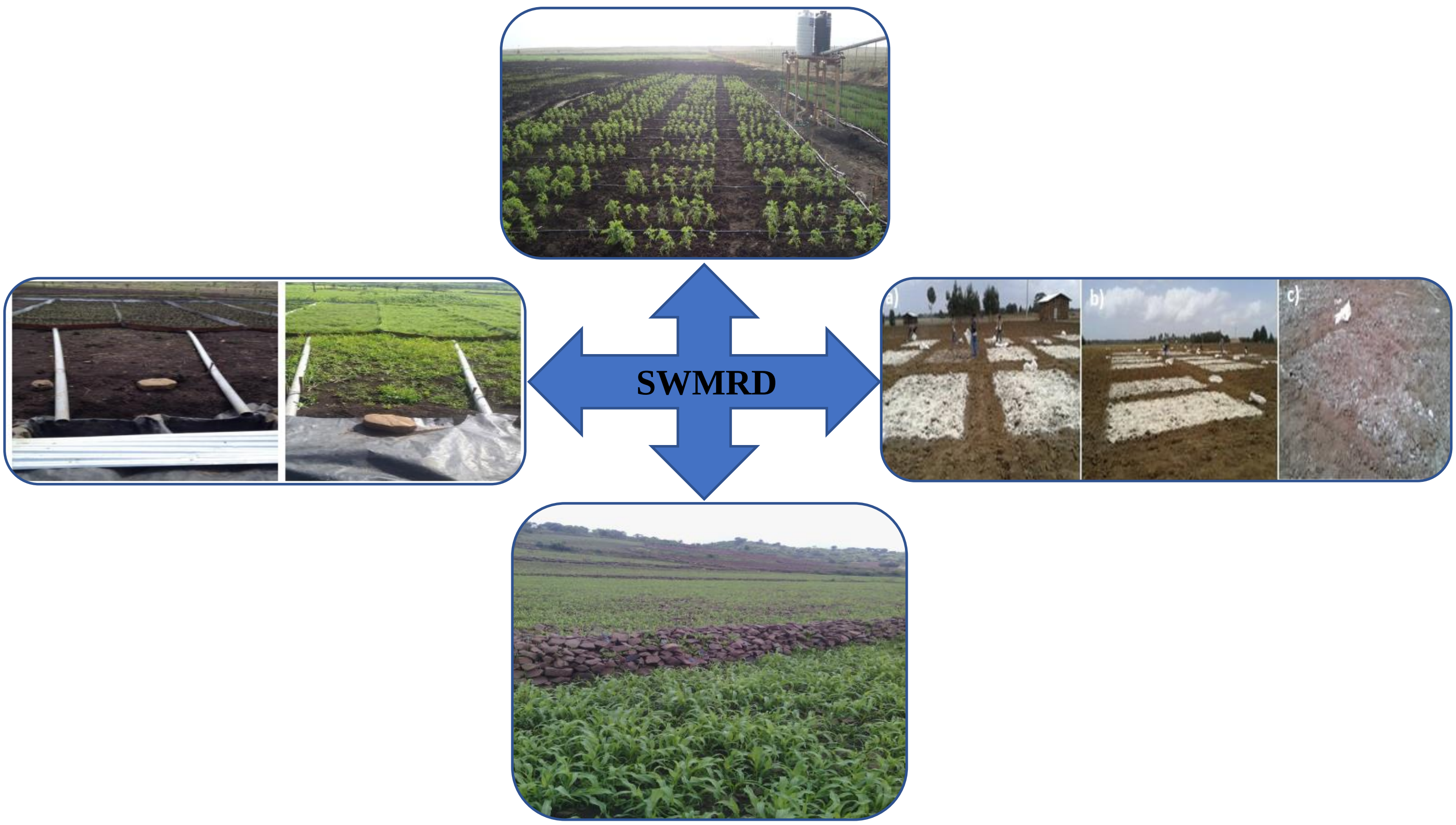
AMHARA REGIONAL AGRICULTURAL RESEARCH INSTITUTE (ARARI)

Proceedings of the 9th and 10th Annual Regional Conferences on Completed Research Activities on Soil and Water Management Research March, 10–20, 2015 and Feb., 16–23, 2016, Bahir Dar, Ethiopia



Editors

Hailu Kendie Addis

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Hailu Kendie Addis

Tesfaye Feyisa Beyene

Amhara Regional Agricultural Research Institute
P.O. Box: 527
Bahir Dar, Ethiopia
Tel: +251(0)58 220 6400
Fax: +251(0)58 226 6077
Website: www.arari.gov.et
Email: arari@ethionet.et

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Restoration of Degraded Highlands through *Acacia Decurrens* Plantation and Its Impact on Selected Soil Properties: The Case of Fagta Lekoma District in Northwestern Ethiopia

Tadele Amare*, Anteneh Abewa and Asmare Wubet

Adet Agricultural Research Center, P.O. Box 08, Bahir Dar, Ethiopia

*Corresponding author: email: tadele17b@yahoo.com

Abstract

A new and innovative form of Acacia decurrens plantation is started at Fagta-Lakuma district of the Amhara National Regional State near a decade ago. It is expanding with high rates within the district and to the neighboring districts. This study was conducted to assess the impact of this plantation and associated activities (charcoal production) on soil properties. A total of 96 soil samples were collected from adjacent cropland and land under Acacia decurrens plantation that range from 1 to 4 years old. In addition, 43 soil samples were collected from charcoal making points. For each soil sample, correspondingly core samples were collected to determine the soil bulk density. Soil samples were analyzed following standard laboratory procedures for each parameter at Adet Agricultural Research Center. The finding of this research is based only on a single rotation of Acacia decurrens plantation (maximum 4 years). The plantation is improving the soil property progressively including the soil organic carbon (2.48% on cultivated land and 3.08% on 4th year plantation) even if the system is new and with a single rotation; its positive effect could be higher for more rotations than the current values with a single rotation. In the study area, the proportion of land under charcoal making was found about 10.3% per hectare. The soil pH from charcoal making points was higher by about a unit and the available phosphorus by 120% over the adjacent non-heated soil samples (both samples acacia field). Based on this finding, it can be concluded that the expansion of A. decurrens in the degraded highlands could be considered as an option for sustainable land management practice.

Keywords: *Decurrens, soil organic carbon, soil pH, available phosphorus, Fagta Lekoma*

Introduction

Land degradation is a chronic problem in the highlands of Ethiopia; contributing its own parts for the current complex ecological, economic and social problems. Deforestation is part of land degradation which is a serious challenge in Ethiopia. Gete, (2000) reported that in the highlands of Gojam (Anjeni and its surrounding), the forest cover declined from 27% in 1957 to 0.3% in 1995. Deforestation negatively affects the ecosystem services including available water, agricultural productivity (soil fertility, soil loss), biodiversity, fuelwood, and fuelwood and wood products. Hurni *et al.* (2005) estimated a run off of 5-30 times higher in the highlands of Ethiopia after the clearing of the original forest that results in a negative impact at local, regional and national levels.

The loss of forest cover in Ethiopia caused mainly by 1) high rates land use change from forest to cropland because of population pressure (Zeleke and Hurni, 2001; Hurni *et al.*, 2005) and, 2) Fuelwood and charcoal are major energy sources derived from forest (Mondal et al., 2018). The gap between demand and supply for fuelwood in Ethiopia is very high, resulting in continuous degradations of the natural forest which is a general challenge in sub-Saharan African countries (Kutsch *et al.*, 2011; Msuya *et al.*, 2011; Oguntunde *et al.*, 2008). Forest degradation in Ethiopian highlands has been more severe than the lowlands because of low population pressure for the latter case. However, its current state of degradation in the lowlands is not any less than the highlands. As a result, there is an increasing energy insecurity crisis as a natural forest is the major sources of firewood and charcoal. This situation helps to expand of eucalyptus in the mid to highlands of the country including to the productive soils.

Ethiopia has been working towards sustainable energy self-sufficiency with a minimum impact on the environment (Finance and Development, 2010). Restoration of the degraded landscapes through plantation is one of the focuses of the country with multiple ecosystem services including fuelwood supply to the rural communities. Interestingly, an innovative form of *A. decurrens* plantation has been evolved recently in Fagta Lekoma district of the Amhara National Regional State (Figure 1) that directly or indirectly supports the strategy of the country towards environmental management and energy expansion. Gojam highland is one of the water towers of the country and it is under serious degradation (Simane *et al.*, 2013). Fortunately, the new form of *A. decurrens* is evolved in one of the districts of Gojam highland and expands with fast rates to every corner of the neighboring districts that may have a positive contribution to water management. The driving force for this innovation and fast expansion are: due to an increase demands of charcoal (about 6% annually) (Mondal *et al.*, 2018), poor crop productivity related to soil acidity and excellent performances of *A. decurrens* for the environment. *A. decurrens* (green wattle acacia) is originated in Australia and grows very well in many tropical areas (Kodela, 2001). It is tolerant to frost (Hakim and Miyakawa, 2015) which is one of the problems in the highlands for the adaptation of tree and shrub crops. Besides, Tegegne (2007) reported that *A. decurrens* is adaptable to both Vertisols and Nitisols of Ethiopia with higher biomass compared to other multipurpose tree species.

Figure 1. Expansion of *A. decurrens* in to other land uses (Amare, 2015)

The new form plantation in the highlands of Gojam is used for only charcoal production with the density of trees about 18000 ha^{-1}. There are two types of plantations exercised over the study area: 1) Sole plantations in the degraded grazing lands and hillsides, 2) together with annual crops mainly with Tefff (*Eragrostis Teff*) in the form of intercropping (during the first year), and during the second year of the plantation, grasses grow very well and used as feed sources for the livestock. Starting from year three there is a complete canopy cover and no undergrowth (grass) mainly due to shading effect. Plantation reaches for harvest to produce charcoal at the age of 5 years. Because of the high population density (innovated by the community) and excellent performance of the species in the study area, high biomass is produced. Charcoals are produced at the sites of the plantation at multiple charcoal making points depending on the size of the plantation. This distribution helps for the management of the charcoal production process and it is part of the innovation made by the community. These charcoal making spots are parts that could not be separated from *A. decurrens* plantations as they have substantial area coverage. These charcoal producing spots may affect the soil properties as reported by Kutsch *et al.* (2011), Msuya *et al.* (2011) and Oguntunde *et al.* (2008). Despite the expansion of the plantation with high rates, there is a lack of empirical evidence about the associated impacts of on soil properties for its further regional and national scale expansions. Therefore, the specific objectives of the research were to evaluate trends of soil properties at different ages of plantation against the adjacent crop lands and assess the trends of soil properties along with the charcoal making spots

Materials and Methods

The study sites

The research was conducted at Fagita Lekoma district, Awi zone of the Amhara National Regional State (Figure 2). The district is characterized by a high and uni-modal type of rainfall. High soil degradation (soil-acidity) with low crop productivity has been the major challenge of agriculture and food security. The farming system is a mixed crop-livestock and subsistence with high rates of current shift to *A. decurrens* plantation. The population of the district is 126,367 with a density of 193.40 per square kilometer (CSA, 2007).

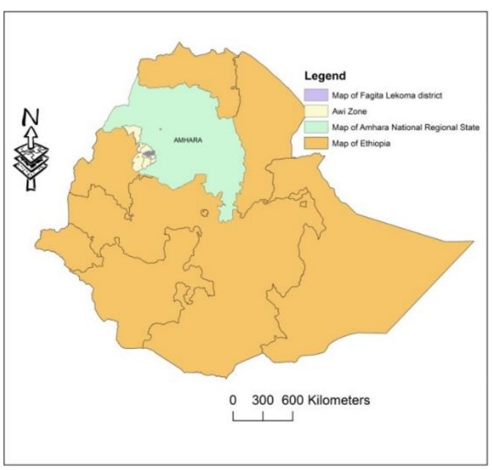

Figure 2. Location of the study site

Soil sampling procedures

The research comprised of two sets of independent activities as briefly indicated below.

Effects of A. decurrens at different ages of plantation compared to cropland on soil properties

The study was conducted at five sites that have different ages of the plantation (1 to 4 years) and cultivated land (cropland) adjacent to each other. For each site, two sampling points were selected and from each point, soil samples were collected at two soil depths (0 to 15 and 15 to 30 cm) per ages of the plantations (1 to 4 years) as well as cultivated land that made 20 samples per site. However, at site five it was impossible to get cultivated land as the site was completely covered by *A. decurrens*. All in all, a total of 96 soil samples were collected for the analysis of soil organic carbon, pH and cation exchange capacity. Correspondingly for each core samples were collected for the analysis of the bulk density and moisture status.

Distributions and effect of charcoal production spots (sites) on soil properties

To evaluate and quantify the effect of the charcoal production process on selected soil properties, soil samples were collected from charcoal production spots/sites/. The study was superimposed from ten sites where charcoal was produced with a maximum of a month before soil sampling and the sites were undisturbed. The general procedures of charcoal production and its associated activities in the district are shown in Figure 3.

Figure 3. Charcoal production and associated activities. Numbers in the figure show: (1) Harvesting of plantation at age of 5 year; (2) leaf-debris; (3-6) charcoal production process; (7) charcoal marketing, (8) Soils after charcoal production and the major target of this study and (9) ploughing after 5 years of plantation for the planation of annual crops with *Acacia decurrens*.

From each site, four soil samples (two from heated and two from adjacent non-heated) were collected from 0 to 15 and 15 to 30 cm depths for the determination of some selected soil properties: pH, SOC, available P (P-Olsen) and bulk density. Forty soil samples that are independent of activity 1 one was collected. Leaf litters, charcoals, and other debris were removed before soil sampling. The size of the land for each sampling site was measured. The numbers of charcoal making points were also counted, and their corresponding area was calculated based on the formula of a circle: A=πr^2 as the shape of charcoal producing points were circular. Where A= area of charcoal making points, π is pi or 3.14 and r is the radius of the charcoal making points. Finally, areas of charcoal making points were summed together to calculate their percentage (heated areas) per the sampling site.

Soil preparations and analysis

All collected soil samples were analyzed at Adet Agricultural Research Center. The samples were air dried under shade, ground using pestle and mortar, and sieved to pass through 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). The organic carbon content was determined by wet digestion method using the Walkley and Black procedure (Nelson and Sommers, 1982). Available phosphorus was determined following the Olsen procedure (Olsen and Sommers, 1982). The cation exchange capacity (CEC) was determined after extraction of the samples with 1N ammonium acetate at pH 7. The soil moisture content was determined following a gravimetric procedure with the formula:

$$\text{Percent moisture (weight)} = \frac{(\text{A} - \text{B})100}{\text{B} - \text{weight of tin}}$$

Where: A is weight of air-dry soil and B is weight of oven-dry soil in grams (Sertsu and Bekele, 2000).

Data analysis

The impacts of independent variables such as the age of plantation and soil heating on soil properties were statistically evaluated. Analysis of variance (ANOVA) was carried out to evaluate the presence of a significant difference between and among treatments. For variables showing a statistically significant difference between treatments ($p<0.05$), further analysis of mean separation was carried out using the Least Significant Difference (LSD) at 5% probability.

Results and Discussion

Effects of *A. decurrens* at different ages of plantation and cropland on soil properties

The highest mean soil organic carbon (SOC) (3.08 %) was found from A. decurrens plantation of 4 years old (Table 1 and Figure 4) followed by the first year and second year with the lowest from the third year. The amount of SOC even under A. decurrens is still lower that may be improved in the long run up on increasing the number of rotations over time. Because the sites were selected from only one rotation as it is a new introduction to the area. Moreover, the earliest plantations including some of the sampling sites for this study were used to plantations as they were less attractive for annual crop production because its acidity and hence croplands used as a comparison of this study were better off before plantation making some ups and downs. The result of this research is encouraging as compared to the long-term impacts of physical soil conservation measures alone (Amare *et al.*, 2013; Amare, 2018). SOC content of the cultivated land is better than soil under all ages of acacia, because plantation at site 1 was mainly done on the degraded soils although its current expansion is too fertile as well as irrigable soil. However, SOC sequestration potential of the degraded soil is much higher than soils with higher amounts of SOC upon implementing prudent rehabilitation of the degraded soils (Minasny *et al.*, 2017).

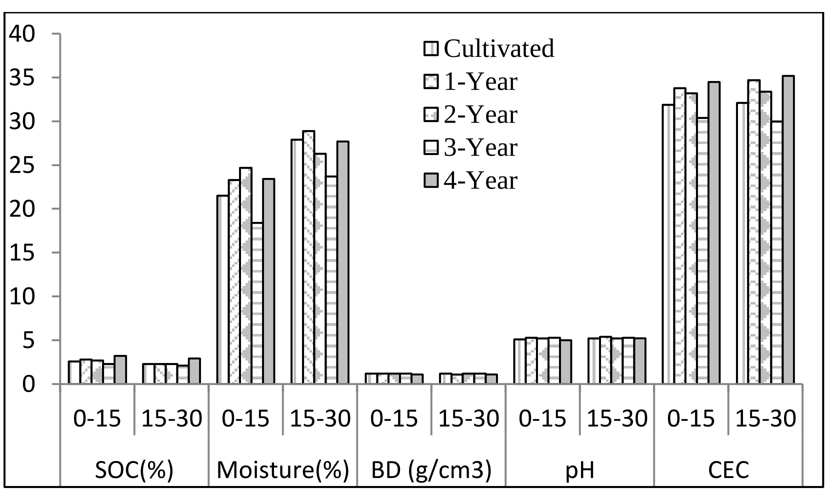

Figure 4. The effect of depth (cm) on soil properties for different ages of plantation and cropland

Table 1. Soil response to different ages of *A. decurrens* compared to cropland

Parameter	Treatment	Site-1	Site-2	Site-3	Site-4	Site-5	Mean
SOC (%)	Cultivated	2.38	2.19	3.13	2.21	-	2.48
	1-Year	0.82	2.59	3.84	4.21	1.30	2.55
	2-Year	1.02	2.58	4.04	2.45	2.46	2.51
	3-Year	1.42	2.61	3.18	2.64	1.35	2.24
	4-Year	1.35	2.32	3.28	6.03	2.40	3.08
	LSD (5%)	0.79	NS	0.5	1.7	NS	NS
pH (H2O)	Cultivated	5.11	5.12	5.18	5.16	-	5.14
	1-Year	5.62	5.31	5.00	5.23	5.53	5.34
	2-Year	5.48	5.03	4.92	5.28	5.31	5.20
	3-Year	5.32	5.14	5.17	5.43	5.34	5.28
	4-Year	5.08	5.12	5.01	5.13	5.03	5.07
	LSD (5%)	0.29	NS	NS	NS	NS	NS
CEC (meq/100g)	Cultivated	35.99	32.00	32.68	27.28	-	31.99
	1-Year	27.54	33.84	37.13	40.83	31.94	34.26
	2-Year	29.97	31.62	38.55	36.56	29.70	33.28
	3-Year	28.23	32.86	32.40	35.62	21.70	30.16
	4-Year	32.61	31.25	35.78	44.37	30.35	34.87
	LSD (5%)	3.24	NS	NS	7.8	2.2	NS

The result of this research indicates that the newly introduced large scale plantation may be one of the best strategies to SLM to restore the degraded lands and improve soil health. Moreover, it is the best approach and practice towards soil carbon management and to mitigate climate change. Similarly, a trend of soil bulk density was reduced as the age of plantation advanced (Figure 4) and better than the cultivated land. Its implication in the long run for repeated rotations plantations the soil health could be significantly improved as bulk density is one of the soil quality indicators. The effect of plantation on the cation exchange capacity of the soil similarly improved with the age of the plantation and better than cultivated land as indicated in Figure 4. The effect on pH and moisture content was also positive compared to adjacent cultivated land and could be considered as best SLM practice that improves the ecosystem sustainably. No significant effect was observed within the sampling depths (0-15 and 15-30 cm). Tegegne (2007) found a substantial contribution of A. decurrens to improve soil fertility at depths below 30 cm. The same author reported 5.97 kg foliage per tree advantage of A. decurrens over E. globulus that could be used for the restoration of the soil fertility upon decomposing.

Effect of charcoal production spots (sites) on soil properties

The shapes of charcoal production spots were found circular with a radius that ranges from 3 to 4.2 meter and a mean of 3.6 meters. The density of these charcoal making spots found to be about 25 per hectare and their proportion was about 10.3% which is a substantial size compared to the size reported by Chidumayo (1993) in Zambia with a total area of 1026 square meter (10.3% of a hectare) which is a significant proportion. The analysis for the number of charcoals making points as well as its area coverage was based on the only first single harvest. Nevertheless, the practice is expected to repeat at least every five years on the same field that increases the density of charcoal making points and associated effects on the soil. Available P and pH were significantly increased in the heated soils compared to adjusted non-heated soil. The effect was higher in the upper 0 to 15 cm depth than the lower 15 to 30 cm depth (Figure 5, 6 and 7). The effect of heating resulted in a change of 0.6 unit of pH that is about the effects of applying 2.4 ton lime per hectare (Figure 5). While looking at the effects of heating on soil properties at 0 to 15 cm and 15 to 30 cm depths separately, both pH and available phosphorus were significantly higher in the upper parts than the lower parts.

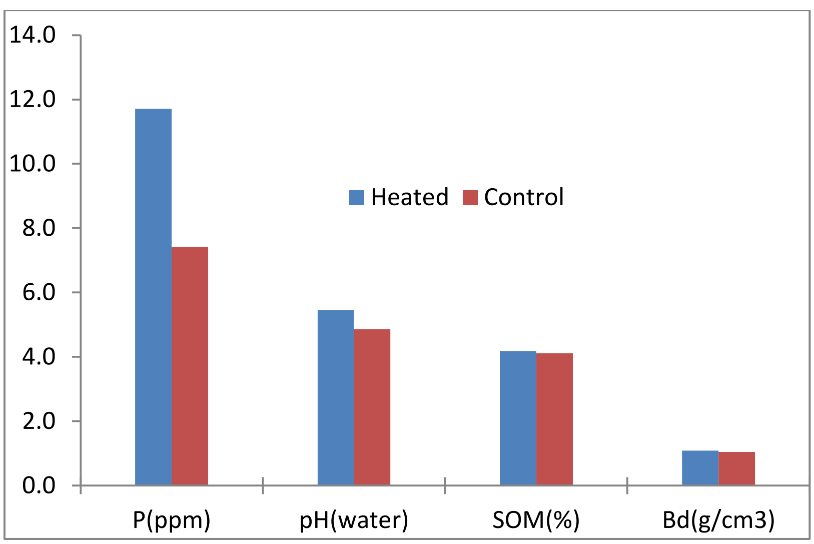

Figure 5. Effects of heating on selected soil properties (the mean values of depths)

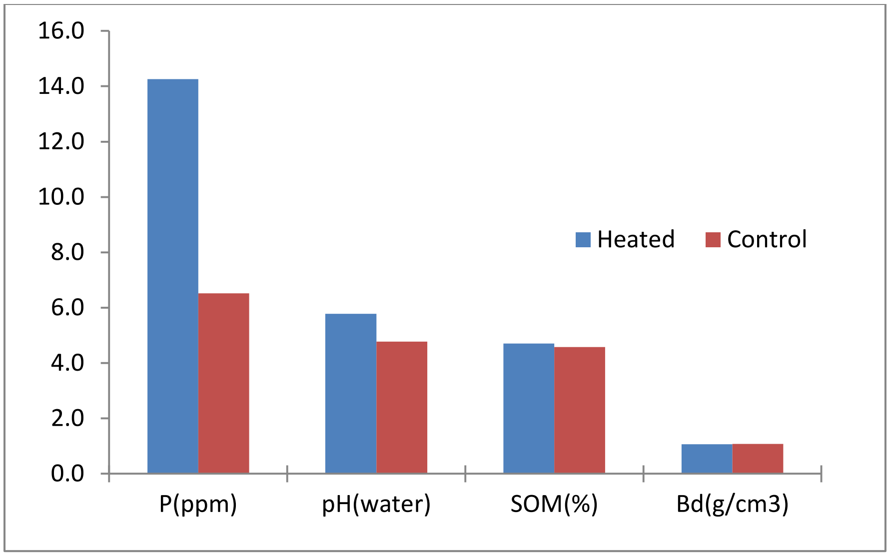

Figure 6. Effect of heating on selected soil properties at 0 to15 cm soil depth

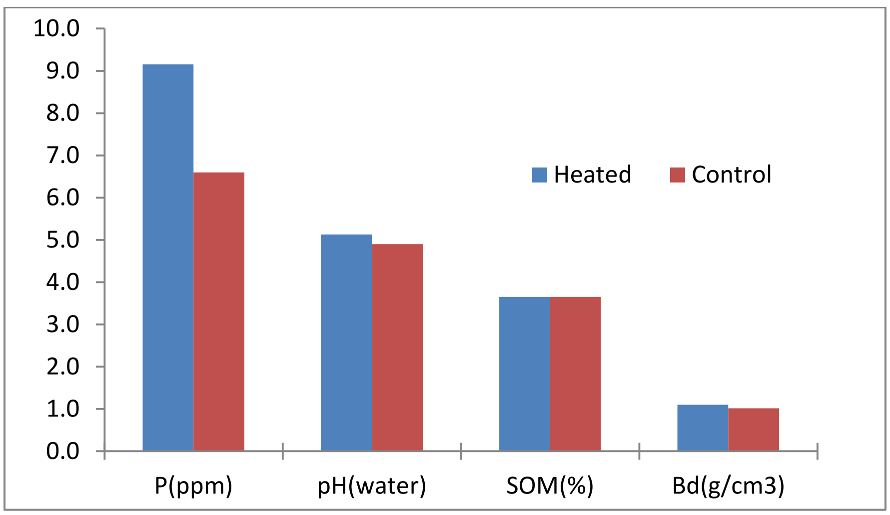

Figure 7. Effect of heating on selected soil properties at 15 to 30 cm soil depth

Available phosphorus from heated soil was increased by 120% as compared to the non-heated one while the pH increased by one unit that is about the effects of the application of four ton of lime per hectare (Figure 6). For the lower parts of the soil depth (15-30 cm) the effect of heating resulted in an increase of 39% of available phosphorus and 0.2 unit of pH over the non-heated one (Figure 7). The implication of this research finding is important in the acid soil where a low level of available phosphorus and low pH are among the challenges for crop productivity. The "guie" system in the central highlands of Ethiopia similarly increased the pH and available phosphorus but significantly reduced SOC (Amare *et al.*, 2013). The finding of this research is in line with the findings of Wahabu *et al.* (2015) who reported the positive effect of charcoal production on soil pH while SOC was negatively affected in their findings may be due to different degree of exposure to heat. In our research, the effect of heating on SOC and bulk density was not significant at all depths (Figure 5-7).

Conclusion and Recommendation

A new and innovative form of A. decurrens plantation started nearly a decade ago in the degraded and acidic areas where annual crop production has been a great challenge. Its innovation was started at Fagta Lekoma district in the highlands of Gojam and expanding to the neighboring districts. The finding of this research indicated plantation of A. decurrens in the degraded landscapes of the study area and the associated activities (charcoal production spots) improved soil-based ecosystem services including SOC with single harvest (rotation) (5 years). This ecosystem service may be sustainably and continuously improved upon increased the number of plantations (rotations) per field. The implication of the finding is a win-win situation of natural resources management on one hand and energy supply on the other hand with A. decurrens plantation. Its shallow root depth makes it one of the best advantages to shifting to any land use systems when and where needed. Therefore, this innovative form of sustainable land management practice is ecologically and technically sound for large scale regional and national promotion of the innovation with similar ecological niches of the study area to curve the current situation of land degradation and energy crises. Further study is needed to find out the best ecological niches of A. decurrens and to find other alternative provenances and/or species to the lowlands where forest degradation is resulting in critical shortages of fuelwood and wood products. The long-term impacts of this innovative land use system on ecosystem services including on restoration and stock of soil organic carbon, soil micro-organisms, native flora, and biodiversity must be monitored. Access to efficient charcoal producing technologies and alternative uses of A. decurrens need a further strategy. Regular monitoring and protecting the misuse of potential areas (fertile land and irrigation areas) that could be used for food crops production is important.

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Crops Response to Balanced Nutrient Application in Northwestern Ethiopia

Tadele Amare[1]*, Zerfu Bazie[1], Erkihun Alemu[1], Asmare Wubet[1], Birhanu Agumas[2], Mengistu Muche[1], Tesfaye Feyisa,[2] Desalew Fentie[3] and Mequanint Andualem[3]

[1]Adet Agricultural Research Center, P.O.Box 08, Bahir Dar, Ethiopia,

[2]Amhara Agricultural Research Institute (ARARI), P.O.Box 527, Bahir Dar, Ethiopia,

[3] Finote-selam Research sub-center

[*]Corresponding author email: tadele17b@yahoo.com

Abstract

Enhancing crop productivity through soil fertility management mainly by the use of synthetic fertilizers has got prior attention in Ethiopia. Recently a soil fertility map of the Amhara National Regional State developed by Ethiopian Ministry of Agriculture and Natural Resources (MoANR) and Agricultural Transformation Agency (ATA) indicates that in addition to the conventional nitrogen and phosphorus containing fertilizers (urea and DAP), the demand of potassium, sulfur, zinc, boron and other micronutrients containing synthetic fertilizers. This research was designed to validate the developed soil fertility map with a response of major cereal crops (maize, Teff, and wheat) at Burie-womberma, Debre-Elias, Enemey, South Achefer, and Yilmana Densa districts to the application of potassium, zinc and boron-containing fertilizers depicted on the map. The findings of the research showed that nitrogen and phosphorus are still the most yield-limiting nutrients. The response to potassium was observed under rare cases that did not fit with the developed soil fertility map, but the finding was verified for one year and those rare cases were not observed. Application of zinc and boron-containing fertilizers didn't show any significant yield advantage, indicating that fertilizers containing NPS nutrients with a major focus of NP are sufficient. Under the Vertisols (Bichena), NPSZnBK (nitrogen, phosphorus, sulfur, zinc boron and potassium) containing fertilizer was showing a yield advantage over NP fertilizer, but upon verification of the findings of the two-years experiments with simple treatments there was no significant effect of the potassium, zinc and boron fertilizer over NPS alone. Based on the findings of this research, zinc, boron, and potassium are not yield limiting nutrients for the study areas and crops. Therefore, potassium, zinc and boron fertilizers recommended by the fertility map of the region shall not be used anywhere without research-based field verification and recommendations. Furthermore, we recommend monitoring on the status of plant nutrients in the soil and crop responses to potassium, zinc and boron fertilizers every 5 to 10 years.

Keywords: *Balanced fertilizer, Potassium, Zinc, Boron, Micro nutrients, Soil fertility map*

Introduction

In Ethiopia, agricultural growth and development is crucial to overall economic and social development. However, this economy has been seriously affected by the steadily growing population that partly played its contribution to unsustainable land management practices (Berry, 2003). According to Nega and Degfe (1999), the population of Ethiopia doubled from 23 to 48 million between 1960 and 1990 and it jumped over 105 million in 2018 (Ethiopian main index, 2018). Ensuring food security for the steadily growing population will continue to be a major challenge unless a strategy is in place to reverse the situations. Improving and maintaining the productivity of the soil resource sustainably is one of Ethiopia's strategies to achieve its food self-sufficiency. Ethiopia’s Growth and Transformation Plan (GTP) recognizes the importance of fertilizer for maintaining soil fertility and maximizing agricultural growth of the country.

In Ethiopia, commercial fertilizer uses in the form of urea and DAP started in the 1960s (Murphy, 1968). Through time, site-specific nitrogen and phosphorus recommendations have been developed for the major soils and major cereal crops of the Amhara Region as these nutrients have been the most yield-limiting under all ecologies and most of the soils in the region. DAP and urea were the only synthetic fertilizers that were imported and used all over the country until 2015 when DAP was replaced by NPS. In Ethiopia, there has been a general lack of crop responses for potassium with the exception of reports by Haile (2011) in southern Ethiopia. On the other hand, a negative input and output balance of plant nutrients of Ethiopian agricultural soils have been reported (Scoones and Toulmin, 1999; Zeleke *et al.*, 2010), that needs a continuous assessment on the state of plant nutrients in the soil that are not currently yield limiting for sustainable food production in the country. Nutrient mining and unbalanced fertilizer use resulted in a multi-nutrient deficiency of Ethiopian soils (Haile, 2011; Asgelil *et al.*, 2007; Astatke *et al.*, 2004). Demand towards balanced and blending fertilizer is growing in several countries including in China (Zhang, 2014).

Ethiopian Soil Information System (EthioSIS) was initiated by the Ministry of Agriculture and Natural Resources (MoANR) in collaboration with Agricultural Transformation Agency (ATA) to develop and disseminate appropriate soil management recommendations and soil health information to nationwide including the Amhara Regional State. Accordingly, the soil fertility maps of the region were developed in 2013 and the final version was released in 2016 (MoANR and ATA, 2016). The map shows 100% of the soil in the region needs nitrogen, phosphorus and sulfur fertilizers; 94% of the soil needs potassium and boron fertilizers while for zinc and copper fertilizers 50.8% and 0.7%; respectively.

Developing the soil fertility map of the country strongly supports the efforts towards sustainable soil fertility management including for location-specific fertilizer recommendations. However, the ground truth for the developed soil fertility map must be verified and supported by field experiments prior to its broad recommendations and applications so as to avoid unnecessary use of fertilizers. Therefore, this research was carried out to validate the response of crops to potassium, zinc, and boron that are recommended by the soil fertility map of the region developed by MoANR and ATA (2016).

Materials and Methods

Description of the study area

The study was conducted on farmers' fields of Debre Elias, Enemey, South Achefer, Yilmana Densa and Womberma districts of the western Amhara Region where maize; Teff and wheat productions are prominent. The districts are among the most productive areas of the country. The responses of maize (South Achefer and Womberma), bread wheat (Debre Elias and Womberma) and Teff (Enemey and Yilmana Densa) were studied. Maize and wheat were tested under the Nitisols while Teff was tested both on Nitisols and Vertisols.

Soil fertility map of ANRS and treatment set up

The soil fertility map of the Amhara National Regional State was developed by the Ministry of Agriculture and Natural Resources (MoANR) in collaboration with Ethiopian Agricultural Transformation Agency (ATA) in 2013 for selected districts and in 2016 for the whole districts of the region (Figure 1). The responsibility of the Amhara Regional Agricultural Research Institute (ARARI) was to validate the response of major cereal crops to potassium, zinc, and boron-containing fertilizers (Table 1) proposed by the developed soil fertility map of the region. This paper presents the research work for the northwestern parts of the region. Economically recommended urea and di-ammonium phosphate (DAP) fertilizer rate for each crop was included in the treatment set up and compared with potassium, zinc and boron-containing fertilizers. The recommended nitrogen rate was kept constant (Table 1, Table 2). Nitrogen was applied half at planting and half at about 30 to 45 days after planting while the whole dose of other nutrients was applied at planting. Crop management practices were kept uniform for all treatments. The experiment was conducted for two consecutive rainy seasons (2014/15 and 2015/16).

BH540 and BH660 for maize, TAY for wheat and kuncho for Teff were the varieties used for the study. For maize, the population was 44 444/ha with a spacing of 30 cm between plants and 75 cm between rows. Wheat and Teff were planted in rows with seed rates of 125 kg/ha and 10 kg/ha, respectively. A randomized complete block design was used for all the crops. Major agronomic data including grain yield were collected. The grain weight and moisture content of wheat and maize were simultaneously taken and finally adjusted to 12.5% moisture content. Collected data were subjected to the analysis of variance (ANOVA) using SAS software (SAS, 2003).

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. 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 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 Sommers, 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).

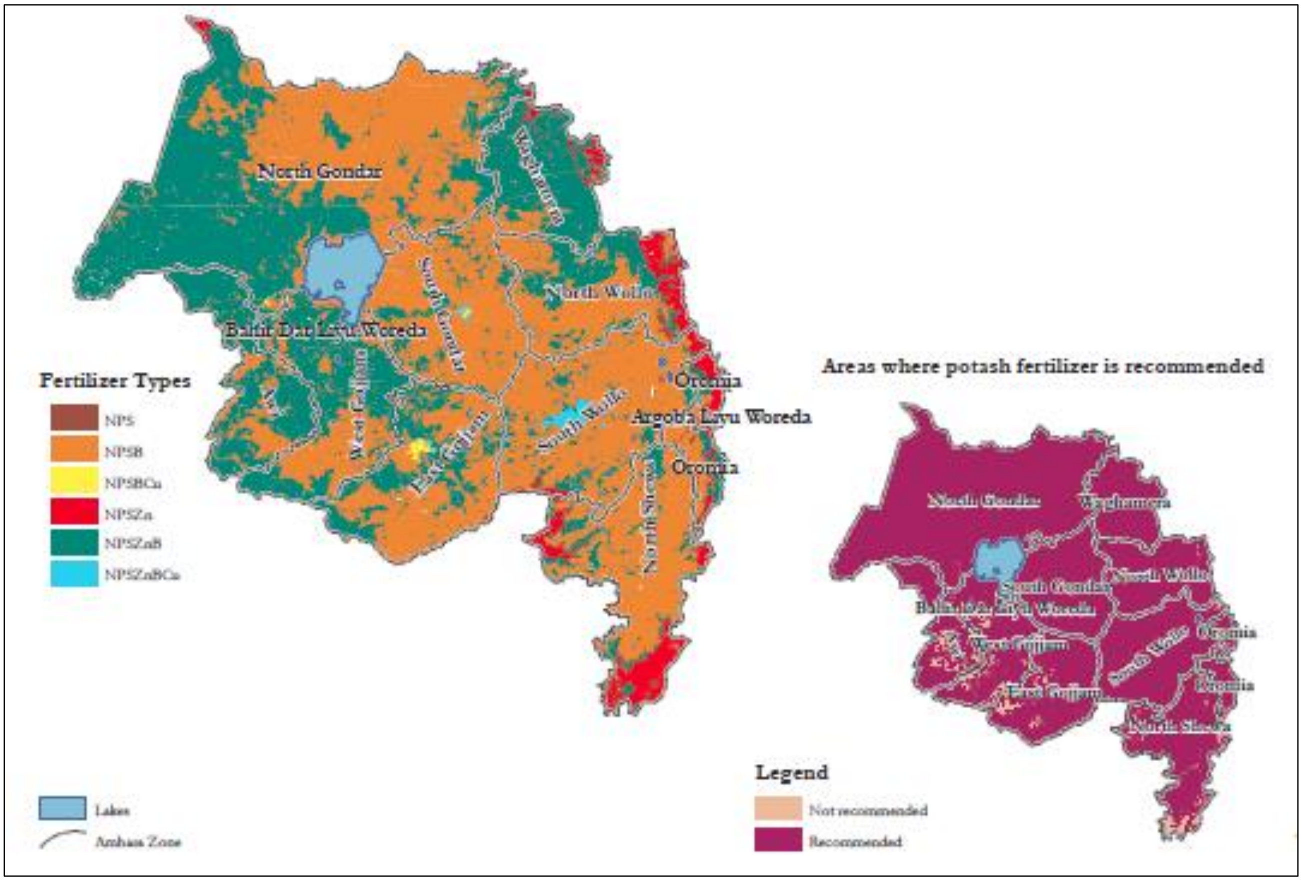

Figure 1. Recommended fertilizers for Amhara National Regional State (MoA and ATA, 2016)

Table 2. Formulas and the nutrient contents

Formula	Formulation (% nutrient composition)	Source of fertilizer
1 (NPS)	19N-38P_2O_5-7S	19 N-38 P_2O_5+7S
2 (NPSB)	18.1N-36.1-P_2O_5-6.7S- 0.71B	95 kg NPS+4.9 kg Borax
3 (NPSKB)	13.7N-27.4P_2O_5-14.4K_2O-5.1S-0.54B	72.2 kg NPS+24.1kg KCl+3.7 kg Borax
4 (NPSZnB)	16.9N-33.8P_2O_5 -7.3S-2.23Zn-0.67B	90 kg NPS +5.5kg ZnSO4+4.5 Kg Borax
5 (NPKSZnB)	13N-26.1P_2O_5-13.7K_2O-5.6S-1.72Zn-0.51B	68.7 kg NPS+22.9kg KCl+4.84kg ZnSO4 + 3.5 Borax
6 (Formula 4 modified)	17.5 N-34.9P_2O_5-7.6S - 2.23Zn -0.25B	89.38 kgNPS+6.4kg ZnSO4+1.7 kg Borax
7 (Formula 5 Modified)	13N-26.1P_2O_5-14.8K_2O-5.6S-1.72Zn-0.25B	68.7kg NPS+24.74 kg KCl+4.9kg $ZnSO_4$+1.7 kg Borax

Table 2. Treatment setups for the test crops at specific districts

Fertilizer formula	Fertilizer types and amounts (kg/ha) *						
	Maize		Teff			Wheat	
	South Achefer	Burie-Womberma	Yilmana Densa		Bichena	Burie-Womberma	Debre Elias
	Nitisols	Nitisols	Nitisols	Vertisols	Vertisols	Nitisols	Nitisols
1 (NPS)	250 (176)	250 (176)	-	-	-	-	150 (260)
2 (NPSB)	150 (220)	150 (220)	150 (50)	100 (50)	100 (146)	150 (260)	150 (260)
3 (NPSKB)	-	-	-	-	-	-	200 (262)
4 (NPSZnB)	150 (220)	150 (220)	150 (53)	100 (53)	100 (137)	150 (260)	150 (260)
5 (NPKSZnB)	150 (235)	150 (235)	200 (47)	150 (47)	150 (132)	150 (275)	-
6(Formula 4 modified)	250 (185)	250 (185)	200 (32)	150 (32)	150 (117)	200 (245)	200 (262)
7(Formula 5 Modified)	250 (208)	250 (208)	200 (33)	200 (33)	200 (118)	200 (263)	200 (262)

* Numbers in parenthesis indicate the amount of urea in kg/ha top-dressed in addition to the specified amounts of formula. The vacant (-) indicates that specific formula was not used.

Results and Discussion

Maize

As shown in Table 3, Table 4 and Table 5, maize did not respond to applied fertilizers containing potassium, zinc, and boron. On the other hand, the yield was highly variable within short distances for both Achefer and Burie-Womberma districts where a single soil type (Nitisols) is dominating with similar rainfall patterns of each district. A rare observation of response to potassium, zinc, and boron-containing fertilizers could not support for general recommendations as it was observed in Aferefida of south Achefer. At Aferefida in south Achefer, the maximum yield of maize (7350 kg/ha) was obtained from higher rates of potassium (Table 4) which was a rare case for the two years across all the study sites that maize response to applied potassium was observed. Of course, the exchangeable soil potassium of Aferefida site was lower (0.43meq/100g soil) than Ahuri (1.12 meq/100g soil) a very nearby site; both of them are above 0.25 meq/100g which is the critical value based on ammonium acetate extraction (IPI, 2016). At this site, the second highest yield (6310 kg /ha) was obtained from the lowest rate of phosphorus but with the addition of potassium. Nevertheless, this response was a single observation that was not repeated across our experimentation (Table, 3, 4, and 5). Moreover, intensive research verification with simple treatment setups (with and without potassium, zinc, and boron) showed a non-significant result (Tadele et. al., 2018). The overall result of the research is in line with findings reported by Tadele et al. (2008), but it did not support the soil fertility map developed by the MoANR and ATA (2016) for the Amhara Region. It rather intended to respond for higher rates of nitrogen and phosphorus fertilizer rates. A recent ongoing research result on maize (unpublished) in south Achefer showed that a grain yield of maize greater than 10000 kg/ha with nitrogen and phosphorus alone (with 150 kg N/ha and 125 kg P_2O_5).

Therefore, potassium application does not pay any significant yield increase of maize as the supply of the soil is presently sufficient. However, research should continue monitoring on the state of soil potassium and maize response to potassium application in case it becomes a yield-limiting nutrient sometime in the future. Experiences from countries including China show that potassium fertilizer application started very late as compared to nitrogen and phosphorus fertilizers (Portch and Jin, 2009; Zhang, 2014); while The Netherlands reached 100 kg/ha K_2O

on average in 1936 (Isherwood, 2010). Crop productivity in Ethiopia is still limited by nitrogen and phosphorus nutrients than potassium.

The yield of maize was not increased by the addition of the micronutrients (Boron and Zinc) for all sites for the two cropping seasons that also fail to prove the deficiency of the micronutrients mapped for the study areas (MoANR and ATA, 2016). The finding is in line with yield response of maize to applied micronutrients in Pakistan that only increased marginal yield (6950 kg/ha with control, 7230 kg/ha with micronutrient) as reported by Khan *et al.* (2014). Severe deficiency of micro-nutrients including boron and zinc mostly occurs for soils with higher pH values (Singaraval *et al.*, 1996) and (Zayed *et al.*, 2011) claims rice productivity in rice growing countries shows a reducing trend mainly because of micro-nutrients deficiency. In contrast, the soils where the present study carried out are Nitisols and their pH ranges from slightly acidic to acidic that does not limit the availability of micro-nutrients except molybdenum.

Table 3. Maize (Variety - HB540) yield response to balanced fertilizer at South Achefer (Year 2014/15)

	Grain yield (kg/ha)			
Treatments	Aferefida	Sibet	Layjufi	Mean
NP (200 kg Urea/ha + 200 DAP kg/ha) *	6510	4090	3700	4767
250 kg/ha Formula 1 + 176 kg/ha Urea	6430	4970	4340	5247
150 kg/ha Formula 2 + 220 kg/ha Urea	7120	5390	3840	5450
150 kg/ha Formula 4 + 220 kg/ha Urea	7380	5710	3710	5600
150 kg/ha Formula 5 + 235 kg/ha Urea	7060	6180	4580	5940
250 kg/ ha Formula 6 + 185 kg/ha Urea	6230	6300	4270	5600
LSD				NS
CV (%)				26.5

*Economical recommended rate (NP)

The northwestern parts of the region including the districts where the present research was carried out are characterized by high rainfall amounts and good distributions. Nevertheless, maize productivity is still below the expected potential of the area because of the low rate of fertilizer application. Hence, increased production and productivity of crops including maize will be realized through judicious management and utilization of nitrogen and phosphorus containing synthetic fertilizers.

Table 4. Maize (Variety - HB660) yield response to balanced fertilizer at South Achefer (Year 2015/2016)

Treatments	Grain yield (kg/ha)				
	Aferefida	Keltafa	Ahuri	Kier	Mean
NP (200 kg Urea/ha + 200 kg DAP/ha)	5980	6950	6440	4780	6038
250 kg/ha Formula 1 + 176 kg/ha Urea	4580	7050	8500	4180	6078
150 kg/ha Formula 2 + 220 kg/ha Urea	4600	6610	6690	4250	5538
150 kg/ha Formula 4 + 220 kg/ha Urea	5140	6260	7620	5323	6086
150 kg/ha Formula 5 + 235 kg/ha Urea	6310	5830	5920	5202	5816
250 kg/ ha Formula 6 + 185 kg/ha Urea	5970	6620	7220	6846	6664
250 kg/ha Formula 7 + 208 kg/ha Urea	7350	5180	5990	8129	6662
LSD					NS
CV (%)					19.8

Table 5. Maize (Variety BH 540) yield response to balanced fertilizer at Womberima (Year 2014/2015)

Treatments	Grain yield (kg/ha)					
	Sebadar	Bolden	Markuma	Wegedad	Marweld	Mean
NP (200 Urea/ha+200 kg DAP/ha)	3890	3090	4390	7080	6120	4914
250 kg/ha Formula 1+176 kg/ha Urea	5280	4180	4570	7120	5890	5408
150 kg/ha Formula 2 + 220 kg/ha Urea	5010	3100	5540	7200	5990	5368
150 kg/ha Formula 4 + 220 kg/ha Urea	6270	3670	5460	7220	4470	5418
150 kg/ha Formula 5 + 235 kg/ha Urea	4760	4050	5250	6820	5940	5364
250 kg/ ha Formula 6+185 kg/ha Urea	4060	5000	5920	7750	5550	5656
250 kg/ha Formula 7+ 208 kg/ha Urea	5360	4010	5580	6870	6450	5654
LSD (0.05)						NS
CV (%)						24.8

Bread wheat (*Triticum aestivum*)

The response of bread wheat to fertilizers containing potassium, boron, and zinc was also insignificant at both Debre Elias and Womberma Districts for the two cropping seasons (Table 6 and Table 7) that does not fit to the recently developed soil fertility map of the districts (MoANR and ATA, 2016). The result did not support the findings of bread wheat response to applied potassium by Hailu *et al.* (2017) and Astatke *et al.* (2004). They reported a significant yield increment of bread wheat for the vertisols of the central highlands of Ethiopia using potassium fertilizer. For some of the study sites, the recommended NP fertilizer was better than the ones with potassium, zinc and boron-containing fertilizers (Table 6 and 7) indicating that nitrogen and phosphorus are still the most yield-limiting nutrients than other nutrients including potassium. The verification of research with simplified treatments showed no significant yield advantage of potassium, zinc, and boron over NPS alone (Tadele et al., 2018)

There was no response to applied micro-nutrients; not supporting the soil fertility map developed for the districts. If micronutrients including zinc and boron were a very deficit as stated by the soil fertility map of the studied districts, the yield could be significantly affected as they are essential to plant nutrients. Malakouti (2008) reported that the yield of crops like durum wheat (*Triticum durum* L.) could be increased by about 50% using micro-nutrients and under very severe deficiency of the micronutrients; there could be a situation of no harvest.

Table 6. Response of bread wheat for different blended fertilizers at Womberma

Treatment	Grain yield (Kg/ha)									
	Year1					Year 2				
	Bolden	Markuma	Wegedad	Marwold	Mean	Bolden	Markuma	Wegedad	Sebadar	Mean
NP (260 kg Urea +150 kg DAP/ha) *	4170	4280	4970	4110	4383	2510	4370	3640	2900	3355
150 kg/ha Formula 2+260 kg Urea/ha	3700	4400	5440	4150	4423	2100	4490	3230	3100	3230
150 kg/ha Formula 4+260 kg Urea/ha	3710	3830	5080	2960	3895	2500	4570	3510	3050	3408
200 kg/ha Formula 6+245 kg Urea/ha	3540	4040	5240	3290	4028	2280	4510	3830	3310	3483
150 kg/ha Formula 5+275 kg Urea/ha	3730	2150	4900	4030	3703	2300	4550	3490	3220	3390
200 kg/ha Formula 7+263 kg Urea/ha	3510	3600	5120	3930	4040	2260	4460	3120	3230	3268
LSD (0.05)					NS	LSD (0.05)				NS
CV (%)					20	CV (%)				27

Table 7. Response of bread wheat for different blended fertilizers at Debre Elias

	Grain yield (kg/ha)*											
	Year 1						Year 2					
Treatments	Abe.1	Yek.	D/E.Z1	D/E.Z2	Abe.2	Mean	Abe.1	Yek.	D/E.Z1	D/E.Z2	Abe.2	Mean
NP (260 kg Urea+150 kg DAP/ha)	4800	4380	4230	3960	3110	4096	4190	4340	4070	3240	4070	3982
150 kg/ha Formula 2 + 260 kg Urea/ha	5780	3920	5110	2000	2110	3784	2950	6010	3680	3600	4320	4112
150 kg/ha Formula 4 +260 kg Urea/ha	5320	3520	4580	1840	2150	3482	3280	4390	3490	3380	4060	3720
200 kg/ha Formula 6 + 245 kg Urea/ha	5650	3270	4030	2530	1980	3492	3580	4640	2720	3320	4080	3668
150 kg/ha Formula 5+275 kg Urea/ha	5180	3690	4220	2520	2700	3662	3630	3880	3580	2300	3760	3430
200 kg/ha Formula 7+ 263 kg Urea/ha	4990	3720	3790	2070	2450	3404	4020	4330	4180	2700	4020	3850
LSD						NS	LSD					NS
CV (%)						35	CV (%)					19

* Are the study sites where: Abe.1= Abeshma 1, Yek.= Yekegat, D/E.Z1= Debre Elias zuria 1, D/E.Z2 = Debre Elias zuria 2 and Abe.2= Abeshma

Teff

Teff is one of the dominant cereal crops in northwestern parts of the Amhara National Regional State. It grows well both in the Vertisols and Nitisols. This paper presents the findings of two years of research on the response of Teff to potassium, zinc, and boron for both Nitisols and Vertisols. At Yilmana Densa district, the response of Teff to potassium, boron and zinc-containing fertilizers was insignificant (Table, 8) which did not support the 100 kg/ha potassium chloride recommendation by IPI (2016) and (MoAR and ATA, 2016). At Enemey, there was yield gain by the addition of balanced fertilizers over nitrogen and phosphorus use alone; which was significant in the first year (Table, 9); however, there was no significant difference in the second year (Table 10). However, under our verification taking NPS fertilizer as standard, there was no yield difference with the presence or absence of potassium, zinc and boron-containing fertilizers (Tadele et al., 2018). Therefore, similar to maize and wheat, potassium, zinc, and boron are not yet yield limiting for Teff in the study areas.

Table 8. Response of Teff for different blended fertilizers at Yilmana Densa (Nitisols)

Grain yield (kg/ha) Treatments	Year 1	Year 2
NP (130kg DAP/ha +36 kg Urea/ha)	1840	1810
150 kg/ha Formula 2+ 50 kg/ha Urea	1710	1760
150 kg/ha Formula 4+ 53 kg/ha Urea	1840	1720
200 kg/ha Formula 5+ 47 kg/ha Urea	1970	1730
200 kg/ha Formula 6 +32 kg/ha Urea	1780	1840
200 kg/ha Formula 7+ 33 kg Urea	1850	1850
LSD	NS	NS
CV (%)	8.3	10.1

Table 9. Response of Teff for different blended fertilizers at Enemay Vertisols (Year 1)

	Grain yield (kg/ha)				
	Year1				
Treatments	Weyra	Yerez	Yezerezer	M/Birhan	Mean
NP (140 kg/ha Urea + 87 kg/ha DAP)	1960	2690	2370	1700	2180
00 kg/ha Formula 2+146 kg/ha Urea	2240	2880	2880	3220	2805
100 kg/ha Formula 4+137 kg/ha Urea	2410	2540	2520	3570	2760
150 kg/ha Formula 6 +117 kg/ha Urea	1970	2140	2620	3630	2590
150 kg/ha Formula 5 +132 kg/ha Urea	2330	3230	3180	3100	2960
200 kg/ha Formula 7 + 118 kg/ha Urea	2240	2620	2750	3210	2700
LSD (0.05)					755
CV (%)					19.1

Table 10. Response of Teff for different blended fertilizers at Enemay Vertisols (Year 2)

Treatments	Grain yield (kg/ha)				
	Year 2				
	Weyra	Yerez	Yezerezer	M/Birhan	Mean
NP (140 kg/ha Urea + 87 kg/ha DAP)	1500	2160	2930	2420	2253
100 kg/ha Formula 2+146 kg/ha Urea	2200	1990	3060	3280	2633
100 kg/ha Formula 4+137 kg/ha Urea	1770	2260	2460	3140	2408
150 kg/ha Formula 6 +117 kg/ha Urea	2350	1710	2440	3020	2380
150 kg/ha Formula 5 +132 kg/ha Urea	2130	1500	3020	3220	2468
200 kg/ha Formula 7 + 118 kg/ha Urea	2190	1820	3200	3470	2670
LSD (0.05)					NS
CV (%)					26.8

Soil analysis results

In general, the response of crops to potassium, zinc and boron-containing fertilizers did not agree with the recommendation made by the fertility map of the Amhara National Regional State (MoANR and ATA, 2016). The exchangeable potassium (cmol(+)/kg) for the study sites was ranged south Achefer (0.77 to 1.40), Debre Elias (1.3 to 1.45), Enemay (1.22 to 1.44), Yilmana Densa (0.91 to 1.31) and Burie-Womberma (0.93 to1.34). For all the sites the lowest values are above three times the critical values of exchangeable potassium (0.25 cmol/kg) based on ammonium extraction methods (IPI, 2016) indicating a finding of crop responses was strongly justifiable.

The problem of the map with potassium may be associated with the introduction of 0.7:1 correction factor exchangeable potassium to exchangeable magnesium based on (Loide, 2004). The research finding of (Loide, 2004) was about liming materials and their effects on the respective exchangeable base ratios including potassium to magnesium which is less relevant to our system. Interestingly, more than 90% of the region is in the range of optimum without the introduction of the correction factor; then 94% of the soil of the region converted to potassium deficiency with the correction factor (MoANR and ATA, 2016). Moreover, the critical limits used to map the map are the major ones that affect the quality of the map. For example, MoANR and ATA, (2016) used a wider range as well as higher values of exchangeable potassium (190 - 600 mg/kg equivalent to 0.49 to 1.54 cmol/kg).

The pH of the soil for the study sites was below 6 except for Enemay that ranges from 6.8 to 7.4. Therefore, the cost of sustainable soil health in addition to crop responses must be considered upon applying zinc and boron based on the soil fertility map of the region (MoANR and ATA, 2016) under these acidic soils as the cumulative effect of these nutrients matter. The soil organic carbon content for most of the soils was below 2% which is the critical point (Murphy, 2014) that rather needs an integrated soil fertility management. The total nitrogen was in the range from less than 0.1% to 0.29% (low to very low ranges), while the available phosphorus for most of the sites was below 10 ppm.

Conclusions

The research was conducted in agriculturally potential districts of the northwestern Amhara National Regional State (Burie-womberma, Debre-Elias, Enemay, South Achefer, and Yilmana Densa) to evaluate the response of major cereal crops (maize, wheat and Teff) to fertilizers that contain boron, potassium and zinc plant nutrients. The findings of the research for crops under all districts with respect to the addition of fertilizer including potassium containing ones did not show any significant yield advantage that did not justify the recommendations made by the recently developed soil fertility map of the region. The soil fertility map of the region jumped into conclusions and recommendations of fertilizers with less or no ground truth of crop responses for potassium, zinc and boron fertilizers. Recommending fertilizer without any yield advantage will hurt the economy of the country in general and the poor Ethiopian farmers in particular. Fertilizer recommendation for nutrient maintenance and build up without any yield advantage could not be accepted by our poor and subsistence farmers. Accordingly, the northwestern parts of the Amhara National Regional State should focus only on urea and NPS fertilizers. There is no option for NPS as DAP is completely out of the Ethiopian market. We do not have any proof of NPS is better than DAP. Assessment on the long-term effect of fertilizer types including NPS on soil acidity shall be considered. It will not be sure with this research finding how long will the soil support to supply sufficient amounts of potassium and micro-nutrients and hence continuous assessment of the status of soils for these nutrients and crop responses are critically important.

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Nitrogen and Phosphorus Rate Determination for Sorghum Production in Wag-Lasta, North Eastern Ethiopia

Workat Sebnie* and Merse Mengesha

Sekota Dry-Land Agricultural Research Center, P.O Box 62 Sekota, Ethiopia

*Corresponding author email: workat71@yahoo.com

Abstract

Continuous cultivation of land became a common practice in major sorghum producing areas of Ethiopia, which eventually led to soil fertility decline and subsequent reduction of crop yields indicating importance of using inorganic fertilizers to enhance crop yield. A field experiment was conducted at Lasta and Sekota districts, Eastern Amhara, Ethiopia, to evaluate the effects of application of different rates of nitrogen and phosphorous fertilizers on yield and yield components of Sorghum (Sorghum bicolor L.*). Four rates of nitrogen (0, 23, 46, 69, kg N ha^{-1}) and three rates of phosphorous (0, 23, 46, kg P_2O_5 ha^{-1}) were arranged in Randomized Complete Block Design (RCBD) with three replications in a factorial arrangement. All phosphorus and half nitrogen were applied at planting while half nitrogen was applied at knee height. Composite soil samples were collected from 0-20 cm depth and major nutrient contents were determined following standard laboratory procedures. Agronomic data were collected and subjected to statistical analysis using statistical analysis software. Significant treatment means were separated using least significant difference LSD at 5%. Nitrogen and phosphorus showed significant effects on yield and yield components of sorghum. Application of 46 kg N and 23 kg P_2O_5 ha^{-1} increased sorghum yield by about 60.37% compared with the control. Therefore, application of 46 kg P_2O_5 and 23 kg N ha^{-1} was recommended for sorghum production at Sekota and similar agro-ecologies. While, application of 23 N kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} was recommended for sorghum production at Lalibella and similar agro-ecologies.*

Keywords: *Fertilizer, nitrogen, phosphorus, sorghum, yield.*

Introduction

Globally, sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal crop after maize, rice, wheat and barley (Faostat, 2014). It is an important crop staple food crop in the semi-arid tropics of Africa, South Asia and Central America (Mbwika *et al.*, 2011). In Ethiopia, sorghum is a major staple food crop, ranking second after maize in total production. It ranks third after wheat and maize in productivity per hectare, and after Teff and maize in area cultivated. It is grown in almost all regions, covering a total land area of 1.8 million ha (CSA, 2015). Sorghum grain is as nutritious as other cereal grains; containing about 11% water, 340 k/cal of energy, 11.6% protein, 73% carbohydrate and 3% fat by weight (Thimmaiah, 2002; Taylor *et al.*, 2006; Yan *et al.*, 2012).

Despite the large-scale production and various merits, sorghum production and productivity have been by far below the potential. Currently, the average regional productivity is 2.65 t ha^{-1} but, the study area productivity is below 1.5 t ha^{-1} which is very low as compared to other small grain cereals grown in Ethiopia (CSA, 2019). Low productivity of crops has been attributed to abiotic stress (drought and low soil fertility) and biotic stress (disease, insect and weed) (Mbwika *et al.*, 2011). Wortmann *et al.* (2006) also reported that drought, low soil fertility (nutrient deficiencies), insect stem borers, insect shoot fly, quelea birds, Striga, and weeds were recognized as major production constraints affecting sorghum in eastern Africa.

To feed the ever-increasing population and generate income, continuous cultivation of land became a common practice in major sorghum producing areas, which eventually led to soil fertility decline and subsequent reduction of crop yields. Thus, as noted by Mwangi (1995) the use of inorganic fertilizer is critical to increase crop yield. Gruhn *et al.* (1998) also suggested that, the levels of the fertilizer being used are very low and this must be increased to meet the demand for food with population growth. In Waglasta, most farmers used to produce sorghum without any input though they are advised to use the blanket recommendation (100 kg urea and 100 kg DAP) and their harvest is very minimal and couldn't support their family for more than half a year. Based on these facts the objective of this research was to determine the optimum rate of nitrogen and phosphorus fertilizer on yield and yield components of sorghum in Wag-Lasta areas.

Materials and methods

Study Area description

The study was conducted at Lalibella (Lasta district) and Aybra (Sekota district) Eastern Amhara, Ethiopia. The study site at Lasta was located at 11^o 58’ 50.15’’ N latitude and 38^o 59’ 03.22’’ E longitude at an altitude of 1966 masl (meters above sea level) while the study site at Aybra was located at 12^o 43’ 52.82’’ N and 39^o 01’22.01’’ E longitude at an altitude of 1915 masl (Figure 1).

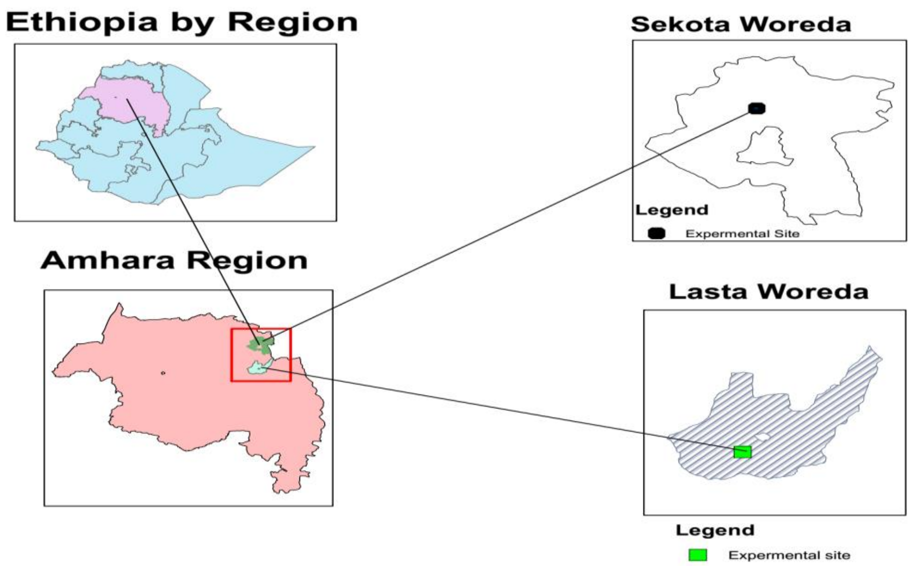

Figure 1. The experimental locations

Experimental design and treatments

The experiment was conducted during the main cropping season 2014 and 2016 at the aforementioned locations. The treatments were composed of four nitrogen levels (0, 23, 46 and 69 kg N ha^{-1}) and three phosphorous levels (0, 23 and 46 kg P_2O_5 ha^{-1}). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in a factorial arrangement. The plot size was 14.25m^2 (3.75 m X 4 m) and consisted of 5 rows and the net plot size was 9 m^2. A spacing of 0.5 m and 1 m were left between plots and blocks, respectively. The spacing of 75 cm x 15 cm was used between rows and plants, respectively and there were 26 plants per row with a total of 133 plants per plot. Urea and TSP were used as a source of nitrogen and phosphorus fertilizer, respectively. Nitrogen fertilizer was applied by split application method in the form of urea half at planting and the remaining half at 45 days after planting. Phosphorus was applied once in the form of TSP at the time of planting. Agronomic practices such as weeding, cultivation, and tie-ridging were done uniformly for all treatments whenever needed. The test sorghum variety was Miskir.

Data collection and analysis

The average plant height, length of sorghum head, the average weight of sorghum head, grain yield and above ground biomass were recorded from each plot. The data obtained were subjected to the analysis of variance using SAS statistical software version 9.0 and significant treatment effects were compared using the Fisher's Least Significant Differences test at 5% level of significance.

Partial budget analysis

The partial budget analysis was done to see the economic feasibility based on the manual developed by CIMMYT (1988). The costs include fertilizer cost and price of sorghum was collected from the study areas.

Soil sampling and analysis

Composite soil samples were collected from 0-20 cm depth using augur sampler for the determination of major soil chemical parameters following standard procedures. The soil samples were air-dried and sieved through 2 mm sieve to determine pH, EC and soil texture and through 0.5 mm sieve to determine total nitrogen and organic carbon contents. 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. Soil organic carbon was determined following the wet digestion method as described by Walkley and Black (1934) while percentage organic matter of the soils was determined by multiplying the percent organic carbon value by 1.724. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method.

Table 1. Soil analysis of the study area

Site	pH	EC dec/m	OM %	TN%	Texture			
					Sand %	Silt%	Clay%	Textural class
Lalibella	6.23	1.3	1.06	0.07	39	27	34	Clay loam
Aybra	5.96	1.8	1.09	0.084	33	32	35	Clay loam

Results and discussion

Soil properties of the study sites (Aybra and Lalibela)

The pH of the surface soil at Lalibella was 6.3 and at Aybra was 5.96. Based on Tekalign's (1991) classification, the pH of the surface soil collected from Aybra was moderately acidic and from Lasta was slightly acidic. The organic carbon and total nitrogen contents were low for both sites (Tekalign *et al.*, 1991). The low organic carbon and total nitrogen might be attributed to the continuous cultivation and removal of crop residues from the farms. The result also indicates that a lot has to be done to improve the soil organic matter, total nitrogen and other nutrient contents through organic and inorganic amendments for both sites.

Effect of nitrogen and phosphorus on sorghum yield and yield parameters at Aybra

Plant height (cm)

Nitrogen and phosphorus highly significantly ($P \leq 0.001$) affected sorghum plant height (Table 2). The tallest mean plant height was (140.01cm and 140.08 cm) was obtained from 23/46 kg N/P_2O_5 ha^{-1} which was significantly higher plant height compared to the control but at par with the other combined rates (Table 3). The result of the current study is inline with the finding of (Legesse and Gobeze, 2015) who reported nitrogen and phosphorus at the rate of 18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} with tie-ridge had a significant effect on plant growth in southern Ethiopia. Similarly, Tesfahunegn (2012) observed that nitrogen and phosphorus at the rate of 18 kg nitrogen ha^{-1} and 46 kg phosphorus ha^{-1} with in situ moisture conservation had higher plant height.

Table 2: ANOVA of the effect of N and P on sorghum yield combined over years at Aybra.

Source of variation	DF	Mean square values				
		Plant height	Panicle Length of sorghum	Panicle weight of sorghum	Grain yield	Biomass yield
N	3	1879.41**	3.96ns	922.14**	3463406.69**	246540773**
P	2	1460.56**	3.61ns	667.37**	2959677.33**	223566291**
N*P	6	186.92*	7.34ns	310.57**	373721.83**	50981317**
Rep	2	72.02ns	580.26ns	14.92ns	34422.65ns	10681603ns
Error	40	60.65	66.26	41.11	72891.91	10725818

Table 3: Effects of nitrogen and phosphorus on sorghum growth parameter at Aybra combined over years

Treatment kg ha^{-1} P_2O_5	N	Plant height (cm)	Panicle Weight of sorghum (g)
0	0	109.74^{f}	14.30^{c}
0	23	126.11^{de}	24.00^{bc}
0	46	132.26^{dc}	31.12^{abc}
0	69	134.20^{bcd}	26.02^{bc}
23	0	128.52^{de}	21.90^{bc}
23	23	141.63^{abc}	37.43^{ab}
23	46	143.79^{abc}	28.70^{bc}
23	69	146.36^{ab}	47.90^{a}
46	0	119.26^{ef}	15.81^{c}
46	23	152.30^{a}	33.75^{ab}
46	46	141.43^{abc}	33.95^{ab}
46	69	138.30^{bcd}	21.90^{bc}
LSD (0.05)		12.42	17.59
CV (%)		8.1	25

Grain yield (kg ha^{-1})

The grain yield was significantly affected by nitrogen and phosphorus rates at ($P<0.05$) (Table 2). Increasing nitrogen and phosphorus rates from 0/0 to 23/46 kg ha^{-1} increased sorghum yield from 1172 to 2959.2 kg ha^{-1} (Table 4). The highest grain yield was obtained from 23/46 kg N/P_2O_5 ha^{-1} followed by 69/23 kg N/P_2O_5 ha^{-1} and 23/46 kg N/P_2O_5 ha^{-1} while the lowest was from the control (Table 4). Application of 23/46 kg N/P_2O_5 ha^{-1} gave 60.4% grain yield advantage over the control. All nitrogen and phosphorus rates gave significant yield difference over the control implying that production of sorghum without input is wastage for the yield obtained is very low and couldn't satisfy the annual food consumption of the household. Our result is line with the finding of (Legesse and Gobeze, 2015 and Tesfahunegn, 2012) who reported that application of nitrogen fertilizer at the rate 18 kg ha^{-1} and application of phosphorus at rate 46 kg ha^{-1} increased the grain yield of sorghum significantly. Similarly, research done by Gebrekidan (2003) showed that application of 46 P_2O_5 and 18 N with tie-ridge increased sorghum grain yield by 15-38% in the moisture stress areas of Eastern Ethiopia.

Biomass yield (kg ha^{-1})

Sorghum biomass yield was significantly ($P< 0.05$) affected by different rates of Nitrogen and Phosphorus (Table 5). The highest biomass yield (13731.5 kg ha^{-1}) was recorded at the rate of 69/23 kg N/P_2O_5 ha^{-1} followed by 46/23 kg N/P_2O_5 ha^{-1}, 69/46 N/P_2O_5 ha^{-1} and 23/46 N/P_2O_5 ha^{-1} whereas the lowest biomass yield (5086.5 kg ha^{-1}) was recorded from the control (Table 5). The biomass yield is very important because the leaves and stalks are used for cattle feed during the long dry season (Birhane, 2012).

Partial budget analysis

The partial budget analysis showed that application of 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} had the highest net benefit (16,523.46 ETB ha^{-1}) with MRR of 2276 % followed by 46 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} with net benefit 13086.94 birr ha^{-1} and MMR of 509% (Table 6). The budget analysis showed that by incurring one Ethiopian birr, the producer can gain 22.76 and 5.09 additional Ethiopian Birr respectively.

Effect of nitrogen and phosphorus rates on sorghum yield and yield parameters at Lalibella

Plant height (cm)

Nitrogen and phosphorus rates highly significantly ($P \leq 0.001$) affected sorghum plant height (Table 7). Application of 69/46 kg N/P_2O_5 ha^{-1} gave the highest plant height (Table 8). The increment in plant height due to nitrogen application could be attributed to the effect of nitrogen on cell division and elongation which lead to growth and increased height of the stems and leaves (Rabinowitch and Currah, 2002). The result of this study is in line with the findings of Gebremariam and Assefa, (2015) who reported significant effect of nitrogen at a rate of 69 kg ha^{-1} on plant growth in northern Ethiopia. Similarly Legesse and Gobeze (2015) also observed that 69 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 had significant effect on height of sorghum plant.

Table 4. Effect of nitrogen and phosphorus on grain yield (kg/ha) of sorghum at Sekota (Aybra) combined over year

	P_2O_5 level (kg ha^{-1})		
N level (kg ha^{-1})	0	23	46
0	1172.5[e]	1507.1[de]	1559.0[d]
23	2104.0[c]	2293.8[bc]	2959.2[a]
46	1480.2[de]	2404.9[bc]	2111.3[c]
69	1656.5[d]	2546.2[b]	2301.2[bc]
	LSD (5%)	348.99	
	CV (%)	15.04	

Table 5. Effect of nitrogen and phosphorus on biomass yield (kg/ha) of sorghum at Sekota (Aybra)

	P level (kg ha^{-1})		
N level (Kg ha^{-1})	0	23	46
0	5086.3[g]	7126.6[f]	7433.2[f]
23	9048.0[e]	10810.9[cd]	12018.8[bcd]
46	10679.4[d]	13407.4[ab]	11382.2[cd]
69	9058.6[e]	13731.5[a]	12151.0[ab]
	$LSD_{5\%}$	1410	
	CV %	12.01	

Gain yield

The grain yield was significantly affected by the application rates of Nitrogen and Phosphorus fertilizers at ($P<0.05$) at Laibella (Table 9). The highest grain yield (3888.3 kg ha^{-1}) was obtained from the plots receiving 69/23 kg N/P_2O_5 ha^{-1} while the lowest grain yield (1698.4 kg ha^{-1}) was obtained from the control (no NP). However, the highest grain yield obtained from the plots applied with 69/23 kg N/P_2O_5 ha^{-1} was at par with that obtained from the plots which received 46/23, 23/23 and 23/46 kg N/P_2O_5 ha^{-1}. The sorghum grain yield obtained from the application of 69/23 and 46/23 kg N/P_2O_5 was higher by 2189.9 kg (128.9%) and 2148 kg (126.6%) over the control. The result is in agreement with the findings of (Masebo and Menamo, 2016) who reported sorghum grain yield increment due to increased application of N and P. Similarly, Ashiona *et al.* (2005) also reported that increasing rate of nitrogen had increased sorghum grain yield.

Table 6. Partial budget analysis at Sekota (Aybra)

P2O5	N	Unadjusted yield	Adjusted	Gross benefit	Costs that varies	Net benefit	MRR%
0	0	1172.5	1055.25	7386.75	0	7386.75	
0	23	2104	1893.6	13255.2	608.5	9256.52	307.12
23	0	1507.1	1356.39	9494.73	755.5	8739.23	D
0	46	1480.2	1332.18	9325.26	1217	8108.26	D
23	23	2293.8	2064.42	14450.94	1364	13086.94	507
46	0	1559	1403.1	9821.7	1511	8310.7	D
0	69	1656.5	1490.85	10435.95	1825.5	8610.45	D
23	46	2404.9	2164.41	15150.87	1972.5	13178.37	15.03
46	23	2959.2	2663.28	18642.96	2119.5	16523.46	2275.57
23	69	2546.2	2291.58	16041.06	2581	13460.06	D
46	46	2111.3	1900.17	13301.19	2728	10573.19	D
46	69	2301.2	2071.08	14497.56	3336.5	11161.06	D

Table 7. ANOVA for N and P on the plant height, sorghum head length, head weight, grain yield and biomass at Lalibella Combined over years

Source of variation	DF	Mean square values		
		Plant Height	Grain Yield	Biomass Yield
N	3	1185.19**	10591267.03***	140261599.0**
P	2	152.80**	1267516.55**	1058796.5*
N*P	6	170.91**	1010479.64**	7253023.4**
Year	1	4402.58**	23109478.2**	483484.8*
Rep	2	25.98ns	81695.80ns	296755.9ns
Error	40	660.77	41557.58	458748.6

Biomass yield

Sorghum biomass yield was significantly ($P< 0.05$) affected by different rates of Nitrogen and Phosphorus fertilizers (Table 10). The highest biomass yield (24924 kg ha^{-1}) was recorded from the application of 69/23 kg N-P_2O_5 ha^{-1} followed by the biomass yield recorded from 46/46, 23/23 and 23/46 kg N-P_2O_5 ha^{-1}. While the lowest biomass yield (8993 kg ha^{-1}) was recorded from the control (no NP). Application of the combination of NP fertilizer increased sorghum biomass yield by 91% - 177% over the control.

Table 8. Effect of nitrogen and phosphorus on sorghum grain yield (kg/ha) at Lalibella

Treatment	Plant height (cm)			Length of sorghum head (cm)			Weight of sorghum head (g)		
N kg ha^{-1}	1st year	2nd year	Comb	1st year	2nd year	Comb	1st year	2nd year	Combined
0	140.80^{b}	156.69^{d}	149.17^{d}	19.11^{b}	18.63^{c}	18.87^{b}	40.12^{c}	44.60^{b}	42.96^{b}
23	146.78^{b}	161.73^{c}	156.50^{c}	19.51^{ab}	20.42^{b}	19.96^{a}	55.48^{a}	47.28^{b}	50.39^{a}
46	154.44^{a}	171.07^{b}	163.97^{b}	19.46^{ab}	21.11^{ab}	20.28^{a}	42.92^{bc}	54.60^{a}	48.74^{a}
69	154.46^{a}	179.26^{a}	167.38^{a}	19.95^{a}	21.44^{a}	20.70^{a}	44.13^{b}	56.37^{a}	49.11^{a}
LSD $_{0.05}$	6.48	3.43	2.73	0.83	0.93	0.73	2.94	4.04	4.96
P_2O_5 kg ha^{-1}									
0	146.86^{b}	165.88^{b}	157.84^{b}	19.35	20.18	19.76	45.74^{b}	47.49^{b}	46.28
23	147.93^{ab}	168.94^{a}	157.96^{b}	19.66	20.54	19.96	49.27^{a}	53.71^{a}	49.56
46	152.57^{a}	168.41^{a}	162.17^{a}	19.51	20.76	20.14	41.98^{c}	50.94^{ab}	45.39
LSD (0.05)	5.61	1.33	2.37	ns	ns	ns	2.54	3.5	ns
CV (%)	4.46	8.91	5.23	4.41	5.19	5.49	6.61	8.19	15.64

Partial budget analysis

The partial budget analysis showed that application of 23 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} had the highest net benefit (23,447.23 Birr ha^{-1}) with MRR of 1083% and followed by 23 kg N ha^{-1} with net benefit (16,269.97 Birr ha^{-1}) and MMR of 952%.

Table 9. Effect of nitrogen and phosphorus on grain yield (kg/ha) of sorghum at Lalibella

	P level (kg P_2O_5 ha^{-1})		
N level (kg ha^{-1})	0	23	46
0	1698.4^{d}	2160.2^{dc}	1718.9^{d}
23	2607.7^{bc}	3822.6^{a}	3319.6^{ab}
46	2790.0^{bc}	3846.4^{a}	2887.6^{bc}
69	2454.4^{dc}	3888.3^{a}	3293.4^{ab}
	LSD (0.05)	800.16	
	CV (%)	7.09	

Table 10. Effect of nitrogen and phosphorus on sorghum biomass yield (kg/ha) at Lalibella

N level (kg ha^{-1})	P level (kg ha^{-1})		
	0	23	46
0	8993[d]	10387[cd]	9786[d]
23	12452[bcd]	18253[ab]	18156[ab]
46	12493[bcd]	17212[bc]	18628[ab]
69	12184[bcd]	24924[a]	17554[b]
	LSD (0.05)	6983	
	CV (%)	18.55	

Table 11. Partial budget analysis at Lalibella

P	N	Unadjusted yield kg ha^{-1}	Adjusted kg ha^{-1}	Gross benefit	Cost that varies	Net benefit	MRR%
0	0	1698.4	1528.56	10959.77	0	10959.77	
0	23	2607.7	2346.93	16827.49	557.5	16269.99	952
0	46	2790	2511	18003.87	1115	16888.87	111
0	69	2454.4	2208.96	15838.24	1672.5	14165.74	D
23	0	2160.2	1944.18	13939.77	662.5	13277.27	D
23	23	3822.6	3440.34	24667.23	1220	23447.23	1083
23	46	3846.4	3461.76	24820.81	1777.5	23043.31	-72
23	69	3888.3	3499.47	25091.19	2335	22756.19	D
46	0	1718.9	1547.01	11092.06	1325	9767.06	D
46	23	3319.6	2987.64	21421.37	1882.5	19538.87	D
46	46	2887.6	2598.84	18633.68	2440	16193.68	D
46	69	3293.4	2964.06	21252.31	2997.5	18254.81	D

Conclusions and Recommendations

The result showed that Nitrogen and phosphorous fertilizers improve sorghum production and optimize farmers profit through in the study areas and similar agro-ecologies. The mean sorghum grain yield was significantly affected by NP fertilizer rates. The agronomic maximum grain yield was recorded from the application of 69/23 kg N/P_2O_5 ha^{-1} at Lalibella and from the application of 23/46 N/P_2O_5 ha^{-1} at Aybira while the economic optimum yield was obtained from the application of 23/23 N/P_2O_5 for Lasta (Lalibella) and 23/46 kg N/P_2O_5 ha^{-1} at Aybira. Hence, 23 kg P_2O_5 ha^{-1} and 23 kg N ha^{-1} was recommended for optimum sorghum yield at Lasta (Lalibella) similar agro-ecologies and 23 kg N and 46 kg P_2O_5 ha^{-1} was recommended for optimum sorghum yield at Sekota (Aybira) and similar agro-ecologies.

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Refining fertilizer recommendations for bread wheat production in South Wollo of Amhara Region

Samuel Adissie[1]*, Habtemariam Teshome[1], Abebe Get[2] and Tadese Hailu[1]

[1]Sirinka Agricultural Research Center, P.O. Box, 74, Woldia, Ethiopia

[2]Adet Agricultural Research Center, P.O. Box, 08, Bahir Dar, Ethiopia

*Corresponding author email: sammy.ab1990@gmail.com

Abstract

Bread wheat (Triticum aestivum L.) is among the most important crops produced in the highlands of Ethiopia. However, declining soil fertility due to poor management practices have resulted in low crop yield. Among the poor soil fertility management practices, a very general crop-specific guideline or more often, a blanket recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0) was practiced in most parts of the country. Accordingly, this study was conducted to examine the optimum rate of nitrogen, phosphorus and sulfur fertilizers for bread wheat under balanced fertilizers in Jamma district of South Wollo Zone, Amhara region in 2015 and 2016. The study was comprised of six levels of N, P and S studied independently under specified balanced fertilizers. The combined analysis of variance over years indicated that there was significant response of wheat grain and straw yields to the application of nitrogen fertilizer. Application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave similar yield which has grain yield advantage of 156%, 53%, 50.6% and 15.8% over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. The economic optimum rate of nitrogen for wheat grain and straw yield is the application of 115 kg/ha while it gives similar and higher agronomic optimum yield compared to the application of 138 kg/ha nitrogen in Jamma district. There is also a significant yield response for phosphorus fertilizer rate for wheat yield and the economically profitable yield response was recorded from the application of 20 kg/ha phosphorus. Whereas there was no significant yield response to sulfur fertilizer rates in Jamma district.

Keywords: Economically profitable, optimum fertilizer, wheat, yield response.

Introduction

Wheat (*Triticum aestivum* L.) is one of the major global cereal crops, ranking second after paddy rice both in area and production, and provides more nourishment than any other food crop (Curtis *et al.*, 2002). Bread wheat is one of the most important cereal crops in Ethiopia and used both as a source of food and income. It is the fourth most widely grown crop after Teff, maize, and sorghum (Motsara and Roy, 2008). Ethiopia produces 3.8 million tons of wheat per year, making it the second largest wheat producer country in Sub-Saharan Africa (SSA) next to South Africa. However, the amount of wheat produced is insufficient to meet the domestic needs, which is compelling the country to import about 25 to 35% of the annual wheat grain required for consumption (CSA, 2014).

The national annual mean wheat yield of Ethiopia was estimated at about 2.2 t/ha (CSA, 2014). Global Agricultural Information Network Number ET1401. Addis Ababa Ethiopia However, by international standards such yields are considered to be low. The Government of Ethiopia (GOE) estimates that over 4.5 million households are involved annually in wheat production, but that still does not satisfy the country's annual domestic demand. Hence, a large quantity of wheat is imported every year to meet the rising domestic consumption demand (CSA, 2014). The declining of soil fertility is a fundamental impediment to agricultural development and the major reason for the slow growth rate in food production and food insecurity in Ethiopia (Gebrekidan, 2005).

Wheat production in the country is adversely affected by low soil fertility and suboptimal use of mineral fertilizers in addition to diseases, weeds, erratic rainfall distribution in lower altitude zones, and water-logging in the Vertisols areas (Gorfu *et al.*, 2003). The root causes of the current low soil fertility problem of the country are soils of inherent low fertility; continual nutrient mining due to continues cropping without replacement of nutrients taken together with the harvest and topsoil removal through water erosion (Asnakew Woldeab, 1994). Ethiopia's fertilizer sub-sector shows that fertilizer was introduced in the 60s by higher learning institutions through limited laboratory and research activities (Murphy, 1968). In the early 70s nationwide on-farm demonstrations trials were conducted and as a result of these works a blanket rate of 100 kg ha^{-1} DAP or 50 kg ha^{-1} Urea + 100 kg DAP ha^{-1} were recommended irrespective of crop and soil types (Ho, 1992).

Current fertilizer recommendation in Ethiopia is also based on very general crop-specific guidelines or more often, a single recommendation for all crops (100 kg DAP (18-46-0) and 100 kg Urea (46-0-0). This blanket recommendation often fails to take into consideration differences in resource endowment (soil type, labor capacity, climate risk) or make allowances for dramatic changes in input/output price ratio, thereby discouraging farmers from fertilizer application. Moreover, the nutrients in the blanket recommendation are not well balanced agronomically and its continued use will gradually exhaust soil nutrient reserves. Nutrient mining due to suboptimal fertilizer use in one hand and unbalanced fertilizer use on other have favored the emergence of multi-nutrient deficiency in Ethiopian soils (Astatke *et al.*, 2004) that in part may contribute to fertilizer factor productivity decline experienced over recent past.

Therefore, neither yields nor profits can be sustained using imbalanced application of fertilizers, as the practice results in accelerating deficiencies of other soil nutrients. Since the absence of one or more nutrients besides N and P can depress yield significantly. This could explain, in part, the modest crop yield improvements observed over the last few decades in contrast to significant increases in fertilizer use and investment made in the country. Today, in addition to Nitrogen and Phosphorus fertilizers, S, B and Zn deficiencies are widespread in Ethiopian soils and some soils are also deficient in K, Cu and Mn (Astatke *et al.*, 2004; Asgelil *et al.*, 2007). To overcome the constraint of low nutrient recovery and optimize fertilizer use, there is a need to replace such general and over-simplistic fertilizer recommendations with those that are rationally differentiated according to agro-ecological zones (soils and climate), crop types, nutrient uptake requirements and socio-economic circumstances of farmers. Better matching fertilizer application recommendations to local climate, soil, and management practices help ensure that production can be intensified in a cost-effective and sustainable way and, thereby, enhance regional food security. In view of this, the present study was carried out to determine optimum Nitrogen, Phosphorus and Sulfur fertilizers response curve under balanced fertilization and to establish economic mixes of blended fertilizers for wheat.

Materials and Methods

Description of study site

The study was carried out in 2015 and 2016 main cropping seasons in Jamma District of South Wollo Zone of the Amhara Region in Ethiopia. The District is situated within the geographical boundaries of 10^o 06' 24'' - 10^o 35' 45'' N latitudes and 39^o 04' 04'' - 39^o 23' 03'' E longitudes and altitudinal ranges of 1428 - 2752 meters above sea level. Based on the last ten years (2008-2017) meteorological data obtained from Ethiopian Meteorological Agency, Kombolcha station, the district receives a mean annual rainfall of 873.0 mm with mean minimum and maximum temperatures of 10.3 and 21.6 ^oC, respectively. The range of the physico-chemical properties of surface soil (0-30 cm) of the study districted is presented in Table 1. The dominant soil type of the study District is Vertisols, and the area is characterized by poor drainage and water-logging, difficulty to work in but has a high potential for the production of wheat and Teff.

Treatments and Experimental Design

The study was conducted using six levels of Nitrogen, Phosphorus and Sulfur fertilizers each independently with balanced fertilizers rate of 69/80/30/2/1 P_2O_5/K_2O/S/Zn/B kg ha^{-1} for Nitrogen trial, 92/90/30/2/1 N/K_2O/S/Zn/B kg ha^{-1} for Phosphorus trial and 92/69/90/2/1 N/P_2O_5/K_2O/Zn/B kg ha^{-1} for Sulfur-trial for all treatments (Table 2). The treatments were laid out in a randomized complete block design (RCBD) with three replications on three representative farmers' fields in each year (2015 and 2016). The experimental plot had a gross plot size of 4 m x 3.2 m; while, the harvestable plot area was 4 m x 1.6 m.

Table 3. Range of physico-chemical properties of surface soil (0-30 cm) of Jamma District

Soil Properties	Values
pH (H_2O)	6.10-6.80
Organic matter (OM) (%)	1.36-1.92
Total Nitrogen (TN) (%)	0.09-0.31
Available P (mg kg^{-1} soil)	7.05-21.05
Exchangeable Ca ($cmol_C$ kg^{-1})	30.60-46.30
Exchangeable Mg ($cmol_C$ kg^{-1})	9.90-12.90
Exchangeable K ($cmol_C$ kg^{-1})	0.60-0.70
Cation exchange capacity (CEC) ($cmol_C$ kg^{-1})	52.00-61.70
Percent base saturation (PBS) %-	82.50-97.61
Bulk density (gm cm^{-3})	1.30-1.50
Sand %	16.3-17.5
Silt %	20.0-21.3
Clay %	62.5
Textural class	Clay

Table 4. Rates of Nitrogen, Phosphorus and Sulfur fertilizers.

Treatments	N-rates	P-rates	S-rates
1	0 N	0 P	0 S
2	46	10 P	10 S
3	69	20 P	20 S
4	92	30 P	30 S
5	115	40 P	40 S
6	138	50 P	50 S

Experimental Materials and Procedures

Bread wheat variety *Dinknesh* was used as a test crop. The test crop was planted in a row with a spacing of 20 cm between rows and seeding rate of 150 kg ha^{-1} on pre-prepared broad bed furrow which had a 0.8m bed and 0.4m furrow. The beds were used for planting of wheat and the furrows were used for draining excess water from the experimental area. Phosphorus, Potassium, and Sulfur fertilizers were applied as triple super phosphate (TSP), muriate of potash (KCl) and calcium sulfate ($CaSO_4$) straight fertilizers, respectively, in a row all at planting. Nitrogen fertilizer was applied as urea in split, half at planting and the remaining half side dressed at 45 days after planting. The micronutrients Zn as $ZnSO_4$ and B as Borax weighed in plot-level were each dissolved in tap water in a plastic container and poured into 16 liters volume spraying knapsacks and filled up with tap water up to the mark. Thereafter, water dissolved Zn and B micronutrients were applied as foliar application 50 and 60 days after planting, respectively.

Data Collection

Fresh biomass yield was measured by weighing the total above ground biomass of the entire harvestable area. The dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105 ^oC for 24 hours and adjusting the fresh biomass weight in to dry weight basis. While grain yield was measured by weighing the seed harvested from the 6.4 m^2 harvestable area and adjusted with a moisture correction factor. The straw yield was calculated by subtracting the grain yield from the dry biomass. Harvest index was calculated by dividing the grain yield by total biological yield.

Data analysis

The collected data were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS, 2004). The mixed model procedure was used for the combined analysis over the testing sites in which the only N was used as a fixed variable while site and replication were used as random variables. Since experimental sites were not fixed in the two years, the year was neither considered as a fixed or random variable. A significant difference between treatment means was delineated by Duncan's Multiple Range test (DMRT) at P<0.05. Simple nonlinear regression analysis was run using SAS to determine the goodness of fit of yield response curves. The farm gate prices of 12.00, 31.50, 62.50 Ethiopian Birr (ETB) kg^{-1} for Wheat grain, Nitrogen and Phosphorus fertilizer, respectively, were used for partial budget analysis following the CIMMYT procedure (CIMMYT, 1988). The mean grain yields used in the partial budget analysis were adjusted to 90% of the actual yield.

Results and discussion

I. Response of wheat to N fertilizer

The study showed that there were significant grain and straw yield responses to nitrogen fertilizer from three testing sites and there was also a similar trend of treatments with three sites in Jamma District in 2015 (Table 3). Thus, the combined analysis of grain yield by applying 115 kg ha^{-1} was found biologically maximum compared to the other treatments. Similarly, the combined analysis of wheat grain and straw yields in 2016 showed that application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave higher yield compared to other treatments (Table 4). From Table 5, the interaction of treatments and location over the two years on grain and straw yield was insignificant. Thus, the result revealed that nitrogen fertilizer applied in the three sites could be discussed as a combined analysis over 2015 and 2016. Accordingly, application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave similar grain yield which have 156%, 53%, 50.6% and 15.8% grain yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Similarly, application of 115 kg ha^{-1} and 138 kg ha^{-1} nitrogen gave 151%, 63%, 26.3% and 16% straw yield advantage over the control, 46 kg ha^{-1}, 69 kg ha^{-1} and 92 kg ha^{-1} nitrogen respectively.

The response of wheat to nitrogen fertilizer in this study was accredited to the low total nitrogen (0.09-0.31%) in the surface soil of the study district (as shown in Table 1), according to the ratings by Tekalign Tadese, 1991. This low amount of nitrogen led to the inadequacy of crop-available nitrogen which is likely to be stored in organic matter and clay minerals (Birkeland, 1984). Many nutrient response studies in Ethiopia also revealed that wheat responds positively to nitrogen fertilizer especially in Vertisols (Harfe, 2017; Solomon and Anjulo, 2017). The findings of this study are also similar to the finding by Allam (2003) who reported that increasing nitrogen levels increased grain yield (Figure 1).

Table 5. Response of wheat to nitrogen fertilizer in 2015 from three locations of Jamma District and combined analysis of the three sites.

	Grain yield (kg ha^{-1})				
Treatment	Yedo	Gebreguracha	Faji	combined	Straw yield (kg/ha)
0N+BF	1411.7b	1080.8d	1285c	1262.8c	1927.8d
46 kg N ha^{-1} + BF	3228.8a	2718.8c	1789.8bc	2579.1b	4486.9c
69 kg N ha^{-1} + BF	3847.5a	4091.3ab	1865.2bc	3268ab	5847b
92 kg N ha^{-1} + BF	3237.4a	3885.3b	2241.9ab	3121.5ab	6062.5b
115 kg N ha^{-1} + BF	3958a	4509.4a	2697a	3721.5a	7250.5a
138 kg N ha^{-1} + BF	4031a	4017.3ab	2564a	3537.4a	6653.6ab
CV (%)	14.09	9.18	17.5	28.5	22.5
Trt*Loc				NS	NS
Loc				NS	NS

Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. ns = non-significant at p > 0.05.

Table 6. Effect of different rates of N fertilizer on wheat yield over sites and combined in 2016

	Grain Yield(kg/ha)				Straw
Treatments	Meja	GebreGuracha	Yedo	Combined	yield (kg/ha)
0 N+BF	902e	1228e	862.8d	997.6e	2265.4d
46 kg N ha^{-1} + BF	1342.2de	1368.6de	1339.2c	1350d	2261.1d
69 kg N ha^{-1} + BF	1526.4cd	1663.7cd	1875.9b	1688.7c	2871.5c
92 kg N ha^{-1} + BF	1977.2bc	1956bc	2289.5ab	2074.3b	3411.8b
115 kg Nha^{-1} + BF	2185.4b	2170b	2531.8a	2295.8b	3757.8b
138 kg Nha^{-1} + BF	2907.4a	2501.7a	2680a	2696.4a	4386.9a
CV (%)	18.2	9.5	12.9	14.6	16.2
Trt*Loc				NS	NS
Loc				NS	NS

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. NS = non-significant at p > 0.05.*

Table 7. Effect of different rates of N fertilizer on wheat yield combined over 2015&2016 at Jamma.

Treatments	Grain Yield(kg/ha)	Straw yield (kg/ha)
0N+BF	1174.7d	2193.6d
46 kg N ha^{-1} + BF	1964.6c	3373.9c
69 kg N ha^{-1} + BF	2478.3b	4359.1b
92 kg N ha^{-1} + BF	2597.9b	4737.2b
115 kg N ha^{-1} + BF	3008.6a	5504.1a
138 kg N ha^{-1} + BF	3116.9a	5520.3a
CV (%)	19.54	20.18
Trt*Loc	NS	NS
Loc	NS	NS

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. NS = non-significant at p > 0.05.*

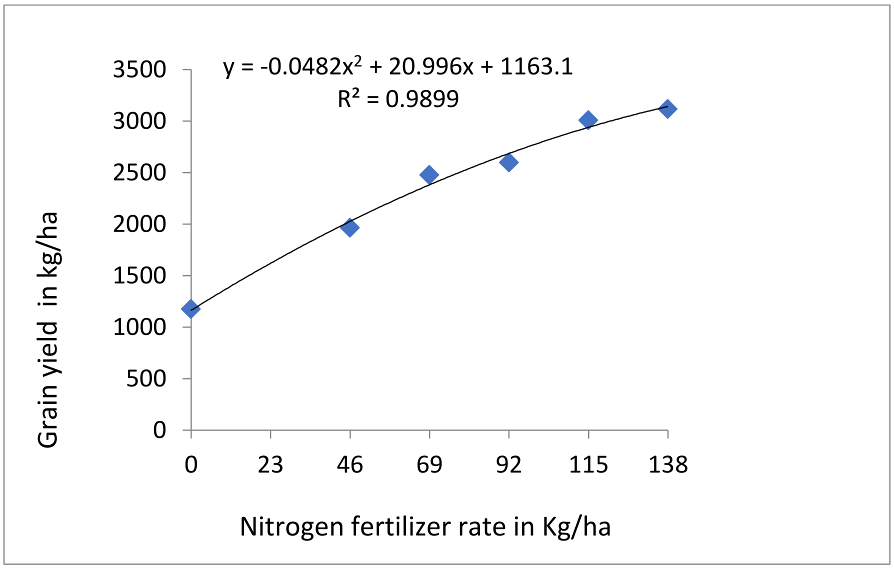

Figure 8. The effect of different nitrogen fertilizer rates on the grain yield of wheat on Jamma district.

Partial budget analysis of Nitrogen fertilizer

The partial budget analysis (Table 6) shows that all nitrogen rates except 92 and 138 kg/ha gave an acceptable marginal rate of return (i.e., MRR greater than 100%). Accordingly, the partial budget analysis stripped that the highest MRR is 610 from the application of 69 Kg nitrogen/ha with a net economic return of 27552.3 Ethiopian Birr per hectare. But according to CIMMYT (1988), when there are two and more treatments with MRR greater than 100%, the treatment with greater net benefit should be selected for recommendation. Therefore, application of 115 kg/ha nitrogen which gave 32574.5 Ethiopian Birr per hectare while possessing MRR of greater than 100% is economically viable in Jamma district.

Table 8. Partial budget analysis of the variable costs on mean grain and straw yields of wheat in Jamma district for nitrogen fertilizer

N	AGY	GYP	ASY	SYP	TR	FC	TFC	LC	TVC	NB	MRR
0	1040.5	12	2193.6	1	14679.5	31.5	0	0	0	14679.5	
46	1768.2	12	3373.9	1	24591.6	31.5	1449	1200	2649	21942.6	270
69	2230.6	12	4359.1	1	31125.8	31.5	2173.5	1400	3573.5	27552.3	610
92	2338.1	12	4737.2	1	32794.5	31.5	2898	1600	4498	28296.5	80
115	2707.7	12	5504.1	1	37996.9	31.5	3622.5	1800	5422.5	32574.5	460
138	2805.2	12	5520.3	1	39182.8	31.5	4347	2000	6347	32835.8	30

All costs are expressed in Ethiopian birr (ETB). N = Nitrogen fertilizer rates AGY=Adjusted grain yield (kg ha^{-1}); GYC=Grain yield price kg-1 (ETB), ASY=Adjusted straw yield (kg ha^{-1}), SYP=Straw yield pricekg-1 (ETB), TR=Total revenue (ETB), FC=Fertilizer cost kg-1 (ETB), TFC= total fertilizer cost (ETB), LC=Labor cost (ETB), TVC=Total variable cost, NB=Net benefit (ETB); MRR=Marginal rate of return(%).

II. Response of wheat to Phosphorus fertilizer

The analysis of variance showed that there was no significant difference in wheat grain yield among the phosphorus rates including the control (Table 7) at Jamma. The reason for the no wheat grain yield response to phosphorus fertilizer may be attributed to the higher available phosphorus content of the soil of the experimental site and the pH of the soil was neutral and no P fixation. However, the difference in straw yield was significant among the P rates and the highest straw yield was obtained from the application of 50 kg P ha^{-1} which was at par with the straw yield obtained from 20 – 40 kg P ha^{-1}.

Table 9. Effect of Phosphorus rates on bread wheat yield combined over years (2015 and 2016)

Treatments	Grain Yield (kg/ha)	Biomass wt. (kg/ha)
0 P +BF	2242	5538.2c
10 P + BF	2181	5934.6bc
20 P + BF	2294.1	6333.9ab
30 P + BF	2346.6	6591.4ab
40 P + BF	2427.3	6481.5ab
50 P + BF	2369.9	6649.3a
CV (%)	11.97	13.76
LSD (0.05)	NS	NS

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. ns = non-significant at p > 0.05.*

Partial budget analysis of Nitrogen fertilizer

The partial budget analysis (Table 10) showed that the highest MRR (*i.e*., 200%) was obtained from the application of 20 kg P ha^{-1} which brought about a net benefit of 27,285.4 Ethiopian Birr (ETB). This study is similar to the finding of Abreha *et al.* (2008) which indicated that application rates of 10 and 20 kg P/ha is feasible in Enderta, Ethiopia. Similarly, Fisseha Hadgu (2008) reported that 20 Kg P ha was economically feasible and recommended to be applied as maintenance.

Table 11. Partial budget analysis of the variable costs on mean grain and straw yields of wheat in Jamma district for phosphorus

P	AGY	GYP	ASY	SYP	TR	FC	TFC	LC	TVC	NB	MRR (%)
0	2017.8	12	2193.6	1	26407.2	62.5	0	0	0	26407.2	
10	1962.9	12	3373.9	1	26928.7	62.5	625	500	1125	25803.7	-50
20	2064.7	12	4359.1	1	29135.4	62.5	1250	600	1850	27285.4	200
30	2078.3	12	4737.2	1	29676.6	62.5	1875	700	2575	27101.6	D
40	2190.5	12	5504.1	1	31790.2	62.5	2500	800	3300	28490.2	D
50	2133.0	12	5520.3	1	31116.3	62.5	3125	900	4025	27091.3	D

All costs are expressed in Ethiopian birr (ETB). N = Nitrogen fertilizer rates AGY=Adjusted grain yield (kg ha^{-1}); GYP=Grain yield price kg^{-1} (ETB), ASY=Adjusted straw yield (kg ha^{-1}), SYP=Straw yield price kg^{-1} (ETB), TR=Total revenue (ETB), FC=Fertilizer cost kg^{-1} (ETB), TFC= total fertilizer cost (ETB), LC=Labor cost (ETB), TVC=Total veriable cost, NB=Net benefit (ETB); MRR=Marginal rate of return(%).

III. Response of wheat to Sulfur fertilizer

Combined over years and locations, there was no significant difference in wheat grain and straw yields to sulfur rates (Table 12) at Jamma district and similar agro-ecologies. This might be attributed to the availability of optimum sulfur in the soil for the optimum crop growth. The result confirms the findings the other study made in the same district to validate the multi nutrient EthioSIS soil fertility map.

Table 12. Effect of Sulfur fertilizer rates on wheat grain yield at three testing sites in 2015 at Jamma District

	Grain yield (kg ha^{-1})		
Treatment	Meja	Gebreguracha	Yedo
0 S + BF	2946.9ab	2591.0	2547.3
10 S + BF	3085.9a	2580.7	2253.3
20 S + BF	2748.5ab	2748.7	2369.2
30 S + BF	2824.7ab	2789.7	2461.3
40 S+ BF	2877.8ab	2598.4	2267.8
50 S + BF	2478.7b	2719.2	2818.6
CV (%)	10.2	9.9	14.4

Table 13. Effect of Sulfur fertilizer rates on wheat grain yield at three testing sites and combined analysis in 2016 at Jamma District

Treatments	Grain Yield(kg/ha)			
	Meja	Gebreguracha	Yedo	Combined
0 S + BF (ha^{-1})	1821.2a	2083.8	2067.3b	1990.8
10 S + BF	1588.3ab	2107.8	2096.7ab	1930.9
20 S + BF	1764.6a	2074.4	2140.9ab	1993.3
30 S + BF	1521.3ab	2104.3	2077.8b	1942.7
40 S+ BF	1781.1a	2024.8	2363.1a	2056.3
50 S + BF	1792.5a	2075.6	2328.1ab	2065.4
CV(%)	13.34	4.43	8.22	8.87

*Means followed by the same letter are no significantly different at p > 0.05. * and **- significant at 0.05 and 0.01 probability levels, respectively. ns = non-significant at p > 0.05.*

Table 14. Effect of Sulfur fertilizer rates on grain and straw yield of wheat combined over 2015 and 2016 at Jamma District

Treatments	Grain Yield(kg/ha)	Biomass Wt.(kg/ha)
0 S + BF	2342.9	3770.7
10 S + BF	2285.4	3916.5
20 S + BF	2307.7	4092.8
30 S + BF	2321.3	3929.0
40 S+ BF	2318.8	3803.5
50 S + BF	2368.8	3866.7
CV (%)	14.37	13.49

Means followed by the same letter are not significantly different at p > 0.05.

Conclusions and Recommendations

Application of different rates of nitrogen fertilizer significantly affected wheat grain and s traw yields in Jamma district. The combined analysis over years indicated that there was significant difference in wheat grain and straw yields to nitrogen fertilizer rates. Thus, application of 115 kg N ha^{-1} and 138 kg N ha^{-1} (with equal yield) gave 156%, 53%, 50.6% and 16% grain yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Similarly, 115 kg N ha^{-1} and 138 kg N ha^{-1} gave 151%, 63%, 26% and 16% straw yield advantage over the control, 46 kg N ha^{-1}, 69 kg N ha^{-1} and 92 kg N ha^{-1} respectively. Therefore, 115 kg N ha^{-1} and 138 kg N ha^{-1} were recommended for wheat for Jamma district and similar agro-ecologies for they gave similar agronomic and economic yields. Similarly, 20 kg P ha^{-1} was economically feasible and recommended for Jamma district and similar agro-ecologies. There was no significant wheat yield difference to sulfur fertilizer rates. Hence, 115 kg N ha^{-1} nitrogen and 20 kg P ha^{-1} are economically feasible and recommended for Jamma district and similar agro-ecologies.

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Evaluation of Lime Requirement Estimation Methods for Acid Soil Management and Yield of Bread Wheat and Food Barley in Wadla District of North Wollo Zone of The Amhara Region

Abebe Getu[1]*, Samuel Adissie[2], Tilahun Taye[2] and Tadesse Hailu[2]

[1]*Adet Agricultural Research Centre P.O. Box 08, Bahir Dar, Ethiopia*

[2]*Sirinka Agricultural Research Centre, P.O. Box 74, Woldia, Ethiopia*

**Corresponding author, email: abegetu3@gmail.com*

Abstract

Soil acidity is a major challenge constraining agricultural productivity in the highlands of Ethiopia while liming is the most common practice for its mitigation. However, accurate estimation of lime requirement (LR) has been a concern since liming practice began. Thus, field research was carried out at Wadla district of North Wollo Zone of the Amhara Region in 2014 and 2015 to evaluate the accuracy of different lime testing methods in predicting LR and investigating the response of bread wheat and food barley to the combined use of lime and phosphorus (P) fertilizer. The experiment was composed of a factorial combination of four lime testing methods; (SMP single buffer, $Ca(OH)_2$ direct titration, permissible acid saturation percentage (PASP) and exchangeable acidity (EA)) three phosphorus levels (0, 10 and 20 kg P ha^{-1} for bread wheat and 0, 15 and 30 kg P ha^{-1} for food barley). The treatments were laid out in a randomized complete block design with three replications. Calcitic lime was applied by broadcasting three weeks before planting. Significant yield response to the main effect of liming was obtained at the testing site where the soil pH was 5.14 for wheat and 5.0 for barley, while there was no significant yield response to liming where the soil pH varied from 5.25 to 5.60 for wheat and >6.0 for barley. The highest mean wheat grain yield (3.6 t ha^{-1}), and barley, (3.2 t ha^{-1}), were obtained from plots treated with lime estimated by SMP buffer method which is statistically at par with the yield obtained from plots treated with lime estimated by $Ca(OH)_2$ titration method. Similarly, wheat yield was significantly affected by main effect of phosphorus at two testing sites, while barley yield was significantly affected by phosphorus at all sites. The highest wheat grain yield (3.7 t ha^{-1}) was obtained from 20 kg P ha^{-1}, while, the highest barley grain yield (3.25 t ha^{-1}) was obtained from 30 kg P ha^{-1} gave. The lime estimated by SMP buffer $Ca(OH)_2$ titration methods raised the soil pH by 0.3 to 1.4 units. The amount of lime estimated by $Ca(OH)_2$ titration method was lower by 41.7% than LR estimated with SMP buffer method indicating that SMP buffer method tends to overestimate the LR. On the contrary, PASP and EA methods were found to underestimate the LR. Thus, $Ca(OH)_2$ titration method can be recommended for LR estimation among the methods evaluated in this study.

Keywords: *Acidity, lime requirement, lime testing, liming, wheat.*

Introduction

Acid soils are rampant and occupy about 41 percent of the land in Ethiopia (Schlede, 1989; Taye, 2007). Soil acidity problem in the country extends from south-west to north-west limited by the eastern escarpments of the Rift Valley. Out of the 41% of total coverage, 28% are moderate to weakly acidic (pH of 5.5 - 6.7); 13.2% are strong to moderately acidic (pH < 5.5) and nearly one-third have aluminum toxicity problem (Schlede, 1989). Soil acidification and soil erosion are the major soil degradation issues in the humid and highland areas of North Wollo Zone of the Amhara Region. Different studies have shown that soils in the highland areas of North Wollo including the present study area, Wadla district, have become acidic ranging from moderately to slightly acidic (Unpublished data).

Acid soils are a problem to agriculture production due to the consequences of nutritional disorders, deficiencies of essential nutrients such as calcium, magnesium, molybdenum, and phosphorus, and toxicity of aluminum, manganese and hydrogen activity (Carver and Ownby, 1995; Jayasundara *et al.,* 1997). Amendments of acid soil by different liming materials can raise soil pH, benefiting soil properties and plant growth and as a result liming is widely practiced for improving the acid soils productivity (Edmeades and Ridley, 2003; Lal, 2006; Omogbohu Anetor and Akinkunmi Akinrinde, 2007). Lime requirement (LR) is the amount of liming material that must be applied to soil to raise its pH to the level selected for near-optimum plant growth (McLean, 1973). Thus, to reclaim the soil acidity problems in North Wollo Zone, the North Wollo Zone Bureau of Agriculture with Dessie Regional Soil Testing Laboratory conducted soil acidity assessment survey and advised LR recommendations on farmer’s field level. However, the LR testing method i.e., permissible acid saturation percentage method (PASP) as described by Taye *et. al.* (2007 unpublished), which had been formerly used to determine LR was reported to underestimate the actual LR. Some soil testing laboratories in the region have later adopted SMP single buffer method (Shoemaker *et al.*, 1961) for LR determination.

However, different LR testing methods can give widely divergent results (Peech *et al.*, 1965). Certain methods are better suited to specific soil conditions depending on the physico-chemical characteristics and buffering capacity of the soil (Mehlich *et al.*, 1976). Many qualitative and quantitative methods have been used to estimate the LR including $CaCO_3$ incubations, titration techniques, buffer methods, determination of exchangeable aluminum, and indirect LR determination methods. Lime requirement estimation with buffer methods such as SMP buffer method and Adams and Evans buffer methods (Adams and Evans, 1962), are indirect lime estimation methods developed in US for American soils based on calibration/regression experiments with the widely accepted LR determination method i.e., soil incubation with $CaCO_3/Ca(OH)_2$ (Mehlich *et al.*, 1976; Barrow and Cox, 1990). Therefore, these indirect LR determination methods need to be calibrated and validated to the Ethiopian soils before they are directly adopted. In addition, the level of accuracy of any LR testing methods needs to be tested and validated under field conditions.

On top of that, highly weathered tropical and acid soils have strong P sorption capacities which intensify the limitation of land suitability. Phosphorus (P) fixation by the predominant Al^{3+} and Fe^{2+} ions in strong acid soil conditions leads to P deficiency. Therefore, the lime application needs to be integrated with P fertilizer supply in order to achieve maximum crop yields in acid soils. This study was, therefore, proposed with the objectives of selecting the most appropriate and relatively accurate LR determination methods suitable for the study area and similar agro-ecologies, and evaluating the yield response of wheat and barley crops to the combined application of lime and P fertilizer.

Materials and Methods

Site description

The study was conducted in 2014 and 2015 main cropping seasons in Wadla district of North Wollo zone of the Amhara Region. The study district is situated with an altitude range of 2000-2800 meters above sea level and within the geographical coordinates of 11^o 49’59” N and 38^o 49’59” E. The district receives a mean annual rainfall of 800-1200 mm with minimum and maximum temperature of 17 and 22^{o}C, respectively.

Experimental procedures

Evaluation of accuracy of LR estimation methods on farmers’ fields

Soil samples were collected from ten farmers' fields prior to starting the experiment for pH analysis (1:2.5 soil:water ratio). According to the ratings by Jones Jr (2002), seven famers fields with surface soil pH ranging from strongly to slightly acidic were purposively selected for the study. Four LR estimation methods including 1) SMP single buffer method (Shoemaker *et al.*, 1961), 2) $Ca(OH)_2$ direct titration method (Liu *et al.*, 2004), 3) permissible acid saturation percentage method-PASP (Taye *et. al.,* 2007 unpublished) and 4) exchangeable acidity method (EA) multiplied by a correction factor of 1.5 (included in the second experimental year) were used as LR estimation methods.

Description and soil testing procedures of the LR estimation methods

SMP-single buffer (SB) method

10 ml of SMP buffer (pH 7.5) was prepared and added to the soil-water slurry (1:1 Soil:Water suspension) which was used for pH determination. The soil-buffer mixture was closed tightly and shaken with a mechanical shaker at 250 excursions per min for 10 minutes. The mixture was then left to settle for 20 minutes. The pH of the soil-buffer mixture was measured to the nearest 0.01 pH unit by inserting the pH electrode into the solution of the soil-buffer mixture while swirling. Finally, the LR to the target soil pH of 6.5 was obtained from the final soil-buffer pH measured and existing reference calibrated data developed in the US.

$Ca(OH)_2$ direct titration method

30 ml distilled water was added to 30 g of air dried and ground soil sample which passed through a 2 mm sieve. The soil water mixture (1:1 Soil:Water ratio) was thoroughly and continuously mixed with a glass rod for 30 minutes and left to settle down for 30 min. The initial soil pH was measured by inserting a pH electrode (calibrated with the standard procedure) in the soil-water solution while swirling. Since titration curves are nearly linear within the pH range of most agricultural surface soils (4.5 to 6.5), three aliquots of ($Ca(OH)_2$) were used to develop the slopes of the titration curves for each soil. Three aliquots of 3 ml of 0.022M $Ca(OH)_2$ solution were added to the above soil-water mixture with 30 minutes interval while mixing thoroughly for 30 min after each addition of the 3 ml aliquot of 0.022M $Ca(OH)_2$ solution. The change/raise in the soil pH was measured by inserting the pH electrode in the soil solution while swirling.

The titration curve was plotted by taking the pH values (4 pH values including the initial pH measurement) measured against an equivalent amount of $CaCO_3$ (kg ha^{-1}) to the volume of 0.022M $Ca(OH)_2$ added (Eq. 1). A linear regression graph was fitted by plotting the amount of lime in the abscissa and the change in soil pH measured in the ordinate. The LR was calculated based on the slopes of the linear regression equations and the pH difference between initial pH (y-intercept) and the desired pH i.e 6.5 as shown in the equation below (Eq. 2);

$CaCO_3$ (1000 kg ha^{-1}) = V x 0.146, where V (ml) is the volume of 0.022M $Ca(OH)_2$ added …. Eq. 1

$$\text{LR (kg CaCO3 per ha)} = \frac{6.5 - Intercept}{Slope} \text{ ....Eq. 2}$$

Permissible acid saturation percentage method (PASP)

$$\text{LR (kg CaCO3 per ha)} = 1160x \left[Exchangeable\ acidity - \frac{1}{10}(ECEC)\right].$$

Where, 1/10 (ECEC) is meant for the assumption that the permissible acid saturation percentage level for wheat and barley is 10% (1/10).

Exchangeable acidity method (EA)

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

Where, a 1.5 multiplication factor was adopted based on a recommendation by Iticha *et al.* (2016).

Liming, fertilizer applications and planting

In the field evaluation study, the LRs determined using four lime testing methods and control (without lime) were factorially combined with three levels of P fertilizer (0, half and full of the recommended P, i.e 20 and 30 kg P ha^{-1} for wheat and barley, respectively). The treatments were arranged in a randomized complete block design with three replications. Agricultural calcitic lime, produced from Dejen lime factory, with moisture content of 1.06%, fineness factor of 0.52 and calcium carbonate equivalence (CCE) of > 90% according to Asrat *et al.* (2014) was broadcast evenly and incorporated in to the plow layer (20 cm) of the study fields three weeks before planting. Phosphorus fertilizer was applied in a band all at planting, while, N (69 and 46 kg N ha^{-1} for wheat and barley, respectively) was applied in a row half at planting and the remaining half at tillering (40 days after planting).

The size of each experimental plot was 12 m^2 (3 m * 4 m) with a spacing of 1 m between experimental plots and replications. Bread wheat variety - *Sora* and food barley variety - *Agegnehu* were used for the study. The crops were planted by drilling in a row with 20 cm spacing and at a seeding rate of 150 and 120 kg ha^{-1} for wheat and barley, respectively. There were 20 rows of plants in each plot out of which the innermost 18 rows were harvested and used for data collection and analysis.

Soil sampling and analysis

Composite surface (0-20 cm) soil samples were collected from the seven farmers' fields before application of lime for analysis of pH (H_2O and 0.01 M $CaCl_2$), texture, exchangeable acidity, exchangeable Al^{3+}, available P, exchangeable Ca, Mg, K, and Na. Surface (0-20 cm) soil samples were also collected after harvesting from each plot for analysis of soil pH, exchangeable acidity and exchangeable Al^{3+}. The soil analysis was done following the standard soil testing procedure as described by Sertsu and Bekele (2000).

Data collection and analysis

Grain yield was measured at maturity from the innermost 18 rows and was adjusted to a 12.5% moisture content. Fresh biomass weight was measured by weighing the fresh total above ground biomass of the harvested rows. While, the dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105 ^{o}C for 12 hours and adjusting the fresh biomass weight into dry basis by using the moisture content measured after an oven dry. Plant height was measured at maturity from random five plant samples of the harvestable rows, from ground level to the tip of the spike including the awns. Thousand seed weight was also measured by weighing 1000 seeds on a sensitive balance. All the relevant agronomic and soil data recorded were subjected to analysis of variance (GLM procedure) using SAS software version 9.00 (SAS Institute, 2004). The LSD mean separation method at 5% probability level was used to separate treatment means.

Results and Discussion

Status of soil physico-chemical properties before liming

Selected soil physico-chemical properties of soils (0-20 cm) of the seven experimental fields in the two experimental years are shown in the Tables below (Table 1 - 4). Soil acidity levels of the experimental fields were ranging from pH 4.97 to 6.00, which fall in the range of very strongly to moderately acidic, based on the ratings by Jones Jr (2002).

Table 1. Some physico-chemical properties of wheat experimental fields in 2014

Testing Site	pH (H_2O)	pH ($CaCl_2$)	Exch. H^+	Exch. Al^{3+}	Exch. acidity	Acid Sat (%)
			meq/100 g soil			
Site 1	5.14	4.43	0.380	0.65	1.024	12.70
Site 2	5.51	4.63	0.128	-	0.128	2.10

	Exch. Ca+Mg	Exch. Na	Exch. K	ECEC	Sand	Silt	Clay	

Testing Site	Exch. Ca+Mg	Exch. Na	Exch. K	ECEC	Sand	Silt	Clay	Textural class
	meq/100 g soil				%			
Site 5	7.50	0.195	0.205	9.5321	16	40	44	Silt clay
Site 6	5.05	0.087	0.397	5.6296	22	50	28	Clay loam

Testing Site								Textural class
	meq/100 g soil				%			
Site 1	6.55	0.195	0.269	8.0381	24	48	28	Clay loam
Site 2	5.55	0.130	0.256	6.0642	26	48	26	Clay

Table 2. Some physico-chemical properties of wheat experimental fields in 2015

Testing site	pH (H_2O)	Exch. acidity (meq/100 g soil)	Organic Carbon (%)	Available P (mg kg^{-1})	Textural class
Site 3	5.25	0.192	1.78-1.98	2.90-3.22	Sandy clay loam
Site 4	5.60	0.120	3.17-3.37	2.42-3.02	<<

Table 3. Some physico-chemical properties of barley experimental fields in 2014

Testing Site	pH (H_2O)	pH ($CaCl_2$)	Exch. H^+	Exch. Al^{3+}	Exch. acidity	Acid Sat (%)
			meq/100 g soil			
Site 5	4.97	4.50	0.580	1.06	1.632	17.1
Site 6	6.00	4.75	0.096	-	0.096	1.70

Table 4. Some physico-chemical properties of barley experimental field in 2015

Testing site	pH (H_2O)	Exch. acidity (meq/100 g soil)	Organic Carbon (%)	Available P (mg kg^{-1})	Textural class
Site 7	4.70	0.576	2.38-2.57	4.84-6.76	Sandy clay loam

LR estimated based on the four testing methods

The LR predictions for the experimental fields based on the three (first year) and four (second year) LR testing methods such as SMP buffer method, $Ca(OH)_2$ direct titration method, PASP method and EA method (added in the second experimental year) are shown in the Tables below (Tables 5 and 6).

Table 5. LR ($CaCO_3$ t ha^{-1}) of wheat experimental fields based on the four LR testing methods

Testing sites	SMP buffer	$Ca(OH)_2$ titration	PASP	Exchangeable acidity	Experimental year
Site 1	13.4	8.8	0.3	-	2014
Site 2	9.9	5.0	NL	-	2014
Site 3	3.3	2.22	NL	0.32	2015
Site 4	1.2	1.26	NL	0.20	2015
Mean	6.95	4.32	-	0.26	

NL: No lime is required based on prediction of the method

Table 6. LR ($CaCO_3$ t ha^{-1}) of barley experimental fields based on the four LR testing methods

Testing sites	SMP buffer	$Ca(OH)_2$ titration	PASP	Exchangeable acidity	Experimental year
Site 5	15.1	9.30	0.8	-	2014
Site 6	9.0	4.20	NL	-	2014
Site 7	4.0	2.17	-	0.97	2015
Mean	9.4	5.2	-	-	

NL: No lime is required based on prediction of the method

Effect of application of lime and P fertilizer on the yield of wheat

The first-year result indicated that the main effects of the application of lime rates determined with three different LR estimation methods had significant ($P<0.05$) effect on the yield of wheat at site 1 (Table 7). However, the yield of wheat at site 1 was not significantly affected by application of P fertilizer, which might be due to the better soil fertility status of the soil as this testing site was close to a homestead and there is a possibility of manure and kitchen waste addition. The yield response to the application of lime at site 1 was most likely attributable to raise in the soil pH and elimination of exchangeable Al^{3+} toxicity as the level of Al^{3+} was reduced from 0.65 meq/100 g to 0 meq/100 following liming. This result is supported by Lamond and David (1995), Okalebo *et al.* (2002) and Osundwa *et al.* (2013) who reported that application of lime significantly improved the productivity of wheat on acidic soils. Similarly, Kettering *et al.* (2005) reported that the increase in the agronomic yields due to liming might be attributed to the increases in soil pH, reduction in the ion toxicity of H or Mn and reduction in nutrient deficiency (Ca, P, or Mo) as well as due to the indirect effect of better physical condition of the soil. At testing site 2, there was a significant yield response to the application of P fertilizer (Table 7), which might be accounted for the low soil fertility status and P limitations to crop growth in the study district (FAO, 1986). However, the yield of wheat was not significantly ($P>0.05$) affected by the application of lime at site 2. This might be due to the less adverse effect of the soil acidity level (pH 5.51) of the site on the yield of wheat as wheat is reported to be tolerant to the pH level of 5.2 (Mahler and McDole, 1987).

Table 7. Main effects of application of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (P kg ha^{-1}) on the yields of wheat (kg ha^{-1}) at site 1 and 2 and pooled over sites in 2014

Lime Rates*	Site 1 Grain yield	Site 1 Total biomass	Lime Rates*	Site 2 Grain yield	Site 2 Total biomass	Combined Grain yield	Combined Total biomass
Control (0)	3596.2b	9279.8b	0	3872.9	10014.2	3734.6bc	9647.0ab
SMP (13.4)	4252.5a	10821.8a	9.8	4063.7	9791.7	4158.1a	10306.7a
$CaOH_2$ (8.8)	4002.2a	10763.9a	5.0	3877.9	9572.6	4030.5ab	10133.2ab
PASP (0.3)	3585.1b	9365.1b	-	-	-	3585.1c	9365.1b
LSD (5%)	415.2	1084.0	LSD	ns	ns	319.1	851.7
P rates*			P rates*				
Control (0)	3775.5	9611.1	0	3782.2b	9373.2b	3778.5b	9498.0b
10	3945.5	10117.8	10	3788.4b	9375.0b	3874.8ab	9805.1ab
20	4000.6	10395.6	20	4243.9a	10584.0a	4104.9a	10480.4a
LSD (5%)	ns	ns	LSD	297	989.9	260.6	685.3
CV (%)	10.4	10.2	CV (%)	7.5	9.9	10.5	10.6

*Treatment means followed by the same letter are no significantly different at p> 0.05. ns: Non-significant at p>0.05.

As shown in Table 7, at site 1, the highest grain yield (4.25 t ha^{-1}) and total biomass (10.8 t ha^{-1}) were obtained from application of lime using SMP buffer method followed by the grain yield (4.0 t ha^{-1}) and total biomass (10.7 t ha^{-1}) obtained from application of lime using $Ca(OH)_2$ titration method. However, there was no significant yield improvement due to the application of lime determined with PASP, which was due to the lowest LR prediction by PASP method. The combined analysis of wheat yield from the two testing sites showed a statistically significant effect of both the main effects of lime and P fertilizer on the yields of wheat (Appendix Table 1). The highest yield was obtained from the lime rate with SMP buffer method followed by the yield from lime rate with $Ca(OH)_2$ titration method (Table 7). Application of lime rates with SMP buffer and $Ca(OH)_2$ titration methods gave yield advantages of 11.3 and 7.9%, respectively over the non-limed treatment.

The second-year result from both testing sites showed that there was no significant difference in the yields of wheat due to the main effect of lime and its interaction with P fertilizer (Table 8).

This might be accounted for the less adverse effect of the soil acidity level of the testing sites on the growth of wheat as the surface soil pH levels of the testing sites were in the range of 5.25 to 5.60 (Table 2). However, the main effect of P was found to significantly affect the yield of wheat at site 3, while, at testing site 4 the yield of wheat was not significantly affected by P which might likely be due to the effect of other growth limiting conditions as it can be seen from the very low yield recorded from this site. The pooled analysis of variance over the two testing sites showed that both the main effect of liming and P had a significant effect on the grain yield of wheat. However, there was no significant yield difference among the lime rates applied with the three LR estimation methods (Table 8). Lime by site interaction effect on the grain and total biomass yield was not significant, while, P by site interaction effect was significant indicating the variation in the yield response of wheat to P across the testing sites in the second year.

Table 8. Main effects of application of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (P kg ha^{-1}) on the yields of wheat (kg ha^{-1}) at site 3 and 4 and pooled over sites in 2015

Lime	Site 3		Lime	Site 4		Combined	
Rates*	Grain yield	Total biomass	Rates*	Grain yield	Total biomass	Grain yield	Total biomass
Control (0)	3902.9	9196.4	0.00	1700.0	3817.9	2875.2b	6686.4
SMP (3.30)	3881.4	9302.6	1.20	2188.5	4464.7	3140.7ab	7186.0
$CaOH_2$ (2.22)	4318.7	9590.0	1.26	2020.7	3807.7	3237.3a	6506.1
Exch. acid. (0.32)	4138.9	9392.3	0.20	2008.6	4092.6	3206.9a	6919.1
LSD (5%)	ns	ns	LSD	ns	ns	285.3	ns
P rates*			P rates*				
Control (0)	3823.9b	8687.7b	0	2125.8	4212.9	3015.3b	6450.3
10	3976.3b	9474.3a	10	1796.5	3889.6	2985.5b	6682.0
20	4374.6a	9828.5a	20	2025.2	4007.0	3367.7a	7333.6
LSD (5%)	400.1	568.8	LSD	NS	NS	246.9	NS
CV (%)	9.8	6.6	CV (%)	17.1	14.3	12.8	10.3

**Treatment means followed by the same letter are no significantly different at p> 0.05. ns: Non-significant at p>0.05.*

The pooled analysis of variance of the agronomic data collected overall testing sites and experimental years revealed that the grain yield of wheat was affected by the main effects of both lime and P fertilizer (Table 9). The highest grain and dry biomass yields were obtained from the lime rate determined by SMP buffer method being statistically at par with the grain yield obtained from lime rate determined by $Ca(OH)_2$ titration method. However, the average lime rate (4.32 t ha^{-1} $CaCO_3$) estimated with $Ca(OH)_2$ titration method was lower by 37.6% than the average lime rate (6.93 t ha^{-1} $CaCO_3$) estimated with SMP buffer method. Similarly, the highest grain and total biomass yields were obtained from the application of 20 kg P ha^{-1} followed by the yields from the application of 10 kg P ha^{-1} (Table 9).

Table 9. Main effect of lime rates ($CaCO_3$ t ha^{-1}) and P fertilizer rates (kg P ha^{-1}) on the yields of wheat pooled over testing sites and experimental years

Lime rates*	Grain yield (kg ha^{-1})	Total biomass (kg ha^{-1})
Control (0)	3343.9b	8301.3
SMP buffer (6.93)	3679.3a	8746.4
$CaOH_2$ titration (4.32)	3633.9a	8433.0
LSD (5%)	202.7	Ns
P rates*		
0	3413.3b	8019.0b
10	3503.4b	8524.9a
20	3742.6a	8917.6a
LSD (5%)	202.7	445.6
CV (%)	11.7	10.5

*Treatment means followed by the same letter are no significantly different at p> 0.05. ns: Non-significant at p>0.05.

Effect of application of lime and P fertilizer on the yield of barley

The grain and dry biomass yield at site 5 and 7, where the soil pHs were strongly acidic, were significantly (P<0.01) affected by the main effects of liming (Table 10). The main effect of the application of P was found to significantly (P<0.01) affect both grain and straw yields at all testing sites. However, there was no significant (P>0.05) interaction effect of liming and P fertilizer on the yield of barley at all testing sites. The significant response to liming might be due to the subsequent rise in the soil pH of the study sites after liming. Haynes (1984) and Kettering *et al.* (2005) also reported that the increase in the agronomic yields of barley due to liming is attributed to the improvement in soil pH, reduction in the ion toxicity of H^+, Al^{3+} or Mn^{2+}, release and availability of nutrients like Ca, P, or Mo as well as due to indirect effect of better physical condition of the soil. The positive effect of liming on the growth and grain yield of barley on acid soils was reported by a number of authors (Tang *et al.*, 2003; Kovacevic *et al.*, 2006). Ito *et al.* (2009) also confirmed the positive responses of barley root growth and yield improvements on acidic Andosols due to liming.

The significant yield response to the main effect of applied P fertilizer might also be attributed to the low soil fertility of the testing sites and the supply of P in the P treated plots as compared to the none P treated plots where indigenous soil P was most likely fixed in unavailable form due to the very strong soil acidity. However, at the testing site 6, the yield was not significantly ($P>0.05$) affected by the application of lime (Table 10). This might be due to the slight soil acidity level (pH 6.0) of the testing site which as a result had no significant adverse effect on the yield of barley. But barley yield was rather affected significantly by the main effect of the application of P which was due to the low soil fertility characteristics of the study district (World Bank, 1983; FAO, 1986).

At those testing sites where the soil acidity was very strongly acidic, the highest mean grain and dry biomass yields were recorded from the application of lime estimated with SMP buffer method followed by the mean grain and dry biomass yields obtained from the application of lime determined with $Ca(OH)_2$ titration method. The highest grain and dry biomass yield at all testing sites were recorded from the application of 30 kg P ha^{-1} which was statistically at par with the yields obtained from 15 kg P ha^{-1}. At the testing site 6, where the soil pH was slightly acidic (pH 6.0), the mean grain and dry biomass yields obtained were about 100% higher than the mean grain and dry biomass yields obtained at testing site 5, where the soil was very strongly acidic (pH 4.97), in the same experimental year (2014). This indicated the effect of strong soil acidity on the yield of barley though lime was added as the effect of liming on soil acidity is slow and gradual. This result is supported by Farhoodi and Coventry (2008) who reported a substantial yield increment of barley, wheat, and faba bean a year after lime application.

Likewise, the pooled analysis over the three testing sites in the two experimental years revealed significant ($P<0.01$) response of barley yields to the main effects of lime and P fertilizer (Table 11). The highest mean grain and dry biomass yields of 2.8 and 7.9 t ha^{-1}, respectively, were obtained from application of lime estimated with $Ca(OH)_2$ titration method being statistically at par with the grain and dry biomass yields of 2.7 and 7.8 t ha^{-1}, respectively, obtained from lime estimated by SMP buffer method. Application of lime estimated with $Ca(OH)_2$ titration and SMP buffer methods increased the grain yield of barley by an average of 15.5 and 19.1%, respectively as compared to the non-limed treatment. Similarly, application of 30 kg P ha^{-1} gave the highest grain yield which was statistically at par with the grain yield obtained from 15 kg P ha^{-1}. Grain yield advantages of 37.7 and 26.8% over the treatment where P was not applied were also obtained from the application of 30 and 15 kg P ha^{-1}, respectively.

Table 10. Mean barley grain and dry biomass yields (kg ha^{-1}) affected by the main effects of liming and P fertilizer at three testing sites in 2014 and 2015

	2014					2015		
	Site 5			Site 6			Site 7	
Lime rates* ($CaCO_3$ t ha^{-1})	Grain yield	Dry biomass	Lime rates ($CaCO_3$ t ha^{-1})	Grain yield	Dry biomass	Lime rates ($CaCO_3$ t ha^{-1})	Grain yield	Dry biomass
Control (0)	1229.8c	4045.3c	0.0	2976.8	7689.9b	0.0	2429.9c	7860.1c
SMP buffer (15.1)	2054.9a	6401.2a	9.0	3235.0	8111.1a	4.00	3193.7a	9835.4a
$Ca(OH)_2$ titration (9.3)	1655.8b	5446.5b	4.2	3314.5	8332.2a	2.17	2941.0ab	9218.1ab
PASP (0.8)	952.7c	3671.2c	0.0	-	-	Exc. Acidity - EA (0.97)	2803.3bc	8847.7b
Mean	1512.4	4936.8	Mean	3175.5	8044.4	Mean	2841.9	8940.3
CV (%)	18.0	13.4	CV (%)	12.4	5.0	CV (%)	13.7	10.5
LSD (5%)	290.34	684.12	LSD (5%)	ns	379.5	LSD (5%)	381.8	913.9
P rates* (kg P ha^{-1})			P rates (kg P ha^{-1})			P rates (kg P ha^{-1})		
Control (0)	1011.9c	3838.2b	0	2811.5 b	7435.2b	0	2378.0b	8101.9b
Half of rec. (15)	1645.4b	5356.9a	15	3337.5a	8261.8a	15	2991.6a	9058.6a
Full rec. (30)	1916.6a	5615.4a	30	3377.4a	8436.2a	30	3156.4a	9660.5a
Mean	1512.4	4936.8	GM	3175.5	8044.4	Mean	2841.9	8940.3
CV (%)	18.0	13.4	CV (%)	12.4	5.0	CV (%)	13.7	10.5
LSD (5%)	248.27	591.69	LSD (5%)	393.2	379.5	LSD (5%)	330.7	791.5

**Treatments followed by the same letter are not significantly different at 0.05 probability level; ns=non-significan*

Table 11. Mean barley grain and dry biomass yields (kg ha^{-1}combined over years affected by the main effects of lime rates and P fertilizer

Lime rate* ($CaCO_3$ t ha^{-1})	Grain yield	Dry biomass yield
Control (0)	2346.7b	6887.4b
SMP buffer (9.37)	2709.0a	7786.6a
$Ca(OH)_2$ titration (5.22)	2794.5a	7993.7a
Mean	2630.2	7579.9
CV (%)	13.0	11.2
LSD (5%)	197.7	483.5
P rates* (kg P ha^{-1})		
Control (0)	2162.3c	6742.7b
Half of rec. (15)	2741.3b	7785.7a
Full rec. (30)	2977.8a	8169.5a
Mean	2630.2	7579.9
CV (%)	13.0	11.2
LSD (5%)	197.1	482.3
Lime rate*P rates*Site	ns	ns

**Treatments followed by the same letter are not significantly different at 0.05 probability level; ns=non-significant; Lime rates = the mean lime rate estimated with the two methods of the three testing sites.*

Effect of application of lime estimated with different lime testing methods on soil acidity

The result of laboratory analysis for the soil samples collected at harvesting from the seven experimental fields of both test crops in the two experimental years showed that LR estimated with SMP buffer and $Ca(OH)_2$ titration methods raised the soil pH significantly to the level optimum for wheat and barley growth (Table 12 and 13). However, the application of LR determined with PASP and exchangeable acidity (EA) methods were not found to significantly raise the soil pH as compared to the pH measured from the control treatment. Thus, PASP and EA methods were found to underestimate the actual LR.

The exchangeable acidity and exchangeable Al^{3+} analyzed from the soil samples collected at harvesting was zero due to the significant rise in the soil pH >5.5 as a result of liming. The increase in the soil pH measured at harvesting from the control treatment as compared to the pH measured before planting might be due to the dynamic property of soil pH which was raised as a result of the dry season period during harvesting (Olojugba and Fatubarin, 2015). In addition, although the lime was broadcast with much care to the lime-treated plots, there was a possibility of movement of dust of lime to the control plots by wind due to its fineness. This might also lead to an increase in soil pH on the control plots measured at harvesting.

The rise in the surface soil pHs measured at harvesting due to the application of LRs determined with SMP buffer and $Ca(OH)_2$ titration methods were statistically similar. However, the average amount of lime rate determined with $Ca(OH)_2$ titration method was lower by 37.6 and 44.7% than the lime rate determined by SMP buffer method from wheat and barley experimental fields, respectively. This result is supported by Liu *et al.* (2004) who found out that the 3-points prediction from the direct titration with 30 minute interval time between additions of 0.022M $Ca(OH)_2$ estimated approximately 80% of the soil acidity and LR determined by the widely accepted standard procedure for lime determination i.e., 3-day incubation of the soils with $Ca(OH)_2$. On the contrary, Liu *et al.* (2004) also reported that titration of 1:1 soil:0.01 M $CaCl_2$ solution mixture with $Ca(OH)_2$ was more accurate than titrating soil:water mixture. According to McLean *et al.* (1978), titration of acidic soils with $Ca(OH)_2$ in l:5 soil:water suspensions (though the titration method differs from the method used in this study) yielded LRs that were similar to those obtained by the standard incubation with $CaCO_3$ to pH 6.5 over a 20 months period.

Table 12. Effect of application of lime ($CaCO_3$ t ha^{-1}) on soil pH (at harvesting) from four wheat experimental fields

2014					2015				
Site 1		Site 2		pH	Site 3		Site 4		pH
Lime rate*	pH	Lime rate	pH	Combined	Lime rate*	pH	Lime rate	pH	Combined
Control (0)	5.81b	0.0	6.20b	6.00b	Control (0)	5.75b	0.00	5.79	5.77b
SMP (13.4)	6.49a	9.8	6.93a	6.71a	EA (0.32)	5.97ab	0.20	5.81	5.89ab
CAOH (8.8)	6.63a	8.0	6.74a	6.69a	SMP (3.30)	6.19a	1.20	5.98	6.08a
PASP (0.3)	5.97b	-	-	5.97b	CAOH (2.22)	6.10ab	1.26	5.87	5.98ab
LSD (5%)	0.32	LSD (5%)	0.24	0.22	LSD (5%)	0.39	LSD (5%)	ns	0.22
CV (%)	5.21	CV (%)	3.67	4.55	CV (%)	6.57	CV (%)	4.02	5.43

**Treatment means followed by the same letter are no significantly different at p> 0.05. SMP: SMP buffer method; CAOH: $Ca(OH)_2$ titration method; PASP: Permissible acid saturation percentage method; EA: Exchangeable acidity method.*

Table 13. Effect of application of lime ($CaCO_3$ t ha^{-1}) on soil pH (at harvesting) from three barley experimental fields

2014					2015	
Site 5		Site 6		pH	Site 7	
Lime rate*	pH	Lime rate	pH	Combined	Lime rate*	pH
Control (0)	5.6b	0.0	6.2b	5.9c	Control (0)	5.62b
SMP (15.1)	6.7a	9.0	6.8a	6.8a	EA (0.97)	5.86ab
CAOH (9.3)	6.5a	4.2	6.5ab	6.5a	SMP (4.0)	6.21a
PASP (0.8)	5.4b	0.0	-	5.4b	CAOH (2.17)	6.16
LSD (5%)	0.38	LSD (5%)	0.43	0.30	LSD (5%)	0.35
CV (%)	6.4	CV (%)	6.7	6.4	CV (%)	5.82

*Treatment means followed by the same letter are no significantly different at p> 0.05. SMP: SMP buffer method; CAOH: $Ca(OH)_2$ titration method; PASP: Permissible acid saturation percentage method; EA: Exchangeable acidity method.

Conclusion and Recommendation

The study result revealed that different lime testing methods generate different LR to raise the soil pH level to the desired level. The 3-point $Ca(OH)_2$ direct titration and SMP single buffer methods were found to effectively increase the soil pH level to the desired pH level (pH 6.5). However, PASP and EA methods were found to underestimate the LR. The lime amount estimated by $Ca(OH)_2$ titration method was on average lower by 37.6% for wheat plots and by 44.7% for barley plots than the amount estimated by SMP buffer method indicating SMP buffer method tends to overestimate the LR. Thus, $Ca(OH)_2$ titration method was found to be the most appropriate and accurate lime estimation method among the methods evaluated in this study. Though $Ca(OH)_2$ titration method was found to consume more time as compared to SMP buffer method, it could be recommended as the best LR determination method for routine use in soil testing laboratories as it can reduce about 38-45% of the cost of extra lime expenses predicted by SMP buffer method.

As the buffer methods such as SMP buffer methods are rapid methods of lime testing for routine use in soil testing laboratories, developing conversion factor based on the current recommendation i.e $Ca(OH)_2$ titration method is recommended to accelerate the soil testing process while maintaining the accuracy level. Moreover, we suggest further study on $Ca(OH)_2$ 1-point and 2-point titration evaluations on soil:0.01 M $CaCl_2$ mixture instead of 3-point soil:water mixture to shortening the time required for the soil testing. Although this study simultaneously verified the accuracy of the LRs predicted based on different lime testing methods on the field, calibration of the lime testing methods with the standard soil incubation procedures with $CaCO_3$ or $Ca(OH)_2$ is also recommended.

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Soil Characterization and Soil Fertility Mapping of Main Research Station of Sirinka Agricultural Research Center

Abebe Getu[1]*, Samuel Addisie[2], Tilahun Taye[2] and Sisay Dessale[2]

[1]*Adet Agricultural Research Center, P.O.Box 08, Bahir Dar,*

[2]*Sirinka Agricultural Research Center, P.O.Box 74, Woldia*

*Corresponding author email: *abegetu3@gmail.com*

Abstract

Soil characterization and soil fertility investigation are the basic criteria in selecting sites for research that represent the surrounding recommendation domain. Taking this into account, soil fertility investigation and characterization was done for the main research station of Sirinka Agricultural Research Center (SARC). Following 50 m by 50 m fixed grids, a total of 164 soil samples were collected at two depths, 0-20 cm and, 20-40 cm. Six soil mapping units were identified based on differences in soil color, surface soil texture, and slope. In each soil mapping unit, soil profiles were opened and soil profile description was made based on the Food and Agricultural Organization (FAO) guideline. The reference soil group and subgroup classification were finally made based on the FAO World Reference Base for Soil Resources (WRB) international soil classification system. The soil characterization results show that the soils in the research station are very deep (>150 cm) with surface and subsoil textures of clay and heavy clay, respectively. While the soil structure varied from weak medium granular in the surface to strong very coarse prismatic and weak medium prismatic in the subsoil and weak medium blocky and angular blocky at the bottom layers. The soil reaction (pH) of the research station is in the neutral to a slightly alkaline range (6.90-7.59). The organic matter content of the surface soil varies from 1.91 to 3.4%, the total N content from 0.022 to 0.17% and available phosphorus content from 5.0 to 17.0 mg kg^{-1} and are all rated in the low to medium levels. While the exchangeable cations of the surface and subsurface soils K (0.6-1.2), Ca (>20.0) and Mg (3.0-6.0) content in (cmol(+) kg^{-1} soil) fall within high to very high range. The K:Mg ratio in the surface soil varies from 0.16 to 0.18, indicating a possible antagonistic effect of Mg on K uptake, while, the Ca:Mg ratio of 3 to 6 obtained in the surface soil layer shows a balanced nutrient stock. However, the Ca:Mg ratio (<2) in the subsoil layers indicates a tendency of low Ca supply for deep-rooted plants. Based on the soil profile studies, two soil types, eutric Vertisols, and haplic Cambisols, were identified. The dominant soil type is eutric Vertisols with haplic Cambisols covering only 6.9% of the area. Generally, the results show that the soil in the research station is potentially productive and deep soil capable of supporting annual and perennial crop production. However, the organic matter and total N content are low which indicates a need for a practice of integrated soil fertility management.

Keywords: *Characterization, fertility, mapping, Sirinka, soil.*

Introduction

The basic purpose of soil fertility investigation is to provide information on the nutrient status of the soil, to predict the relative response to added nutrient and for the general planning of agricultural development (Tisdale *et al.*, 1993). Soil fertility refers to the inherent capacity of the soil to supply nutrients in adequate amounts and in suitable proportions for crop growth and crop yield. Soil fertility gives an idea of the status of soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element.

Soil properties change in time and space continuously (Cichota *et al.*, 2006). According to Feng *et al.* (2008), heterogeneity can occur at large scale (region) or at a small scale (community), even in the same type of soil or in the same community. Spatial variability is a term indicating changes in the value of a given property over space (Ettema and Wardle, 2002). It can be assessed using classical descriptive statistics (i.e., mean, range, coefficient of variation) or geo-statistics. The amount and pattern of nutrient variability vary greatly between fields and are affected by soil type, topography, management, fertilization, and land use history. Therefore, knowledge of the spatial variability of soil properties is essential for site-specific soil management and evaluation of various agricultural land management practices.

Agricultural research stations are established based on their representation of a wider area in terms of soil characteristics (soil type and soil fertility), climatic and topographic features as most of the research outputs that are generated in the research stations are supposed to work for the wider target area they represent. So far, some of the research findings have proved to be more or less successful. However, there were also pitfalls in some areas due to a very generalized and approximation of recommendation. Amongst is the difficulty in dissemination and extrapolation of research findings outputs to other areas due to lack of sufficient soil information.

Sirinka Agricultural Research Center (SARC), which is located in Northeastern Ethiopia, is one of the research centers under Amhara Regional Agricultural Research Institute (ARARI). There are two research sub-centers (Kobo and Jari research sub-centers) and five research stations (Chefa, Jamma, Gimba, Geregera, and Estayish) under SARC situated in different agro-ecological areas in Eastern Amhara. So far, there were efforts to assess the farming system including biophysical resources of the research stations. However, there is lack of detail characteristics of soils of the research sites of SARC. This proposal was, therefore, initiated with the objectives of characterizing soils of SARC main research station and developing a detailed soil fertility map.

Materials and Methods

Description of the Study Area

The soil survey was conducted for the main research station of Sirinka Agricultural Research Center (SARC) at Sirinka in 2015. Sirinka Agricultural Research Center is located at an altitude of 1850 meters above mean sea level within the geographical coordinates of 11^{0}45'00''N latitude and 39^{0}36'36''E longitude (Figure 1). The average mean annual rainfall of the study area is 945 mm and the mean maximum and minimum temperatures are 26 and 13^{o}C, respectively. The total area of SARC main research station including the office compound, residents and livestock barn is about 40 ha.

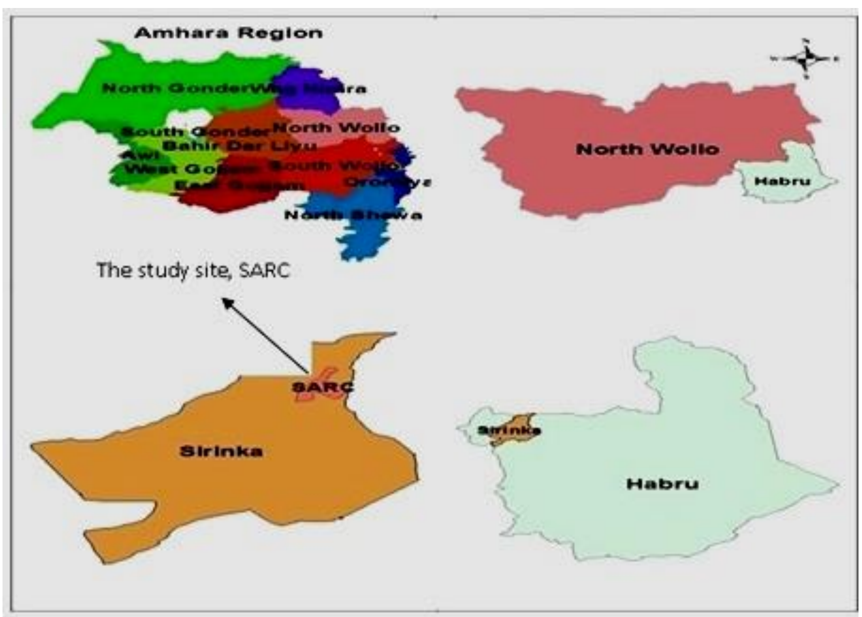

Figure 1. Location map of Sirinka Agricultural Research Center (SARC)

Geology of the Study Area

The geology of Eastern Amhara is covered by Cenozoic volcanic rocks with some sedimentary rocks (Damene *et al.*, 2012). The Cenozoic volcanic rocks have developed from tertiary flood basalt sequences with intercalation of felsic lava and pyroclastic rocks up to 3 km thick. The Cenozoic volcanic rocks and the associated sedimentary rocks are further subdivided into various formations. The major formations are Ashangi, Tarmaber-Megezez, Alajae, Aiba basalts and Amba-Aradom formations covering 49, 18, 14, 12 and 3%, respectively (Teffera *et al.*, 1996).

According to Mohr (1963), the soils of Wollo area have been developed almost exclusively on trap series volcanoes. The soils on the landforms, which include wide parallel valleys, side slopes and volcanic plateaux, are generally stony phase eutric and dystric Vertisols or vertic Cambisols. In the intensively cultivated, even on minimum slopes, these highly erodible soils can become quite shallow. On the steeper landforms, eutric Cambisols predominate, with lithic phases and Leptosols occurring on the steepest slopes.

Survey Methods

Office and field work procedure

Different digital mapping tools like Google Earth images were used to classify different soil mapping units within the study site. A preliminary field assessment was conducted to map the overall layouts, landforms, and attributes of the study site prior to the field soil investigation. During site mapping, altitude and geographical points of block boundaries and important landmarks were recorded with handheld GPS. Soil mapping units were identified and delineated based on slope, soil color, land use history, and surface soil texture. Soil profiles were opened in each mapping units to describe the morphological, physical and chemical characteristics of the soil profile based on the FAO guideline (Shand, 2007). Soil samples were collected from each genetic soil horizons.

All the soil samples collected were analyzed for soil pH (H_2O), texture, organic carbon (OC), total N, available P, Cation Exchange Capacity (CEC), exchangeable bases (Ca, Mg, K and Na). Finally, the reference soil group and subgroup classification were made based on the soil classification system of FAO World Reference Base (WRB) for Soil Resources (Food and Organization, 2014; Wrb, 2015). For the soil fertility assessment and mapping, surface soil samples were collected at two depths (0-20 and 20-40 cm) with auger following 50 x 50 m grid points. The sampling points were geo-referenced with GPS and hence a total of 164 geo-referenced auger observations at two soil depths (0-20 and 20-40 cm) were made.

The shapefile of the study area (SARC main research station) was prepared by importing the study area image from Google earth into ArcGIS/ArcMap v 10.0 software: the study area image was created from Google earth following the add polygon procedure and saved in KML format. The KML format image was converted to layer on ArcMap through the conversion tools procedure and was exported and converted into shapefile. The laboratory analysis values of the nutrients input in Microsoft Excel was added into ArcMap and exported into shapefile. The spatial distribution and soil map of pH and N, P, K, Ca, Mg concentration and the organic matter content (OM) were finally prepared separately for each parameter by Inverse Distance Weighted (IDW) interpolation method by overlying the soil sampling points over the shapefile of the study area created.

The soil map and legend

Soil mapping units were classified based on major soil/land characteristics such as soil color, surface texture, slope, and soil depth. Slope level in the research site ranges from 0-6%. Six soil mapping units were identified based on the above-mentioned criteria (Table 1). Each mapping units are indicated with four codes/elements such as slope class, soil depth, soil texture, and soil color, respectively (Table 2).

Table 1. Mapping unit identification codes

Slope		Soil Depth		Surface texture		Soil color	
Class (%)	Code	Cm	Code	Type	Code	Color	Code
1-4	1	>200	a	Clay	2	Very dark	Vd
4-6	2	150-200	b	Clay loam	3	Black/dark	B
		100-150	c	Silt clay	4	Gray	G
				Heavy clay	1	Brown	Br
						Reddish Brown	Rb

Table 2. Soil mapping units identified in SARC main research site at Sirinka

Mapping Units	Pedon No.	Slope (%)	Soil Depth (cm)	Texture (0-30 cm)	Area (ha)
1a2b	P1	1-4 (4)	> 200	Clay	2.69
1b2vd	P2	1-4	150-200	Clay	5.32
1a3b	P3	1-4	>200	Clay loam	6.13
2b4rb	P4	4-6	150-200	Silt clay	0.71
2c1b	P5	4-6	100-150	Heavy clay	6.47
2b1g	P6	4-6	150-200	Heavy clay	0.80

Laboratory Analysis

Soil texture was determined by the modified Bouyoucos hydrometer method (Bouycous, 1962) using sodium hexametaphosphate as a dispersing agent. Soil textural class names were assigned based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle of the USDA. While soil pH was measured potentiometrically using a pH meter with a combined glass electrode in a 1:2.5 soil-water suspension (van Reeuwijk, 1992). Organic carbon (OC) was determined by wet digestion method, and following the assumptions that OM is composed of 58% carbon, the conversion factor, 1.724 was used to convert the OC into OM (Walkley and Black, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black *et al.*, 1965). Available P was determined colorimetrically using Olsen's method (Olsen, 1952).

Exchangeable bases were extracted with 1M buffered ammonium acetate extractant; K and Na were then measured using flame photometer and Ca and Mg were measured using atomic absorption spectrophotometer (Chapman, 1965). While CEC was determined by 1M buffered ammonium acetate extraction method followed by displacing the ammonium saturated soil with sodium acetate and distilling off the displaced ammonium in a Kjeldahl distillation apparatus while receiving the distillate in boric acid and then titrating with sulfuric acid (Chapman, 1965). As it is mentioned in Annex, the soil nutrient level classifications and ratings were made based on (Cottenie, 1980; Tekalign *et al.*, 1991; Jones Jr, 2002; Jahn *et al.*, 2006; Hazelton and Murphy, 2016).

Results and Discussion

Soil Mapping Units

Based on the aforementioned criteria in the materials and methods section, six soil mapping units, as shown in Figure 2 below, were identified.

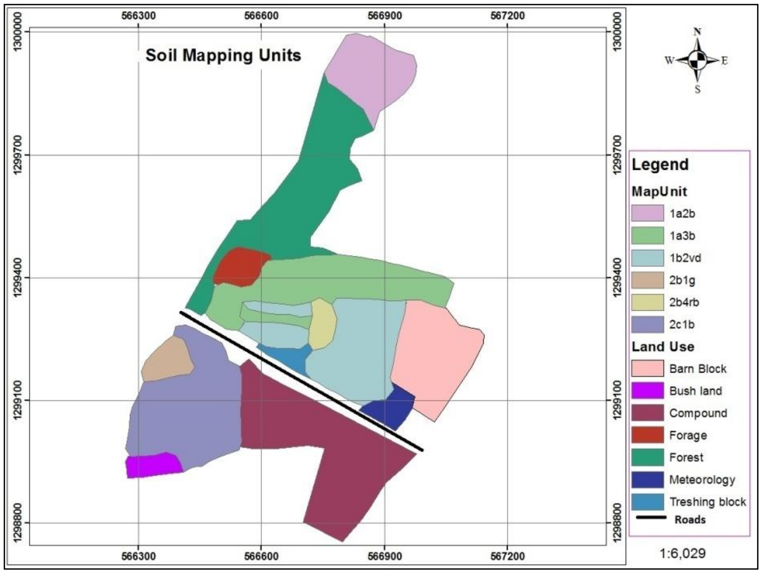

Figure 2. Soil mapping units and the different land uses at SARC

Morphological and Physico-chemical Characteristics of the Soil Mapping Units

The morphological and physico-chemical characteristics of the soil mapping units are discussed in the sections below.

Mapping unit 1: 1a2b

This soil unit refers to the soil behind the forestry arboretum to the north most direction with a regional slope of 4%. Soils of this unit are well drained, very deep (>200 cm) and black 10YR2/1 moist color in the surface and reddish brown (5YR5/3) and grayish (10YR5/1) moist color in the bottom layers. The texture of this soil is dominated by clay (>55%) with weak medium granular structure on the surface layers and strong very coarse prismatic and strong very coarse angular blocky structure in the subsoil and bottom layers, respectively. These soils have a hard consistency when dry and slightly sticky and plastic when wet.

The pH of the surface soil is 7.53 (slightly alkaline) and increases to 7.80 and 8.14 (moderately alkaline) in the sub horizons. The organic matter (OM) content is in the medium to low ranges varying from 2.32 in the surface horizons to 0.99 in the sub soils. But, the second layer lying at the depth of 20-115 cm had an OM content of 3.6% falling in the medium range, which might be presumably due to the movement of surface soil OM to the subsoil through cracks created during the dry season. The total N is in the medium range, 0.169% in the surface soil and decreases to very low, 0.04% in the sub soils. The available P content is in the low to medium ranges (4-10 mg kg^{-1}) and shows an increasing trend along with depth. Ranging from 1.0 to 1.2, 20 to 36, 6.4 to 6.7 cmol(+) kg^{-1} of soil, respectively, the exchangeable K, Ca and Mg fall in the high to very high ranges both in the surface and subsoil layers. The K:Mg concentration in the surface soil varies from 0.19 to 0.15, well below the ideal K:Mg concentration (0.5), indicating a possible antagonistic effect of Mg on K uptake (Hannan, 2011). While the Ca:Mg ratio (3.2-5.5) of the soil layers shows an optimum nutrient balance according to Havlin *et al.* (2016). Being very high based on the rating made by Landon (2014), the CEC ranges from 60.2 in the surface layers to 53.7 cmol(+) kg^{-1} soil in the subsoil layers.

Mapping unit 2: 1b2vd

The soil depth in this mapping unit is greater than 150 cm with deep black 10YR2/1 moist color on the surface and it varies from black 10YR2/1 in the subsoil to reddish brown 5YR5/3 in the bottom. The soil texture varies from clay (>50%) in the surface and subsoils to sandy loam in the bottom layer, while, the soil structure is weak medium granular with moderately sticky and moderately plastic consistency in the surface layer, strong very coarse prismatic with lots of slickenside faces in the subsoil and platy structure in the bottom layers.

The pH of the soil increases downward along with depth ranging from 7.18 (neutral) in the surface soil to 7.45 and 7.82 (moderately alkaline) in the subsoil and bottom layers, respectively. The OM and total N content of the soil which vary from 2.73 and 0.02, respectively in the surface to 1.26 and 0.06, respectively in the subsoil layers fall in the low to medium ranges, while, the available P lies within low ranges (6.7-8.0 mg kg^{-1}) in the surface and subsoil layers. The exchangeable K, Ca and Mg which vary from 1.0 to 1.13, 11.8 to 24.7, 6.9 to 7.2 cmol(+) kg^{-1} of soil, respectively, fall in the high ranges.

The K:Mg concentration in the surface soil was found to vary from 0.16 to 0.15, which is below the optimum K:Mg concentration (0.5), indicating a possible competing effect of Mg on K uptake (Hannan, 2011). The Ca:Mg ratio of 3.4 in the surface soil layer shows a balanced nutrient stock. However, the Ca:Mg ratio (1.7-2.1) in the subsoil layers indicates a tendency of low Ca supply for deep-rooted plants due to possible ion competition from Mg (Havlin *et al.*, 2016). The CEC of the soil varies from 58.0 to 60.0 cmol(+) kg^{-1} and based on the ratings by Landon (2014), it is found to be in the very high range.

Mapping unit 3: 1a3b

Covering the largest portion of the research station, the soil in this mapping unit is very deep (>2m) with a texture varying from clay (>55%) in the surface soil to heavy clay (65%) in the subsoils. The moist soil color varies from dark grayish 10YR4/1 in the surface soil to black 10YR2/1. The surface soil has a weak medium granular structure with moderate stickiness and plasticity, while, the second and third layers of the subsoil have moderate medium angular blocky and strong medium prismatic structure with high stickiness and plasticity, respectively. There are abundant slickenside faces on the surface of the prismatic soil aggregates in the third layer of the subsoil.

Varying from 7.4 to 7.7 (slightly alkaline), the soil pH increases along with depth. While the organic matter content being 1.6% in the surface and 2.06% in the subsoil is in the low range. The total N content of the soil which ranges from 0.109% in the surface soil to 0.067% in the bottom layers is in the medium range, while, the available P content of the soil varies from high (17.0 mg kg^{-1}) in the surface to low (4.0 - 6.0 mg kg^{-1}) in the sub soils. The exchangeable K, Ca and Mg vary from 1.05 to 1.19, 10.7 to 19.9, 6.6 to 7.0 cmol(+) kg^{-1} soil, respectively, are in the high ranges. The K:Mg ratio (0.18 to 0.15) in the surface soil is below the optimum K:Mg nutrient balance (0.5) signifying a possible antagonistic effect of Mg on K uptake. According to Havlin *et al.* (2016), the Ca:Mg ratio of 3.0 of the surface soil layers indicates an optimum nutrient balance between Ca and Mg. However, in the subsoil layers, there is a possibility of low Ca supply for deep-rooted plants due to a competition effect from Mg as the Ca:Mg ratio in the subsoil ranges from 1.6 to 2.7. In both the surface and subsoil layers, the CEC which varies from 55.0 to 60.0 cmole(+) kg^{-1} soil is very high based on the ratings by Landon (2014).

Mapping unit 4: 2b4rb

Soils of this unit are very deep (>175 cm) with the moist color varying from reddish brown 5YR5/3 in the surface layers to dark grayish 10YR4/1 in the sub soils. The texture varies from silt clay in the surface layers to silt loam in the subsoil and bottom layers, while, the soil structure varies from weak medium granular with slight stickiness and plasticity in the topsoil to moderate medium angular blocky with moderate stickiness and plasticity in the sub soils. There are many medium-sized black spots and distinct mottles of Fe and Mn and many $CaCO_3$ concretions. The pH level was observed to be slightly alkaline with an increasing trend from 7.4 to 7.8 across soil depth. The CEC, varying from 56 to 58 cmol(+) kg^{-1} soil, is in the very high range.

Mapping unit 5: 2c1b

The soil is deep (>170 cm) with deep black 10YR2/1 moist color on the surface and gray 7.5Y5/1 moist color in the sub soils. The texture varies from heavy clay on the topsoil layer to silt clay in the subsoil layers. Whilst, the soil structure varies from strong medium prismatic in the top layer with a consistency of highly sticky and highly plastic to strong medium angular blocky structure with a consistency of slightly sticky and slightly plastic in the subsoil. The CEC varying from 57.0 to 60.0 cmol(+) kg^{-1} soil is in all the soil layers is in the very high range.

Mapping unit 6: 2b1g

The soil is very deep (>170 cm) with moist soil color of dark brown 7.5YR4/3 on the surface, grayish 7.5Y5/1 in the middle layers and black 7.5YR1.7/1 at the bottom. The soil texture varies from clay loam in the surface layers to sandy loam and silty clay in the sub-surface and bottom layers, respectively. Whereas, the soil structure varies from weak medium granular with highly sticky and highly plastic consistency on the surface to weak medium prismatic structure with slight stickiness and plasticity in the middle and bottom layers. The CEC varies from 44.0 to 56.0 cmol(+) kg^{-1} soil and based on the ratings by Landon, 1991, it is in the very high range.

Soil Classification

Based on the IUSS Working Group WRB (2014) soil classification system, two reference soil groups, Eutric Vertisols, and Haplic Cambisols were able to be identified. Eutric Vertisols covers 93.1% of the total area (all except soil mapping unit 4; 2b4rb), while, 6.9% of the area (mapping unit 4-2b4rb) is classified as Haplic Cambisols.

Overall Soil Physico-chemical Properties

Soil depth

Almost all of the soil in the research station is very deep (>150 cm) capable of supporting annual and perennial plant growth.

Soil texture

The majority of the surface and sub-soil layers of SARC main research station vary from clay to heavy clay.

Soil structure

Weak medium granular soil structure dominates the surface soils. While the subsoil layers have strong medium prismatic soil structure with abundant slickenside and with some strong medium angular block and blocky structures at the bottom layers.

Soil reaction/Soil pH

The soil pH of most of the area in the research station is in the neutral to a slightly alkaline range (6.9-7.8).

Organic matter

The organic matter content of the surface soil ranges from 1.59 to 2.73% (Figure 3), which falls in the low range based on the critical ratings made by Tekalign *et al.* (1991).

Total nitrogen

The total N content of the surface soil ranges from 0.022 to 0.169% (Figure 4), which, based on the critical ratings made by Tekalign *et al.* (1991), is in the low to medium range.

Available phosphorus

The available phosphorus content of the surface soil ranges from 4.0 to 15.8 mg kg^{-1}, which is in the low to a medium level based on the ratings made by Cottenie (1980). And, it decreases downward in the sub-soils.

CEC and exchangeable bases (K, Ca, Mg and Na)

The CEC of most of the surface soil and subsoil layers ranges from 45 to 60 meq/100 g soil which is in the very high range. Similarly, the exchangeable bases such as K, Ca (Figure 5) and

Mg (Figure 6) content of the surface and sub-soils are also within high to very high ranges based on the ratings made by Jahn *et al.* (2006).

Cationic Balance

The K:Mg concentration of most of the surface soil is below the ideal K:Mg concentration (0.5) which indicates a possible antagonistic effect of Mg on K uptake. While the Ca:Mg ratio of the surface soil layers shows a balanced nutrient balance (3-6). However, the Ca:Mg ratio in the subsoil layers is below 3, which indicates a possible disruption in the Ca supply and uptake by deep-rooted plants due to ion competition effect from Mg.

Soil Maps

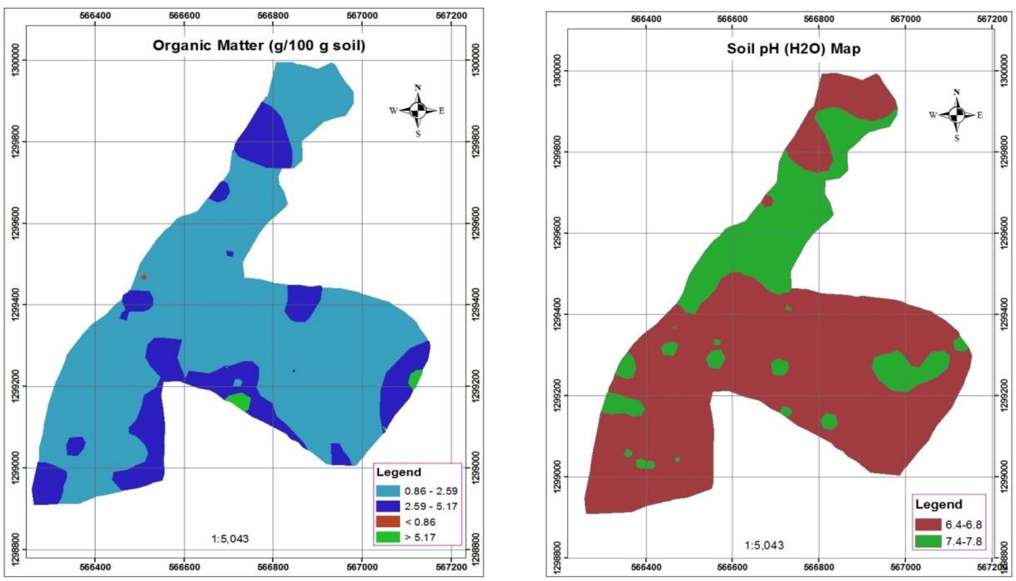

Figure 3. Soil map of organic matter (< 0.86 - Very low; 0.86-2.59 - Low; 2.59-5.17 - Medium; >5.17 - Very high) and soil pH (H_2O) (6.4-6.8 - Slightily acidic to neutral; 7.4-7.8 - Slightily alkaline)

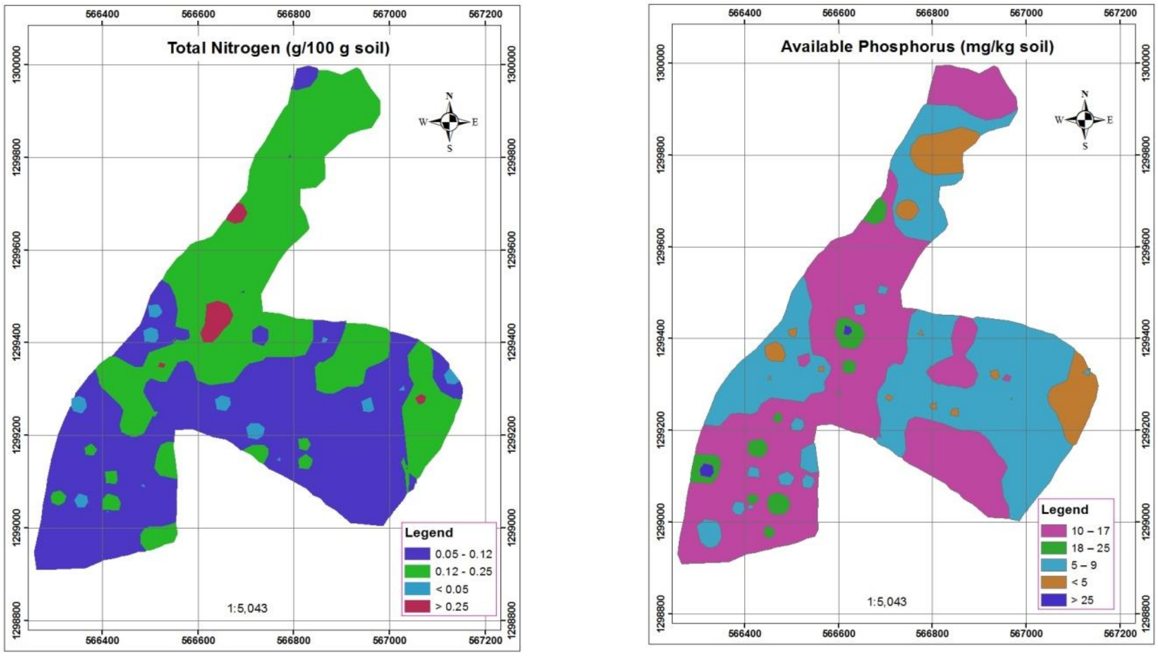

Figure 4. Soil map of total N (< 0.05 - Low; 0.05-0.12 - Medium; 0.12-0.25 – High; > 0.25 - Very high) and available P (> 25 - Very high; 18-25 - High; 10-17 - Medium; 5-9 - Low; < 5 - Very low)

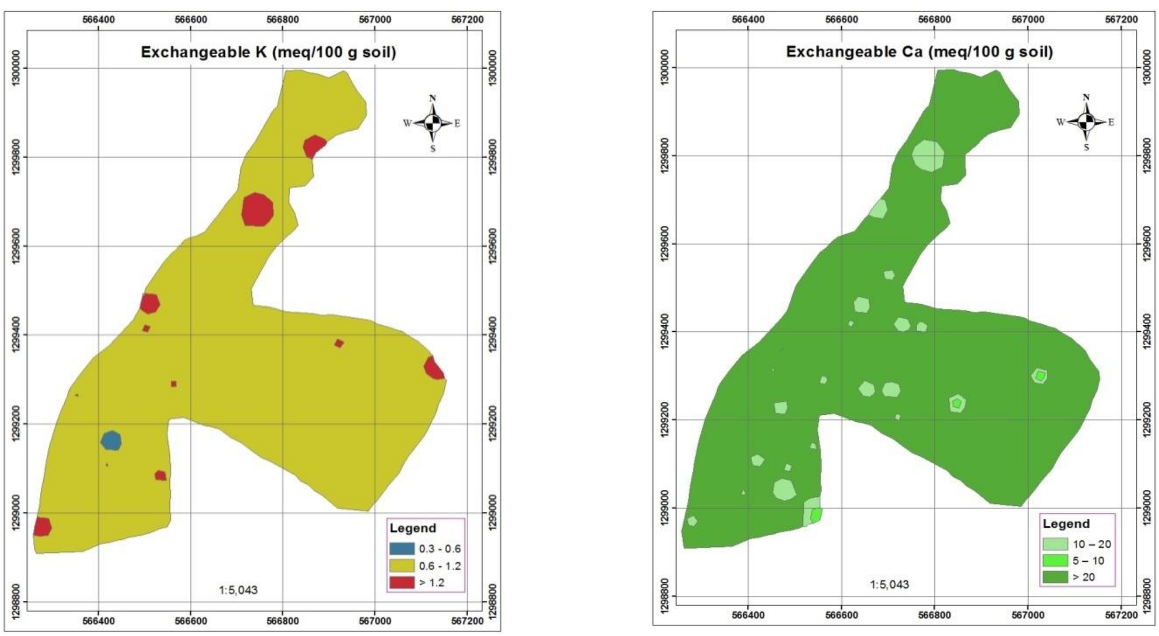

Figure 5. Soil map of exchangeable K (0.3-0.6 – Medium; 0.6-1.2 - High; > 1.2 - Very high) and Ca (5-10 - Medium; 10-20 - High; > 20 - Very high)

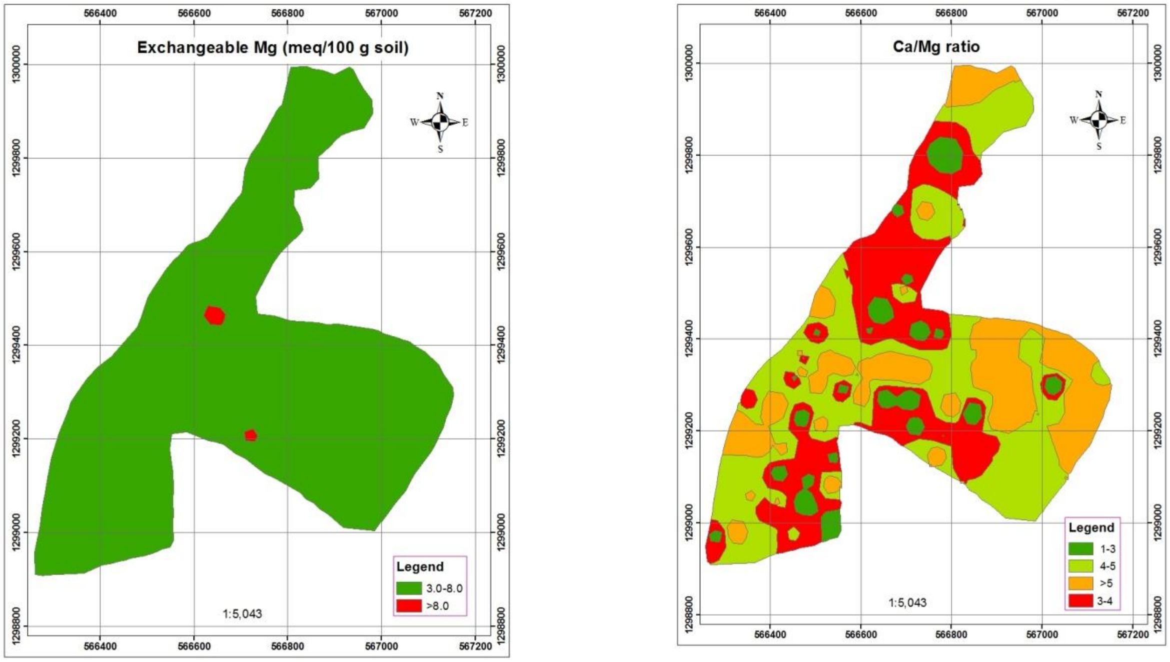

Figure 6. Soil map of exchangeable Mg (3-8 - High; > 8 - Very high) and Ca:Mg ratio

Conclusions and Recommendations

The soil characterization study result of SARC main research station shows that the research station is potentially productive and deep soil capable of supporting annual and perennial crop production. The soil is dominated by clay texture with a moderate medium granular structure in the surface layer and heavy clay texture with a strong medium prismatic structure in the subsoil layers. While the cation exchange capacity of the surface and sub-surface soil is in the very high range dominated by Ca, Mg and K, which are in the high and very high ranges. However, the K:Mg concentration ratios, particularly in the surface soils, indicated an imbalance in the relative concentration of K as compared to Mg which may result in an antagonistic effect of Mg on K uptake which may, in turn, lead to K deficiency. On the other hand, the Ca:Mg ratio shows an optimum nutrient stock in the surface soil and imbalance in the subsoil which may lead to a Ca deficient condition especially for deep-rooted plants. Therefore, nutrient response studies and K fertilization should be considered for balanced plant nutrition in the research station.

The soil fertility assessment of the surface (0-40 cm) soil samples collected in 50 m x 50 m grids revealed that there is spatial variability of soil nutrients within the research station. The surface soil is dominated by clay texture with neutral to slightly alkaline soil reaction. The organic matter and total N content in the surface soil are low. Thus, the organic matter and N content of the soil should be restored by applying different organic amendments and practicing integrated soil fertility management. The available P level varied from low to medium indicating the importance of P fertilization. Based on the soil profile studies, two soil types, eutric Vertisol, and haplic Cambisol, were identified. The dominant soil type is eutric Vertisol with haplic Cambisol covering only 6.9% of the area.

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Soil Fertility Characterization and Mapping of Aybra Research Station in Wag-Hemira Ethiopia

Workat Sebnie*, Belaynesh Asgedom and Gebrehana Girmay

Sekota Dryland Agricultural Research Center, P.O. Box 62 Sekota, Ethiopia

*Corresponding autho: Wokat Sebnie, email: workat71@yahoo.com

Abstract

Periodic soil characterization and mapping of soil attributes can help to apply appropriate agricultural technologies and effective design of soil fertility management techniques. Therefore, this experiment was designed to characterize, classify and map the soils of Aybra research main station of SDARC in 2015. Three mapping units were identified on the basis of the slope, depth, and texture. In each mapping unit, three representative soil profiles were opened and profile description was made based on the Food and Agricultural Organization (FAO) guidelines. The reference soil group and subgroup classification were finally made based on the FAO World Reference Base for Soil Resources (WRB) international soil classification system. Soil samples were collected from each horizon, prepared and taken to the laboratory for the determination of selected soil physico-chemical properties following the standard procedure. The soils were generally very dark gray to very dark brown. Overall, the soil of Aybra had friable consistency, medium bulk density (1.24-1.39 g/cm^3), subangular to angular blocky structure. The pH (6.9- 7.8) of the soils were neutral to moderately alkaline and low organic matter and total nitrogen. The CEC value of the soil was high to very high and available Phosphorous contents of the surface soil was high to low (12.02-7.29 mg kg^{-1}). Exchangeable Calcium content (9.80-6.60 coml$_c$kg^{-1}) of the surface soil was medium while exchangeable potassium (4.8-2.5 coml$_c$ kg^{-1}) and Magnesium (5.2-3.2 coml$_c$ kg^{-1}) contents were high. The PBS ranges from (35.19-66.37%) and in all profile of studied site was above 35.19% medium to high. The concentration of extractable Zinc (0.43-0.19 mg kg^{-1}) and Copper (1.99-1.37 mg kg^{-1}) were low in surface horizon whereas the concentration of Manganese (20.03-10.64 mg kg^{-}) was medium and Iron (2.81-1.11 mg kg^{-1}) was medium to low. Based on survey and soil analytical data three soil types were identified. Leptic Cambisols, Haplic vertisols and Haplic Leptosols.

Keywords: *Horizon, mapping unit, soil characterization, soil classification, soil fertility*.

Introduction

Soil classification is one of the most important stages in natural resources assessment. Soil fertility assessment through their physical, chemical and biological properties and mapping can help to apply appropriate agricultural technologies and effective design of soil fertility management techniques. Successful agriculture to meet the increasing demands of food, fiber, and fuel from the decreasing per capita land requires the sustainable use of the soil because it is an important non-renewable land resource determining the agricultural potential of a given area. As a result, the study and understanding of soil properties and their distribution over an area has proved useful for the development of soil management plan for efficient utilization of limited land resources. Moreover, it is very important for agro-technology transfer (Boul *et al.*, 2003). Therefore, soil characterization and classification which provide with knowledge on soil properties are vital in designing appropriate management strategies in agriculture and natural resource for sustainable development.

Periodic assessment of important soil properties and their responses to changes in land management is necessary in order to improve and maintain the fertility and productivity of soils (Aassai and Gebrekidan, 2003). An increase in agricultural production, particularly rain-fed cropping, is a function of soil, climate, and agro-technology. The proper understanding of the nature and properties of the soils of the country and their management according to their potentials and constraints is imperative for maximization of crop production to the potential limits (Abayneh and Berhanu, 2006). As regards soil studies, a number of surveys have been carried out for different purposes at different times by different institutions. These surveys cover a sizable area of the country. A detailed survey is necessary to characterize soils at research centers for the proper understanding of the research media and reliable extrapolation of research outcome (Abayneh *et al.*, 2006). Therefore, this experiment was conducted with the objective of characterizing of the soils of SDARC research sites Aybra based on morphological and selected physiochemical properties of the soil.

Material and Methods

Area Description

Sekota Dryland Agricultural Research Center (SDARC) is located in Amhara National Regional State, Wag-Himra Administrative Zone. It is at about 797 Km North West of Addis Ababa. Its geographical extent is 12^{o} 43’ 651’’N and to 39º 02' 27’’E (Figure 1).

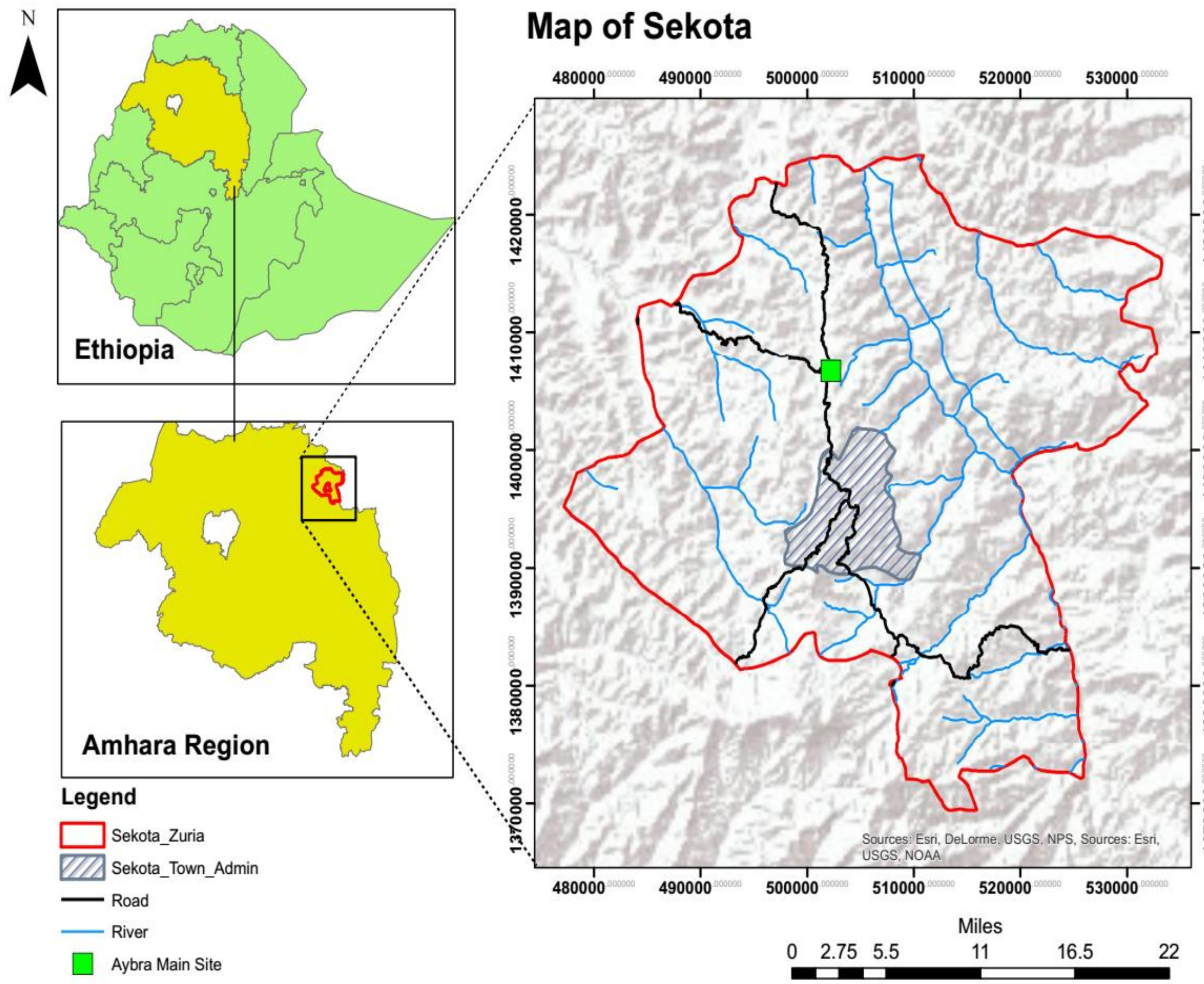

Figure 1. Location map of Aybra main trial site of SDARC

Climate

Five years (20010-2014) data obtained from Kombolcha meteorological station indicates that the study area receives a mean annual rainfall of 769.9 mm. The high amount of rainfall occurring during the main rainy season between July to August (*Kiremt*). The highest rainfall is received in August. Based on 5 years climate data (2009-2013), the mean minimum and maximum annual air temperatures of the area are 9.1 and 31.56 ºC, respectively, with a mean annual air temperature of 20.33 ºC (Figure 2). Referring to the time series mean value; the warmer month was found to be June followed by May while the colder month of the time period was January (Figure 2).

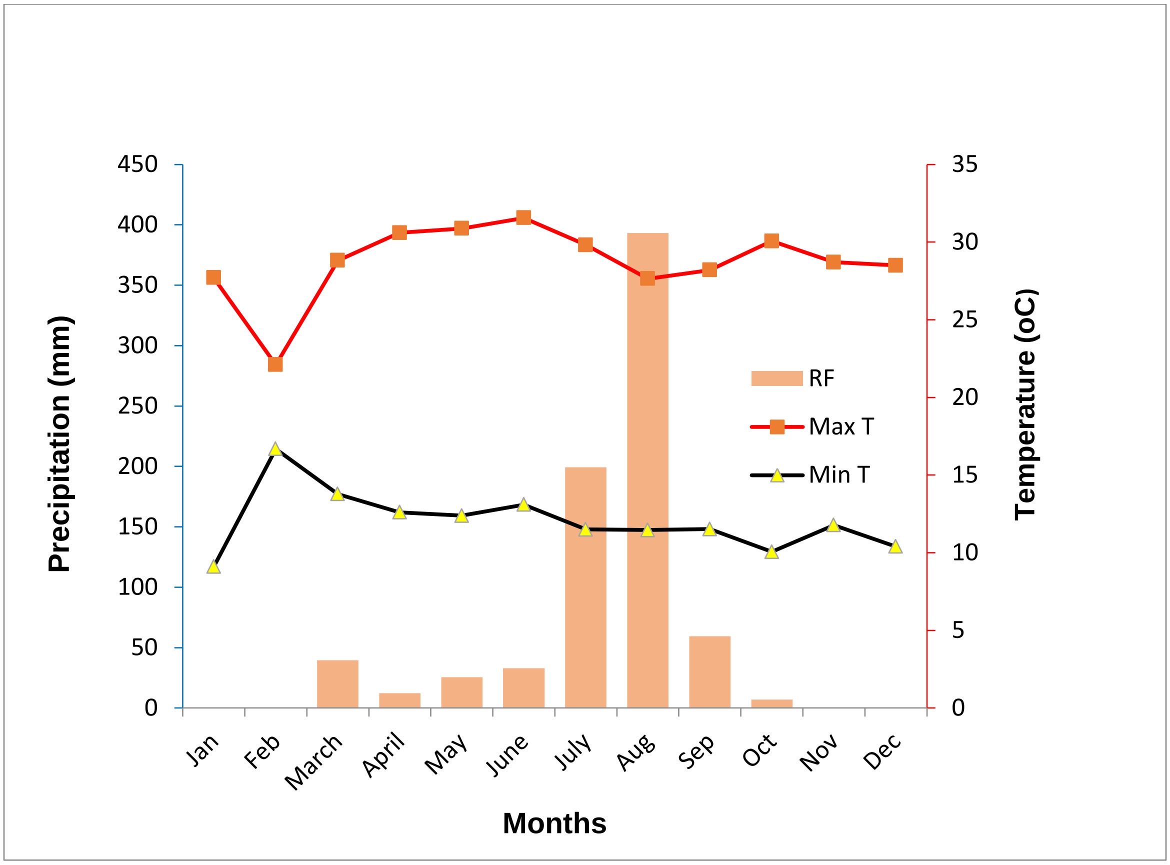

Figure 2. Mean monthly rainfall (2009-2013) and mean monthly minimum and maximum temperatures (2009-2013) of the study area

Field study

In general Auger, observations were made to study land and soil characteristics of the farmland. The augers were made with "Edelman" auger to a depth of 1.2 m unless soil depth is limited or augering is impracticable due to stoniness. The survey technique was a fixed-grid of 50 m by 50 m. In some irregular units, additional observations were made to study the variability. In total 88 auger observations were made (Figure 3). For further soil characterization, 3 soil profile pits (1.5 m width and 2 m length) were dug on representative sites selected based on slope, soil texture, and depth. The soil profile descriptions was made according to (Shand, 2007) system were recorded on the standard form for soil profile description. A total of 7 disturbed and 7 undisturbed (core) soil samples were collected depth wise from each evident genetic horizon for laboratory analysis.

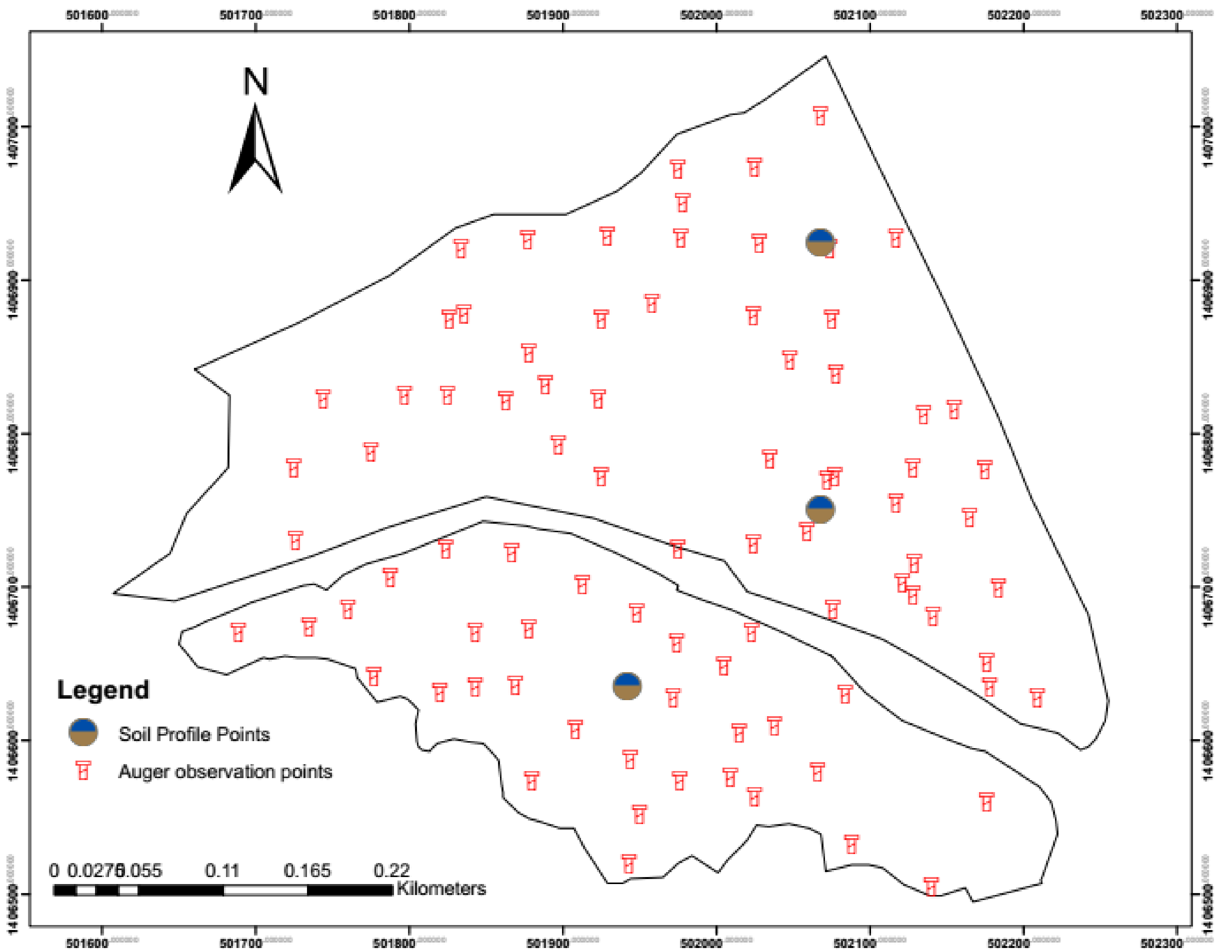

Figure 3. Distribution of auger observation points of the study area

Soil mapping units

Homogeneous land units have been distinguished on the basis of the following three major land/soil characteristics: slope, soil depth, and surface soil texture. Slope percentage in the farm ranges from 0 to 10 and land facets were grouped according to their general slope classes at the first level of generalization. Following, soil depth, as it varies significantly from the farm, was considered to further group homogenous land units of the farm. Land with uniform slope and soil depth was further subdivided on the basis of surface texture. Thus, the soil map of the farm indicates areas that are uniform in slope, soil depth and surface texture (Table 1). In general, 3 different mapping units have been identified (Table 2).

Table 15. Distinguishing criteria of the mapping units

Slope [%]		Soil depth [cm]		Texture [0-20 cm]	
Range	Code	Range	Code	Type	Code
0-3	1	>150	A	Heavy clay	1
3-8	2	100-150	B	Clay	2
8-15	3	50-100	C	Clay loam	3
15-20	4	50-30	D		
<30	5	<30	E	Clay loam	5

Table 2. List of mapping unit identify in Sekota Dry-land Agricultural Research Center

Mapping unit	Profile no.	Slope	Soil depth	Texture	Areas		Soil unit (WRB 2014)
					ha	%	
1a1	2	0-3	>150	Heavy clay	5.02	26.01	Haplic Vertisols
2b2	1	3-8	100-150	Clay	8.31	43.05	Leptic Cambisols
5e4	3	>30	26	Clay loam	5.97	30.94	Haplic Leptosols

Soil Analysis

The soil samples collected from every identified horizon were air-dried and ground to pass through 2 mm sieve. For the determinations of total N and organic carbon (OC), a 0.5 mm sieve was used. Analysis of the physicochemical properties of the soil samples was carried out following standard laboratory procedures. Bulk density was determined using the core-sampling method (BSI, 1975). Particle size distribution was analyzed by using the ratio method. Soil pH was determined in H_2O using 1:2.5 soils to solution ratio using a combined glass electrode pH meter (Carter and Gregorich, 2006),

Total N was analyzed by the Kjeldahl digestion and distillation procedure (Bremner and Mulvaney, 1982), whereas OC was determined following the wet combustion method of Walkley and Black as outlined by Van Ranst *et al.* (1999). The available phosphorus was determined using the standard Olsen extraction method (Olsen *et al.*, 1954). Extractable micronutrients Fe, Mn, Zn, and Cu were extracted from the soil samples with Diethylene Triamine Pentaacetic Acid (DTPA) as described by Lindsay and Norvell (1978). All the micronutrients extracted were measured by atomic absorption spectrometry (AAS). As it is mentioned in Annex, the soil nutrient level classifications and ratings were made based on (Cottenie, 1980; Tekalign *et al.*, 1991; Jones, 2002; Jahn *et al.*, 2006; Hazelton and Murphy, 2016). Finally, analysis of simple correlation coefficient among the different soil physical and chemical properties were carried out using SAS (1997) software to reveal the magnitude and direction of relationships between each other.

Result and Discussion

Physico-chemical Characteristics of the Mapping Units

Mapping unit 1a1

This unit refers to moderately sloping and had deep and moderate deep soil. The soil pedon has subsurface sandy loam texture, evidence of change in soil structure from weak fine granular to moderate medium sub-angular in the subsoil, it covers 8.31 ha or 43.05% of the farm. The soil color dark brown (7.5 YR3/4) in color when dry and moist. The texture is varied from clay loam silt clay loam. These soils have a consistency that is friable when moist and plastic to very plastic when wet. The pH of surface soil is 6.9, increasing to 7.1 in subsurface horizons and the electrical conductivity ranges between 0.15 and 0.27 ds/m surface to subsurface respectively. The cation exchange capacity of the soils is a range as medium (25.2 to 32.64 cmol (+)/kg soil) and its percentage base saturation ranges from 41.69 to 66.37%, increasing with depth. The organic matter and total nitrogen content decrease with depth and their values range from 0.34 to 1.55% for organic matter and 0.011 to 0.028 % for total nitrogen; while available phosphorous is low which ranges (4.98 to 8.10 ppm). Available exchangeable cations range between 9.4 to 7 cmolc kg^{-1} for Ca, 5.0 to 3.4 cmolc kg^{-1} for Mg, 4.8 to 2.60 for K and 0.63 to 0.14 for Na. Available micronutrients range between 2.81 surface horizon to 7.29 mg kg^{-1} subsurface horizon for Fe, 23.03 mg kg^{-1} surface to 6.41 mg kg^{-1} subsurface horizon for Mn, 0.36 mg kg^{-1} to 0.97 mg kg^{-1} surface to subsurface horizon respectively for Zn and 1.99 mg kg^{-1} to 0.48 mg kg^{-1} for Cu.

Mapping unit 2b2

This mapping unit refers to those located in flat and gently sloping areas as compared with others and had very deep soil. It covers 5.02 ha or 26.01% of the farm of the research center. The soil of mapping unit had soil color (dry) of very dark gray (7.5YR3/1) to brownish yellow (10YR6/6 whereas color in moist ranging from very dark gray (7.5YR 3/1) to dark brown (7.5YR 3/4) in surface soil. The dry color pattern of subsurface soil color varied from very dark grayish brown (10YR3/2) to very pale brown (10YR7/3) whereas, the moist color ranged from dark brown (7.5YR3/2) to brown (7.5YR5/3). Consistency of the surface horizons was from hard to slightly hard when dry, friable to very friable when moist, very sticky to sticky and very plastic to slightly plastic when wet at surface horizons. On the other hand, the subsurface horizons had slightly hard to very hard when to dry very friable to losses when moist, very sticky to slightly sticky and plastic to slightly plastic when wet consistency. The textural class was clay (43.1%). The pH of surface soil is 6.9 increasing to 7.8 in subsurface horizons and the electrical conductivity ranges between 0.15 mS/cm surfaces to 0.22 mS/cm subsurface. The cation exchange capacity of the soils was high in the surface horizon whereas high to very high in subsurface horizon. The organic matter ranges from 1.55 to 1.48 % surface to subsurface and total nitrogen content ranges from 0.076 to 0.038 surface to subsurface; while available phosphorous is medium to low (12.02 to 7.66 ppm). The exchangeable cation ranges from 6.6 to 11.0 for Ca, 3.20 to 6.80 for Mg, 2.5 to 2.58 for K, 0.65 to 0.83 for Na in surface to subsurface. Available micronutrients range between 1.89 to 2.03 ppm for Cu, 0.43 to 0.13 for Zn, 10.64 to 7.43 for Mn and 1.91 to 1.10 for Fe from the surface to subsurface horizon.

Mapping unit 5e4

This mapping unit is located in steep and gentle slopping as compared with other mapping units and had shallow soil depth. It covers 5.97 ha or 30.94% of the farm of the research center. The soil of mapping unit had soil color (dry) of brownish yellow (10YR6/6) to dark brown (7.5YR3/4 when moist in surface soil respectively. Consistency of the surface horizons was from hard to slightly hard when dry, friable to very friable when moist, very sticky to sticky and very plastic to slightly plastic when wet at surface horizons. On the other hand, the subsurface horizons had slightly sticky to slightly plastic when to wet and very friable to slightly hard when too moist to dry respectively. The textural class was clay loam. The pH of surface soil is 6.9 in subsurface horizons and the electrical conductivity was 0.25 dS/cm surfaces horizon. The cation exchange capacity of the soils was 32.48 in the surface horizon. The organic matter of the surface horizon of the mapping unit was 0.97 % and total nitrogen content was 0.028 in the surface horizon; while available phosphorous is low (7.29 mg kg^{-1}). The exchangeable cation for Ca was 9.80 cmolc kg^{-1}, for Mg 5.20 cmolc kg^{-1}, for K 2.52 cmolc kg^{-1} and for Na 0.8 cmolc kg^{-1} was recorded in the surface horizon. Available micronutrients Fe was 1.11 mg kg^{-1}, Mn was 11.12 mg kg^{-1}, for Zn 0.19 mg kg^{-1} and for Cu 1.37 mg kg^{-1} was recorded in the surface horizon.

The overall soil physico-chemical properties

Soil color

The surface horizon color (dry) varied from very dark gray (7.5YR3/1) in profile 2 to brownish yellow (10YR6/6) in profile 3. Similarly, color (moist) ranged from very dark gray (7.5YR 3/1) in profile 2 to dark brown (7.5YR 3/4) in profile 1. The dry color pattern of subsurface soil color varied from very dark grayish brown (10YR3/2) to very pale brown (10YR7/3) whereas, the moist color ranging from dark brown (7.5YR3/2) to brown (7.5YR5/3). Surface layers had darker color as compared to the subsurface horizons within each pedon. Dark colored surface horizons (values < 3) are often enriched with OM, offering many benefits to the soil this is attributed to the effect of relatively higher OM content in the surface horizons compared to the subsurface of the soil (Table 1). Many authors reported that the surface horizons have a darker color than the corresponding subsurface horizons as a result of relatively higher soil OM contents (Mulugeta and Sheleme, 2010; Dengiz *et al.*, 2011; Yitbarek *et al.*, 2016).

Soil consistency

The consistency of the surface horizons was varied from hard to slightly hard when dry, friable to very friable when moist, very sticky to sticky and very plastic to slightly plastic when wet at surface horizons (Table 3). On the other hand, the subsurface horizons had slightly hard to very hard when to dry very friable to losses when moist, very sticky to slightly sticky and plastic to slightly plastic when wet consistency. Very sticky and very plastic consistency indicates relatively high clay content could be the change in consistency from the surface to subsoil horizons reflects high contents of clay and low contents of organic matter in subsoil horizons. The result is similar to Mohammed and Solomon (2010) indicated that the consistency of the soil is affected by soil texture. The overall friable consistency of the soils indicates that the soils are workable at appropriate moisture content.

Soil structure

The soil structure varied from subangular blocky, angular sub-blocky and blocky angular structure in their surface horizons pedon 1, 2 and 3 respectively. Subsurface horizon structure ranges from granular to blocky angular. The structure variation is might be due to clay content. The result is concurrent with findings of (Ashenafi *et al.*, 2010) who reported that higher clay content could be a reason for the better development of soil structure.

Table 3. Morphological properties of the soil Aybra research site

Horizon	Depth [cm]	Color		Structure			Consistency				Horizon boundary
		Dry	Moist				Wet		Dry	Moist	
				Grade	Size	Shape	Stickiness	Plasticity			
Profile-1											
Ap	0-30	7.5YR3/4	7.5YR3/4	MO	ME	SB	ST	PVP	HA	FR	C S
AB	30-85	5YR4/4	5YR3/4	WE	FI	GR	SST	SPL	SHA	VFR	A S
B	85-105	10YR4/6	7.5YR4/4	WE	FI	GR	SST	PL	SO	VFR	D S
BC	105-145	10YR5/4	7.5YR3/4	WE	FI	GR	NST	NPL	LO	LO	--
Profile- 2											
Ap	0-30	7.5YR3/1	7.5YR3/1	ST	CO	AS	VST	VPL	VHA	FR	D S
AB	30-155	10YR3/2	7.5YR3/2	VST	CO	AB	VST	PL	VHA	FR	--
Profile-3											
Ap	0-26	10YR6/6	7.5YR3/4	MO	ME	AB	SST	SPL	SHA	VFR	C S

Consistence: SO = soft, SHA = slightly hard, HA = hard, VHA = very hard, LO = loose, VFR = very friable, FR = friable, NST = non-sticky, SST = slightly sticky, ST = sticky, VST = very sticky, NPL = non-plastic, SPL = slightly plastic, PL = plastic, PVP = plastic to very plastic.

Structure: WE = weak, MO = moderate, ST= strong, VST = very strong, CO = coarse, ME = medium, FI = fine, SB = sub-angular blocky, AS=angular and sub angular blocky GR = granular, AB = angular blocky. Horizon Boundary C=clear, G=gradual, D=diffuse, S=smooth.

Particle size distribution

The texture class of the surface horizon varies from loam to clay loam in all profiles (Table 4). The soil at slope 3-8 % had relatively higher clay content (30.2 - 43.1 %) in profile 2. This indicates that finer textures became from the upper slope which may be due to the removal of fine soil particles from steeper slope positions by water erosion. On the other hand, the subsurface horizon textural class ranged from loam, clay loam, and clay. This indicates that finer from the upper slope which may be due to the removal of fine soil particles from steeper slope positions by erosion.

Table 4. Selected Physical Characteristic of The Soils of Aybra Site.

Horizon	Depth(cm)	Sand %	Silt %	Clay %	Textural class	BD g cm^{-3}	TP
Profile 1							
Ap	0-30	37.7	31	31.3	CL	1.20	54.71
AB	30-85	51.16	23.83	25	SCL	1.25	52.83
B	85-105	35	28.7	36.3	CL	1.26	52.45
BC	105-145	35.54	43.91	22.53	L	1.35	49.05
Profile 2							
Ap	0-30	23.5	33.4	43.1	C	1.24	53.20
AB	30-155	40.7	29.1	30.2	C	1.25	52.83
Profile 3							
Ap	0-26	19.5	19.1	36	CL	1.39	47.54

Note: C = clayey, CL = clay loam, SCL = sandy clay loam, BD = bulk density, PD = particle density, TP = total porosity

Bulk and total porosity

The bulk density of the surface horizons varied from 1.25 g cm^{-3} to 1.39 g/cm^{-3} with relatively low to high value and the subsurface horizon ranged from 1.22 to 1.35 g/cm^{3}. The result shows that bulk density increases with increasing depth. The difference in bulk density between surface and subsurface layers might be due to organic matter variation within the depth. The result is concurrent with Ahmed Hussein (2002) and Fisseha and Gebrekidan (2007) who reported that the lowest bulk density was found at the surface horizon. The increasing bulk density with the profile depth is due to low organic matter which is 0.34 % at profile 1 and 1.48 at profile 2. According to Landon (2014), for good plant growth bulk densities should be below 1.4 g/cm^{3} this implies that no excessive compaction and no restriction to root development.

Total porosity

The total porosity (TP) of the soil was from 47.54 to 54.99% in the surface profile 3 and 1, respectively. Total porosity was decreased with increasing soil depth. The surface horizons had relatively higher total porosity than the underlying subsurface horizons. This might indicate low organic matter content were at the subsurface of horizons as compared with the top layer of the soil horizon. The result is in line with the finding of Dereje, (2013) and Alem (2014) who reported that the lower total porosity in the subsurface of the soil layer a result of low OM content and high bulk density. Brady *et al.* (2008) confirmed that reduction of total porosity with depth wise is associated with decreasing with organic matter content.

Table 5. Selected chemical characteristics of soils of Aybra

Horizon	Depth (cm)	pH (1:1.25)	EC (ds/m)	TN [%]	OM [%]	Av.P mg kg^{-1}
Pedon 1						
Ap	0-30	6.9	0.15	0.028	1.55	8.10
AB	30-85	6.7	0.27	0.028	1.18	5.62
B	85-105	7.1	0.2	0.018	1.38	5.46
BC	105-145	6.8	0.16	0.011	0.34	4.98
Pedon 2						
Ap	0-30	6.9	0.15	0.076	1.55	12.02
AB	30-155	7.8	0.22	0.038	1.48	7.66
Pedon 3						
Ap	0-26	6.9	0.25	0.028	0.97	7.29

Soil pH

Soil pH (H_2O) of the surface ranges from 6.9 in profile 1 and 2 to 6.7 in profiles 3 (Figure 4). Whereas the pH (H_2O) of the subsurface horizon was varied from 6.7 to 7.8. Based on Tekalign *et al.* (1991) soil pH rating, the value of surface and subsurface soil horizon of the study area was within neutral to slightly alkaline class (Table 5). Increasing pH value in profile 1 and 2 with increasing depth may be indicated the presence of vertical movements of exchangeable cations, which released from the decomposition of organic matter. Similarly, decreasing organic matter content with increasing depth was concurrent with findings of Ayalew and Beyene (2012) and Dereje (2013).

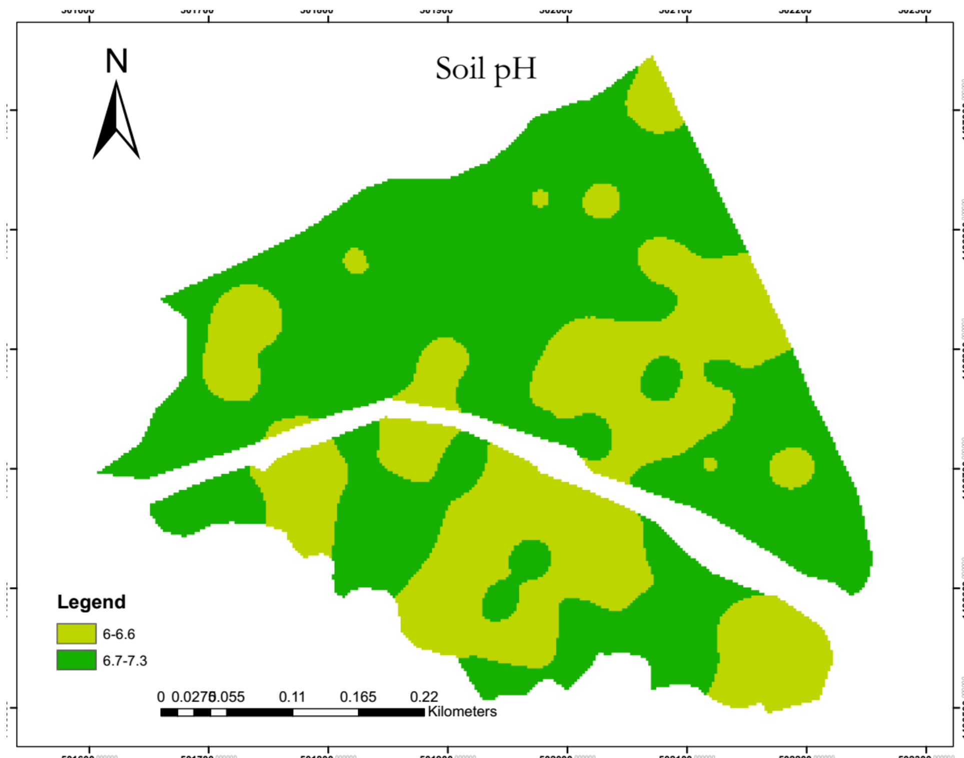

Figure 4. The distribution of P^H value

Electrical conductivity

Electrical conductivity (EC) of the surface and subsurface horizon ranged from 1.5 ds/m in profile 1 and 2 to 1.6 ds/m to 2.7 ds/m surface and subsurface horizons respectively (Table 5). According to low EC value in all the land units in the present study indicate a non-saline condition despite the aridity of the climate and limited rainfall to leach away base-forming cations from the surface soil in the area in general and the study site in particular. low EC value in all the land units in the present study indicate a non-saline condition despite the aridity of the climate and limited rainfall to leach away base-forming cations from the surface soil in the area.

Soil organic matter

The organic matter content in surface horizons of the soil ranged from 1.55 % in profile 1 and 2 to 1.51% in profile 3 while, in the subsurface horizon it varies from 0.38 % in profile 1 to 1.48 in profile 2, the organic matter content variation decreases within depth in profile 1 and 2 (Figure 5). The result is similar to Feyissa *et al.* (2006) and Dereje (2013) indicated that the surface horizon showed higher OM than the subsurface. Ayalew and Beyene (2012) reported that the content of organic matter decreases with increasing depth. According to organic matter, the rating is given by Tekalign (1991) organic matter contents 0.86-2.59 is low so, the organic matter content of all studied profile was low organic matter. This might be the fact that the cultivated land soil have low organic matter than uncultivated land of forest lands (Forth, 1990). The result is concurrent with (Alem *et al.*, 2015; Chekol and Mnalku, 2012; Mohammed and Solomon, 2010) reported that the value is similar to most of the cultivated soils of Ethiopia, which have low organic matter content which is attributed to land use histories such as complete removal of biomass from the field and rapid rate of mineralization.

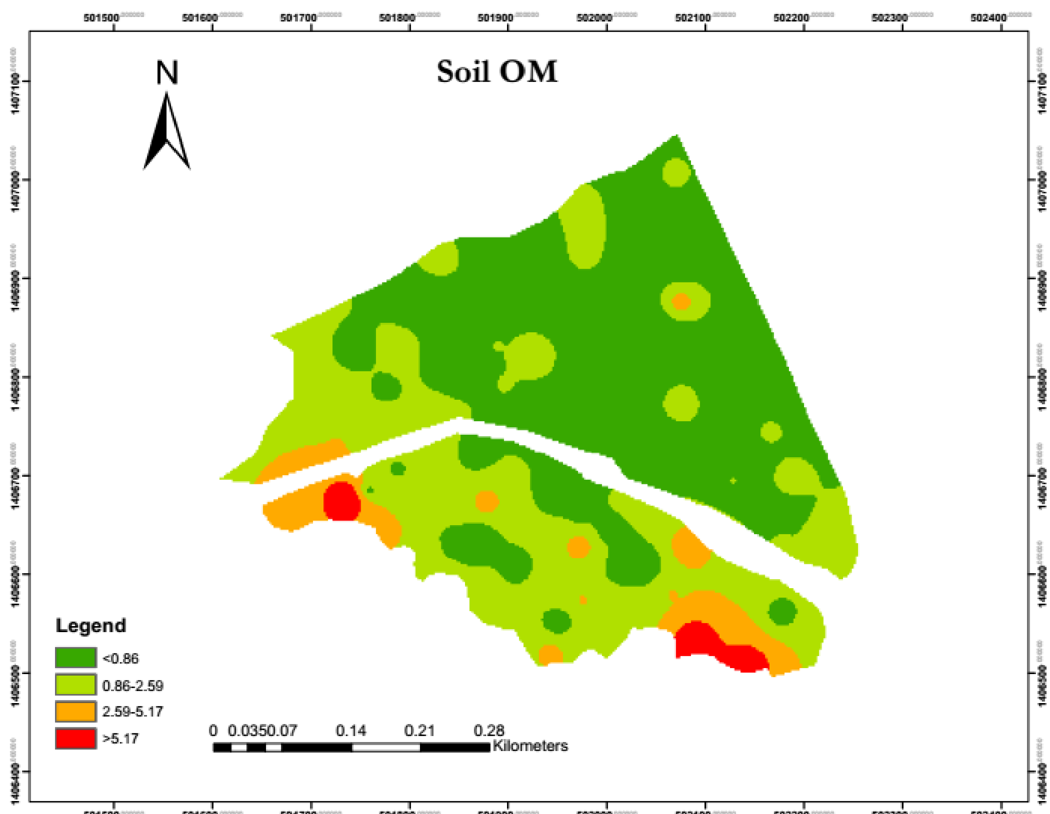

Figure 5. Organic Matter Distribution

Total Nitrogen

Total nitrogen content of the soil surface horizons ranges from 0.028 in profile 1 and 3 to 0.078 in profile 2. In the subsurface horizons, it ranges from 0.011 in profile 1 to 0.038 in profile 2 (Figure 6). According to total nitrogen, the rating is given by Tekalign (1991) total nitrogen content between 0.01 to 0.12 is low. Hence the total nitrogen content of the studied profile was low. The presence of very low total nitrogen in all profiles could be as a result of variation in the amount of organic matter available in the soil. Ashenafi *et al.* (2010) reported that intensive and continuous cultivation aggravated OC oxidation, resulting in a reduction of total N as compared to virgin land.

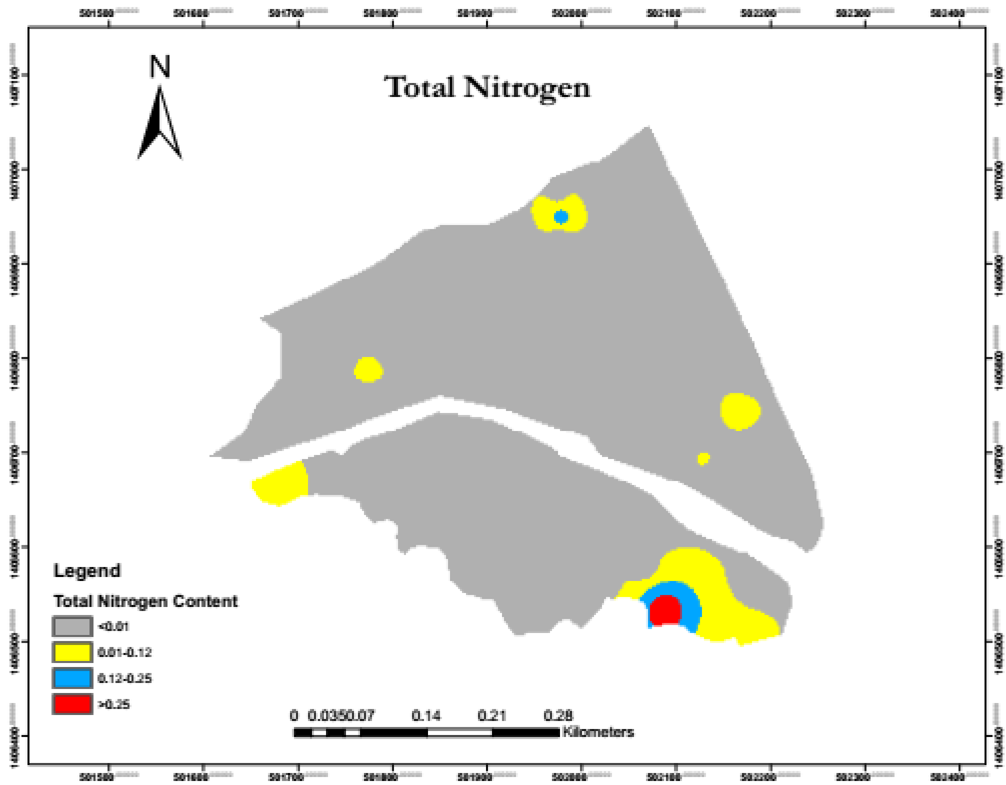

Figure 6. Total Nitrogen Distribution

Available phosphorus

The available phosphorus contents extracted by the Olsen method were medium in all surface horizons except in profile 2 which was high (Table 5). The available phosphorus contents in the surface horizons ranged from 12.02 mg kg^{-1} to 7.29 mg kg^{-1}. Whereas the available phosphorus contents in the subsurface horizons ranged from 7.66 mg kg^{-1} to 4.98 mg kg^{-1}. Available P decreased with the profile depths this result is in agreement the finding of Ashenafi *et al.* (2010) and Alem (2014) who reported that highest amount of Av. P contents of the soil was recorded in the surface horizon. The highest amount of Av. P contents of the soils in the surface horizons of all soil profiles as compared to subsurface horizons could be attributed to the difference in organic matter contents of the horizons. According to the rating set by Olson (1954) available P observed in all surface horizons are categorized as low to high levels.

Table 6. Exchangeable cation CEC, Sum of bases, PBS and ESP of Aybra main trial site

Exchangeable cation (cmolc kg-1)							
Horizon	Depth (cm)	Ca	Mg	K	Na	CEC	PBS %
Profile 1							
Ap	0-30	9.40	5.00	4.80	0.63	29.88	66.37
AB	30-85	7.00	3.40	2.62	0.57	32.6	41.69
B	85-105	9.60	4.80	2.69	0.21	32.64	53.00
BC	105-145	7.60	3.60	2.60	0.14	25.2	55.32
Profile 2							
Ap	0-30	6.60	3.20	2.50	0.65	36.8	35.19
AB	30-155	11.00	6.80	2.58	0.83	40	53.03
Profile 3							
Ap	0-26	9.80	5.20	2.52	0.8	32.48	56.40

Cation exchange capacity

The surface horizon soil had high CEC values which ranged from 29.88 to 36.8 $coml_c$ (+) kg^{-1} of soil, whereas the subsurface horizon the level of CEC was high to very high which ranges from 25.2 to 40 $coml_c$ (+) kg^{-1} (Table 6). According to Landon (2014), CEC values are rated < 5 as very low, 5 - 15 as low; 15 - 25 as medium, 25 - 40 as high and > 40 as very high. The high value of CEC in the study soil might be indicated that presence of high clay accumulation. The result is similar to Hussein and Gebrekidan (2002) and Kibret and Hagos (2014) reported that higher CEC values, as a result, the nature of clay and amount of clay accumulation.

Exchangeable bases

The highest exchangeable Ca value was recorded in the surface horizon of Profile 3 (9.8 cmolc kg^{-1}) followed by Profile 1 (9.4 cmolc kg^{-1}), whereas the lowest was obtained in the surface horizon of Profile 2 (6.60 cmolc kg^{-1}) (Table 6). Similarly, the exchangeable values of Ca in the subsurface horizons were higher in profile 2 (11.00 cmolc kg^{-1}) compared to other profiles. The distribution of exchangeable calcium in subsurface horizons shows inconsistency in the studied profiles 1. This could be due to the presence of Ca bearing parent materials at the site of soil sampling that has contributed much to the high exchangeable Ca contents on the soil exchange complex. According to rating set by Shand (2007) the concentration of exchangeable Ca observed in all surface horizons are categorized as medium levels and the concentration exchangeable Ca of subsurface horizon are categorized as high (profile 2) to medium level.

On the other hand, the distribution of exchangeable Mg in subsurface horizons shows inconsistency in the studied profiles 1. The highest exchangeable Mg value was recorded in the surface horizon of Profile 3 (5.20 cmolc kg^{-1}) followed by Profile 1 (5.00 cmolc kg^{-1}), whereas the lowest was obtained in the surface horizon of Profile 2 (3.20 cmolc kg^{-1}). Similarly, the exchangeable values of Mg in the subsurface horizons were higher in profile 2 (6.2 cmolc kg^{-1}) compared to other profiles. According to Shand (2007) the concentration of exchangeable Mg observed in all profile are categorized as high level. The highest exchangeable Na in surface horizon ranged from 0.8 cmol kg^{-1} in Profile 3 to 0.65 cmol kg^{-1} in Profile 2, while in the subsurface horizon exchangeable Na ranges from 8.3 cmol kg^{-1} in profile to 0.57cmol kg^{-1} in profile 1. The concentration of exchangeable Na observed in all profile is categorized as very low level (Shand, 2007). The highest exchangeable K content in the surface horizon ranged from 4.8 cmol kg^{-1} in Profile 1 to 2.52 cmol kg^{-1} in Profile 2. Whereas in subsurface horizon exchangeable K content varies from 2.69 cmolc kg^{-1} in profile 1 to 2.58 cmolc kg^{-1} in profile 2. The concentration of K in surface and subsurface categorized as in very high rang level in all profiles (Shand, 2007). The percent base saturation (66.37) was found to be highest in the surface horizon of profile 1, whilst the lowest (35.19) was recorded in the surface horizon of profile 2. Highest percentage base saturation in the subsurface (55.32) was found in profile 1 and the lowest was found in 41.69 in profile 1. In general percentage base saturation of the experimental site was above 35.19 in all profile studies.

Micronutrient

The micronutrients contents in pedons 2 decreased with increasing soil depth and also Mn and Cu in pedon 1 decreased with increasing soil depth but, Fe and Zn showed an unsystematic pattern with increasing depth in Pedons 1. Highest Fe (2.81 mg kg^{-1}) and the lowest (1.11 mg kg^{-1}) was registered in the surface horizon of Profiles 1 and 3, respectively, whereas in the subsurface horizons it is varied from 7.29 mg kg^{-1} (Profile 1) to 0.98 mg kg^{-1} (Profile 1) (Table 7). In general, extractable Fe in the surface, as well as the subsurface horizons, shows variation in all studied profiles. According to the interpretative values of DTPA extractable micronutrients set by Jones (2002), all the soils of the study area were rated as low to high in their extractable Fe contents surface and subsurface horizon.

Table 7. Available micronutrient contents of soils of the study area

Micronutrient (mg kg^{-1})					
Horizon	Depth (cm)	Fe	Mn	Zn	Cu
Profile 1					
Ap	0-30	2.81	23.03	0.36	1.99
AB	30-85	0.98	17.71	0.97	0.9
B	85-105	7.29	6.41	0.34	0.48
Profile 2					
Ap	0-30	1.91	10.64	0.43	1.89
AB	30-155	1.10	7.43	0.13	2.03
Profile 3					
Ap	0-26	1.11	11.12	0.19	1.37

The highest concentration of extractable Cu was observed (1.99 mg kg^{-1}) in the surface horizons of Profile 1 and the lowest (1.37 mg kg^{-1}) in Profile 3. In subsurface horizons concentration of available Cu ranged from 2.03 mg kg^{-1} in Profile 2 to 0.48 mg kg^{-1} in Profile 1. The depth wise distribution pattern of Cu in Profiles 1 decreased with soil depth, but in the profile 2 increases with increasing depth. According to nutrient critical value levels suggested by Jones (2003) the studied micronutrient level was below at the critical level in all profile. Highest Mn (23.03 mg kg^{-1}) and the lowest (10.64 mg kg^{-1}) was registered in the surface horizon of Profiles 1 and 2, respectively, whereas in the subsurface horizons it is varied from 17.71 mg kg^{-1} (Profile 1) to 6.41 mg kg^{-1} (Profile 1). Extractable Mn in the surface horizons profiles 2 and 3 did not show variation. All the soil samples were rich in Mn, when compared with the critical levels. A highest (0.43 mg kg-^{1}) concentration of extractable Zn was observed in the surface horizons of the Profile 2 and the lowest (0.19 mg kg-^{1}) in Profile 3. In subsurface horizons concentration of extractable Zn ranged from 0.97 mg kg^{-1} in Profile 1 to 0.13 mg kg^{-1} in Profile 2. The lower value observed in all Profile due to slope positions that the topsoil removed by erosion. The depth wise distribution pattern of Zn in profiles 1 did not follow a specific trend. According to the rating set by Jones (2003) the available Zn was in the range of very low to medium in surface and subsurface horizon of studied profiles.

Conclusions and Recommendations

The study was conducted in SDARC main research site of Aybra in wag-himra zone. The result from the field survey and laboratory analysis revealed that three major soil types namely, Cambisols, Leptosols, and Vertisols were identified. The soils were relatively varied in morphological, physical and chemical characteristics. The color of most of the surface soils varied from brownish yellow (pedon 3 which is in the steep slope) to very dark gray (pedon 2 medium slopes). The friable consistency, medium bulk density (1.24 - 1.39 gm/cm^3), subangular to angular blocky structure, indicate that the soils have good physical condition for plant growth. The pH-H_2O of the soils was slightly acid to neutral in the surface soil but in the subsurface soil, it varies from slightly acidic to moderately alkaline. Electrical conductivity values of the surface and subsurface soils ranged from 1.5 to 2.5 ds/m in profile 1 and 3 to1.6 to 2.7 ds/m in profile 1 and 2 in the subsurface. The OM values varied from 0.97% to 1.5% and 0.38% to 1.5% in surface and subsurface horizons respectively. The total nitrogen (TN) content was low to very low while the organic matter (OM) content was low to moderate in most soil types. The concentration of exchangeable Ca observed (9.80-6.60 $coml_c$ kg^{-1}) in all surface horizons are categorized as medium. The exchangeable potassium (4.8-2.5 $coml_c$ kg^{-1}) and Magnesium (5.2-3.2 $coml_c$ kg^{-1}) in all profile surface horizon were at a high level. The PBS ranges from (35.19-66.37%) and in all profile of studied site PBS was above 35.19%.

Extractable iron (Fe) in the soils ranged from 2.81 to1.11 mg kg^{-1}, while extractable Mn ranged from 23.03 to 10.64 mg kg^{-1} in the surface horizon. On the other hand, the contents of extractable copper (Cu) in the soils ranged from 1.99 to 1.39 mg kg^{-1}, while extractable Zn ranged from 0.43 to 0.19 mgkg^{-1}. Surface and subsurface horizon of the study area was characterized by low extractable micronutrient contents. Based on the result, Aybra soils have low organic matter content and it should be maintained with integrated soil fertility management (application of manure, artificial fertilizer, and incorporation of crop residues). Different conservation measures should be in place in the steep slope areas of the site to minimize erosion. Continuous and proper management of the degraded areas of the site should be made through physical and biological soil conservation measures. Fertilizers recommendation/application should be crop-soil-site specific.

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II) Agricultural Water Management

Determination of Irrigation Regime for Hot Pepper in Dryland Areas of Wag- Himira North Eastern Amhara

Aemro Wale*and Gebrehana Girmay

Sekota Dry Land Agricultural Research Center; P.O. Box 62; Sekota, Ethiopia

*Corresponding author email: aemrowale@gmail.com

Abstract

Driven both by climate change and poor water management, droughts are becoming more frequent and water scarcity is growing; therefore, there is an increasing need to alleviate water related challenges, particularly in water scarce and drought affected parts of the study area. A field experiment to verify CROPWAT model estimations was conducted in 2014 and 2015 on Ziqualla (Tsitsika small scale irrigation scheme) and Abergelle (Bahir small scale irrigation scheme) primarily to determine net irrigation requirements and irrigation schedules for hot pepper using CROPWAT computer model and to validate using field trial. A split plot design (replicated three times) with the main plot of water depth and subplot of irrigation frequency has been used. Three levels of water amount with 75%, 100%, and 125% CROPWAT generated depth and three levels of irrigation frequency at 5, 7- and 9-days interval were used as a treatment. Additionally, one irrigation depth and interval with farmers practice have been used as a control. The experimental result showed that application of 75% CROPWAT generated depth at 5 days irrigation interval gave statistically significantly higher marketable hot pepper yield (11220.5 kg ha^{-1} at Ziqualla and 8855.6 kg ha^{-1} at Abergelle) and water productivity (5.06 kg/m^3 and at Ziqualla and 4.10 kg/m^3 at Abergelle) at par with application of 100% CROPWAT generated depth with 7 days with marketable yield of 11385.3 kg ha^{-1}at Ziqualla and 8653.93 kg ha^{-1} at Abergelle and water productivity of 4.55 kg/m^3 at Ziqualla and 4.09kg/m^3 at Abergelle. However, in addition to saving 25% irrigation water without yield penalty, application 75% CROPWAT generated depth at 5 days interval had yield advantage of 5781 kg ha^{-1} and 3.4 kg m^{-3} water productivity at Ziqualla (Tsitsika small scale irrigation scheme) and 3098 kg ha^{-1} marketable yield and 3.1 kg m^{-3} water productivity at Abergelle (Bahir small scale scheme) over the farmers practices. Hence, considering the above results, application of 75% CROPWAT generated depth at 5 days interval was found economically feasible and recommended for both irrigation schemes Ziqualla (Tsitsika) and Abergelle (Bahir) and similaagro-ecologies.

Keywords: *Hot pepper, Irrigation regime, Marketable yield, Wag-Himira, Water productivity*

Introduction

Hot pepper *(Capsicum annum L.)* is an important commercial crop, cultivated for vegetable, spice, and value-added processed products (Nalla *et al.*, 2017). It originated from the American with their cultivars are now grown around the world because they are widely used as food and medicine (Mazourek *et al.*, 2009). It is one of the most susceptible horticultural crops to drought stress due to its broad range of transpiring leaf surface, high stomatal conductance (Alvino *et al.*, 1994) and shallow root system (Kulkarni and Phalke, 2009; Liu *et al.*, 2012). Pepper production accounts for 34% of the total spice production in the three regions of the country namely Amhara, Oromia and Southern Nations Nationalities and Peoples Regional States (Roukens *et al.*, 2005). FAO (2009) report indicated that the estimated production of peppers in Ethiopia was 220,791ton from 97,712ha in green form and 118,514 ton of dry pepper from an area of 300,000ha. The production of peppers in Ethiopia was 45,853.69 tons from 7,449.59 hectares in green form and 262,790.83 tons of dry pepper from an area of 142,795.16 hectares. Even though the average productivity of pepper at the national level in 2016 was 6.16 and 1.84 t ha^{-1}, yield reduction by 0.18 and 0.05 t ha^{-1} was observed for green and dry pepper from 2014-2016 cropping season, respectively (CSA, 2015).

Increase in population has led to an upsurge in the demand of food (pepper) and fiber which has also resulted in the adoption of irrigation to sustain plant growth (Delfine *et al.*, 2001). However, the cumulative need for crop production due to the growing population in the world is demanding a rapid growth of irrigated agriculture throughout the world. As population rises and development calls for, the distributions of ground and surface water for the domestic, agriculture and industrial sectors augmented; as a result, the pressure on water resources strengthens. The increasing stress on freshwater resources transported about by ever rising demand for water is of thoughtful concern (Steduto *et al.*, 2017). Notwithstanding the increase in water use by subdivisions other than agriculture, irrigation carries on to be the main water user on a worldwide gauge. Irrigated agriculture consumes more than 70% of the water haggard from the rivers of the world and for the developing world; the proportion can reach 80% (Food and Nations, 2002). The condition is no more different in Ethiopia. It has been obviously and noisily stated that if Ethiopia is to feed its ever-increasing population, lessen the risk of disasters caused by drought, and increase population density in the dry and thinly populated areas, incessant and extensive effort need to be made towards developing irrigated agriculture and intensifying agricultural production. Irrigation will, therefore, play a progressively important role now and in the upcoming both to increase the yield from already refined land and to permit the cultivation of what is today called marginal or unusable land due to moisture deficiency.

Water availability is the most limiting factor for crop production in the dry land areas of Wag-Himira. Moreover, lack of crop water requirement studies for major crops had been a challenge for appropriate utilization of scarce water resource in irrigated agriculture and it leads to low water use efficiency through improper irrigation scheduling. Determination of water requirement of the crop, appropriate irrigation scheduling can be designed, which can lead to improvements in the yield, income, and water saving (Bossie *et al.*, 2009). To ensure highest crop production with the least water use, it is important to know the water requirement of the crops (Tyagi *et al.*, 2000). This improves the efficient and economic use of irrigation water. However, effective irrigation water management is possible only with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Applying too much water to the plot of land will cause to extra pumping costs, wasted water due to evaporation and runoff, and increased risk for leaching valuable agrichemicals below the rooting zone. Proper timing of irrigation water applications is therefore an important decision tool for a farm manager to meet the water needs of the crop, to prevent yield loss due to water stress, and for maximizing the irrigation water use efficiency which resulted in beneficial use and conservation of the scarce water resources, and minimize the leaching potential of nitrates (Valipour, 2015).

In Wag-Himira Zone, Abergelle and Ziqualla woredas, irrigation scheduling and inadequate management of irrigation water has been an important limiting factors to pepper production. The farmers in general lack knowledge on features of soil-water-plant relationship and they apply water to the crop irrespective of the plant needs. They seem to relate irrigation occurrence to days after planting with fixed intervals and water amounts rather than to crop stage progress. The knowledge of proper irrigation scheduling, when to irrigate and how much water to apply, is essential to optimize crop production per unit water and for sustaining irrigated agriculture on permanent footing (Kirda, 2002). Therefore, this activity was conducted with the objective of determining the net irrigation requirements and irrigation schedule for hot pepper using CROPWAT computer model and to validate using field trial.

Material and Methods

The study sites are located at 1414332N and 475070E Ziqualla; at 1425280N and 495749E Abergelle. The sites are characterized by clay textured soil. The particle size distribution of clay, silt, and sand is 41.29%, 29.92%, 28.79% at Ziqualla (Tsitsika small scale irrigation scheme) and 41.3%, 26.7%, 32% at Abergelle (Bahir small scale irrigation scheme). Field capacity and permanent wilting points of the sites are 32.92% and 19.03% for Ziqualla (Tsitsika small scale irrigation scheme) and 32.51% and 16.28% for Abergelle (Bahir small scale irrigation scheme).

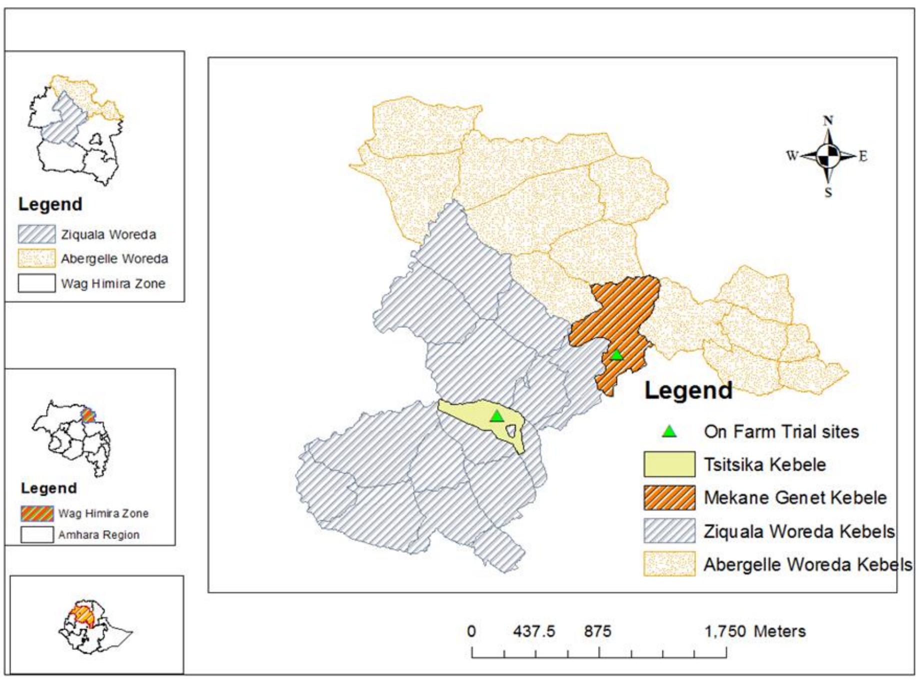

Figure 1. Location map of study areas

Determination of Crop Water Requirement using CROPWAT

Estimation of crop water requirement, net irrigation requirement, and schedule of the water application were carried out with inputs of soil, climatic and crop data using CROPWAT computer programmed. The model requires crop data such as crop type, planting date, duration of growth stage, maximum rooting depth, Kc values, depletion fraction and yield reduction coefficient and climatic data including maximum and minimum Temperature, rainfall, wind, sunshine hours, and relative humidity and soil type. Climatic data of the experimental sites were collected from neighboring stations like Tekez Bridge, Abiyadi, Gonder, and Lalibela and extrapolated using LocClim Software. For estimating the crop water requirement, given the required input data, the reference evapotranspiration was calculated first using the Penman-Monteith equation in the CROPWAT program (Allen *et al.*, 1998). Composite soil samples were collected from field plots and the soil textural analysis was done by hydrometer soil analysis method and soil textural class was determined from soil textural triangle. In addition, the representative soil sample collected from the field with core sampler field capacity, permanent wilting point, and moisture at saturation were determined using Pressure plate apparatus from laboratory analysis of soil samples. Total Available Moisture in the soil for the crop during the growing season was calculated as field capacity minus wilting point times the rooting depth of the crop as indicated as follows. TAM=(FC-PWP)*D, Where, TAM=Total available moisture, FC=water content at field capacity, PWP=water content at a permanent wilting point below it cannot extract by plant roots, D=current root depth of the crop.

Readily Available Moisture (RAM) was calculated as TAM*P, Where P is the depletion fraction as defined by the crop coefficient (Kc) files. The estimated crop water requirements were converted into the field irrigation water requirement. The net irrigation requirement was determined based on the equation. NIR=CWR–Peff, Where, NIR=Net Irrigation Requirement (mm/period), CWR=Crop Water Requirement (mm/period), Peff=Effective Precipitation. The exact volume of water needed to fulfill the irrigation water requirement throughout the growing season was calculated using the equation below.

$$\text{Gross irrigation requirement(mm)} = \frac{\text{Net irrigation requirement(mm)}}{\text{Application efficiency(infraction)}}$$

Water productivity, also known as water use efficiency, was determined as the ratio of crop yield per unit area, in terms of grain, to crop evapotranspiration (mm), and was expressed as kg of grain or biomass per m^3 of consumed water.

$$\text{water productivity}\left(\frac{\text{kg}}{\text{m3}}\right) = \frac{\text{Total yield of green pepper}}{\text{water delivered up to harvesting}}$$

Experimental setup

A field experiment to verify CROPWAT model estimations was conducted in 2014 and 2015. The experiment plot of 2.8m by 3m was used to test irrigation regimes. Hot pepper (Marko fana variety) was selected as test crop. The selected Hot pepper variety has a growing period of 125 days including transplanting up to second harvesting with the initial crop growth stage of about 20 days, crop development stage of 35 days, mid-season stage of 50 days and late season stage of 20 days, which was derived from CROPWAT software. The spacing was 70cm and 30cm between rows and plants, respectively. Blanket recommended fertilizer rate of DAP 100kg at transplanting and urea fertilizer of 100kg at half transplanting and half 45 days was applied in both experimental sites. Both diseases and weed infestation was regularly monitored, and proper management action has been undertaken timely. Cutworms were observed during the early seedling establishments on the actual field, whereas Fusarium wilt was a problem at, vegetative and plant development stages. Karate and Mancozeb (3kg/ha) were used to control the disease infestation which was practiced according to the label (EIAR, 2004).

CROPWAT optimum depth and interval was considered as a benchmark to set ten irrigation regime treatments including farmers practice. Split-plot design with three replications was used at which water depth assigned as main plot and interval as subplot treatments. The depth of irrigation was fixed at 125%, 100%, and 75% of optimum CROPWAT generated depth and irrigation interval of 5, 7, and 9 days. Furrow irrigation was used for applying water at 60% application efficiency.

Data analysis

All the agronomic, yield and water productivity data were recorded and being subjected to analysis. Analysis of variance and correlation was performed using SAS Statistical Software Version 9.1. Effects were considered significant in all statistical calculations if the P-values were ≤ 0.05. Means were separated using Fisher's Least Significant Difference (LSD) test.

Table 1. CROPWAT fixed application depth and optimal time of application on amount of applied water (mm) treatments in the experimental area.

Treatments	Amount of applied water (mm)	
	Ziqualla	Abergelle
125% CROPWAT fixed depth and optimal time of application at 5 days interval	455.3	445.7
125% CROPWAT fixed depth and optimal time of application at 7 days interval	406.9	397.2
125% CROPWAT fixed depth and optimal time of application at 9 days interval	343.2	338.1
100 % CROPWAT fixed depth and optimal time of application at 5 days interval	288.2	295.3
100 % CROPWAT fixed depth and optimal time of application at 7 days interval	284.8	279.4
100 % CROPWAT fixed depth and optimal time of application at 9 days interval	251.1	247.9
75 % CROPWAT fixed depth and optimal time of application at 5 days interval	225.7	229.1
75 % CROPWAT fixed depth and optimal time of application at 7 days interval	233.9	240.7
75 % CROPWAT fixed depth and optimal time of application at 9 days interval	222.9	218.2
Farmers practice irrigation depth and irrigation interval in days (FP)	728.5	796.5

Result and Discussion

As shown in table 2, there was an interaction effect of depth and frequency on marketable yield, total yield, and water productivity at Ziqualla. The result reveals that 75% CROPWAT generated depth with 5 days interval gave marketable yield of 11220.5 kg ha^{-1}, total yield of 11458.6 kg ha^{-1}, and water productivity of 5.06 kg m^{-3}. Whereas, 100% CROPWAT generated depth with 7 days interval provided 11385.3 kg ha^{-1} marketable yield, 11619.2 kg ha^{-1} total yield, and 4.55 kg m^{-3} water productivity. There was statistically non-significance difference in marketable, total yields and water productivity between 75% and 100% water depth at 5 and 7 days interval respectively. In addition, 75% water depth with 5 days interval gave 5780.9 kg ha^{-1} and 100% water depth with 7 days gave interval gave 5945.6 kg ha-1 yield advantage over the farmers' irrigation practices. Moreover, there was statistically significant difference between 100% and 125% water depth at 5 days interval and 75% and 125% water depth at 7 days interval on marketable yield, total yield, and water productivity. In general, 75% depth at 5 days interval provided better yield.

The result in agreement with the finding of Khalkho *et al.* (2013) reported that yield and growth parameter data revealed that the crop receiving irrigation at 60% available soil moisture offered the maximum green hot pepper yield of 9145 kg/ha. Yang *et al.* (2017) stated that water deficit from reducing irrigation amounts to 1/3 to 2/3 of full irrigation during the development and middle stages did not affect pepper yield; compared with full irrigation, the water deficit even increased fruit yields. These results occurred mainly because the water content under deficit irrigation in the study by Yang *et al.* (2017) still reached higher than 70% of FC, which is sufficient for pepper growth (Liu *et al.*, 2012). At the same time, full irrigation with a water content of 100% of FC in their study is very high and can reduce pepper yields (Liu *et al.*, 2012).

The irrigation application of 75%, 100% and 125% CROPWAT generated depth at 9 days interval; however, contributed the lowest marketable yield, total yield, and water productivity. 75% and 100% CROPWAT generated depth at 5 and 7days irrigation application intervals used about a total seasonal water amount of 225.7mm (2257m^3/ha) and 284.8mm (2848m^3/ha) hot pepper crops in Ziqualla respectively. However, irrigation application of 100% application depth at 5 days interval presented 9085.1kg/ha of marketable yields that results in 3.85kg/m^3 of water productivity by using 2882m^3/ha of water. The irrigation scheduling of the farmers' practice furnished 5711.1kg/ha yields and 1.64kg/m^3 of water productivity by using 7285m^3/ha amount of water. Compared that the water productivity of 75% and 100% application depth at 5 days irrigation interval, an amount of 625m^3/ha water was saved by applying 75% irrigation generated depth at 5 days interval. This could be used for irrigating an additional land of 0.28 ha.

This finding in line with Serna Perez and Zegbe (2012) described that hot pepper study, a water deficit of 15–45% can conserve 8–30% of irrigation water, and compared with full irrigation, a water deficit of 60% produced the highest percentage of marketable fruit but at similar yields as those under full irrigation in 2 of 3 years, consequently increasing irrigation water productivity. Compared with full irrigation, deficit irrigation can reduce irrigation depths by 20–50% and ultimately result in a higher water productivity (Dorji *et al.*, 2005; Gençoğlan *et al.*, 2006; Gonzalez-Dugo *et al.*, 2007; Yang *et al.*, 2018; Al-Ghobari and Dewidar, 2018; Abayomi *et al.*, 2012). Likewise, related the irrigation application of 100% and 125% at 7days interval each saved 1221m^3/ha amount of water, which could irrigate additional land of 0.42ha. Moreover, in comparison to the farmer's practice, irrigation application of 75% generated depth at 5days interval and 100% depth at 7days irrigation interval saved 5028m^3/ha and 4437m^3/ha amount of water, correspondingly. This could be used to irrigate an additional land of 2.2ha and 1.5ha with a yield benefit of 25207kg/ha and 17428 kg/ha of hot pepper crop production, respectively.

While observing variations among treatments, the only variation for the experiment was water application depth and time of application among treatments throughout the hot pepper growth stage. The variation in water amount applied to each irrigation was attributed to the K_c value variations in the stages of crop growth. As it is observed from the experiment, crop water requirement was low at the initial stage, increased during the development stage, reached a maximum at the mid-season stage, and declined during the late-season stage. As displayed in table 3 there were non-interaction effects in both depth and frequency on pod length, pod diameter, number of pods per plant, plant height, canopy diameter and unmarketable yield at Ziqualla. The optimum application of 75%, 100%, 125% CROPWAT generated depth had better pod length, pod diameter and a number of pods per plant compared with irrigation scheduling of farmers' practice. However, irrigation application of 75%, 100% and 125% water depth did not show significant difference both in plant height and unmarketable yield compared with farmers' practice.

Table 2. Interaction effects of depth and frequency on marketable yield, total yield and water productivity at Ziqualla (Tsitsika irrigation scheme).

	Total yield(kg/ha)				Marketable yield(kg/ha)				Water productivity(kg/m^3)			
	Depth				Depth				Depth			
Frequency	75%	100%	125%	FP	75%	100%	125%	FP	75%	100%	125%	FP
5	11458.6	9331.4	9204.4		11220.6	9085.1	8912.5		5.06	3.85	2.63	
7	9095.8	11619.2	9115.2		8861.4	11385.3	8868.8		2.86	4.55	2.87	
9	3152.6	3102.0	3406.3		2886.0	2751.2	3145.6		1.82	1.56	1.33	
FP				5711.1				5439.6				1.64
LSD	974.7				1015.1				0.57			
Cv (%)	10.09				10.13				15.21			

Irrigation application of 75% and 100% water depth presented the highest canopy diameter of 39.34 and 38.97cm, respectively while125% application depth and the irrigation schedule of the farmer's practice had the lowest canopy diameter of 38.01 and 34.56 cm, respectively. Moreover, the table also showed that there was a significant difference between the application of 75% and 100% CROPWAT generated depth associated with 125% and farmers' scheduling in terms of canopy diameter. Considering the interval of the irrigation application, statistically, there was a non-significance difference in terms of pod length, pod diameter, number of pods per plant, canopy diameter, and unmarketable yield for 5 and 7 days interval. Likewise, there was a non-significance difference between 9 days and farmers' scheduling on pod diameter, number of pods per plant, plant height, canopy diameter and unmarketable yield. For instance, the farmer's irrigation practices contributed the lowest pod length of 6.42 cm whereas irrigation application with 5, 7 and 9 days irrigation interval had 9.4cm, 8.96cm and 8.42cm, respectively. This result is in line with Delelegn (2011) informed that hot pepper which obtained a better pod diameter of 1.68cm and pod length 8.01cm using Mareko fana variety at Jimma areas. Larger and wider hot pepper pods are considered to be the best in quality and have better demand for fresh as well as dry pod use in Ethiopian markets (Beyene and David, 2007).

Table 3. Effects of depth and frequency on pod length, pod diameter, No pod per plant, plant height, canopy diameter and unmarketable yield at Ziqua1la.

Treatment	Pod length (cm)	Pod diameter (cm)	No of pod per plant	Plant height (cm)	Canopy diameter (cm)	Unmarketable yield (kg/ha)
Depth						
75%	9.06a	1.47a	18.78a	71.33a	39.34a	242.98a
100%	8.80a	1.45a	20.15a	70.62a	38.97a	276.95a
125%	8.92a	1.41a	19.65a	69.07a	38.01ab	266.34a
FP	6.42b	1.18b	13.96b	64.30a	34.56b	271.43a
LSD	1.97	0.19	3.15	9.95	3.67	95.04
Cv (%)	17.09	10.57	12.47	10.71	7.18	27.14
Frequency						
5 days	9.40a	1.51a	23.85a	76.32a	42.28a	255.33a
7 days	8.96a	1.45a	22.36a	71.82ab	42.44a	238.20a
9 days	8.42a	1.37ab	12.37b	62.90b	31.60b	271.43a
FP	6.42b	1.18b	13.96b	64.30b	34.56b	292.74a
LSD	1.97	0.19	3.15	9.95	3.67	95.04
Cv (%)	17.09	10.57	12.47	10.71	7.18	27.14

As described in the above and presented in table 2, it can be taken as a suggested 75% CROPWAT generated a depth and irrigation application of 5 days interval offered the highest value for the yield and yield related parameters in case of Ziqualla. The result indicated that the variability of the amount of water application and irrigation interval has a significant effect on yield and yield correlated component for hot pepper.

Correlation analysis between yield parameters was tested using t-test as shown in table 4. The result revealed that there was a very high significance difference correlation coefficient ($r \geq 0.9$) of marketable yield with a number of pods per plant, total yield, and water productivity. Similarly, water productivity had also highly significance correlation ($r \geq 0.8$) with the number of pods per plant. However, the unmarketable yield was negatively correlated with other parameters at $p<0.05$ probability as showing in table 4.

Table 4. Correlation coefficient of different parameter (number of pods per plant, marketable yield, unmarketable yield, total yield and water productivity) from the study data.

parameters	number of pods per plant	marketable yield	unmarketable yield	total yield	water productivity
number of pods per plant	1				
marketable yield	0.93***	1			
unmarketable yield	-0.11ns	-0.15 ns	1		
total yield	0.93***	0.99***	-0.12ns	1	
water productivity	0.84**	0.90***	-0.13ns	0.90***	1

*($P \leq 0.05$) *** Very highly significant, ** Very significant, * significant*, ns none significant

By way of presented in table 5, there was an interaction effect both in depth and irrigation frequency on a number of pods per plant, marketable yield, total yield, and water productivity in a situation of Abergelle. The effect indicated that irrigation application of 75% and 100% CROPWAT generated depth with 5 and 7 days interval were recorded the highest pods per plant with 19.6 and 20.0, marketable yield, 8855.6kg/ha and 8653.9kg/ha, total yield, 9215.9kg/ha and 8905.0kg/ha, water productivity, 4.10kg/m^3 and 4.09kg/m^3 respectively. These results were statistically significant pods per plant, marketable yield, total yield, water productivity compared with other treatments; on the other hand, there was a non-significant difference between them. They had a yield enhancement of 3123.9kg/ha and 2813.0kg/ha in that order related to the farmer's irrigation application scheduling. The irrigation application of 75%, 100% and 125%

CROPWAT generated depth at 9 days irrigation interval and farmer practices irrigation scheduling had the lowest water productivity, total and marketable yield.

In relationships of water productivity, irrigation application of 75% and 100% CROPWAT generated depth with 5days irrigation interval in seasonal irrigation water requirement of hot pepper was 229.1mm and 295.3mm at Abergelle correspondingly. Whereas, associating that 75% and 100% irrigation application depth through 5 days interval, about 662m^3/ha amount of water was saved which would like to irrigate an additional land of 0.29ha that produce 2662.9kg/ha and the yield variance between the two application depth was 3784.4kg/ha of hot pepper crop yield advantages by using 75% CROPWAT generated depth. Zegbe-Dominguez *et al.* (2004) and Kang *et al.* (2001) reported that for optimum irrigation scheduling, sound knowledge of the soil-water status, crop water requirements, crop stress status, potential yield reduction if the crops remain in stressed condition is required to maximize yield and optimizes water productivity. In the same way as compared to farmer irrigation scheduling practices, 5675m^3/ha amount of irrigation water, which could confine to irrigate another land of 2.4ha and 22,118kg/ha the yield gain of hot pepper production in Abergelle areas.

As given away in table 6, there were not at all interaction effects in both depth and frequency on pod length, pod diameter, plant height, canopy diameter and unmarketable yield of hot pepper crops trendy instance of Abergelle. However, irrigation application using CROPWAT generated depth of 75%, 100%, and 125% had better pod diameter, canopy diameter is proportional to farmers' irrigation request practices. Since the irrigation interval point of view, the table exhibited that there was the non-significance difference between irrigation application of 5 and 7 days in terms of pod length, pod diameter, plant height, and canopy diameter. Nonetheless, there were significant differences at 9 days interval and farmers’ irrigation application practices.

Table 5. The interaction effects of depth and frequency on No of pod per plant, total yield, marketable yield and water productivity in Abergelle (Bahir small scale irrigation scheme).

	No of pod per plant				Total yield (kg/ha)				Marketable yield(kg/ha)				Water productivity(kg/m^3)			
	Depth				Depth				Depth				Depth			
Frequency	75%	100%	125%	FP	75%	100%	125%	FP	75%	100%	125%	FP	75%	100%	125%	FP
5 days	19.6	17.6	17.3		9215.9	8094.4	7650.7		8855.6	7836.5	7206.3		4.10	3.14	2.00	
7 days	13.9	20.0	18.7		7822.2	8905.0	7919.0		7580.1	8653.9	7595.2		2.92	4.09	2.73	
9 days	10.4	12.9	14.4		3010.1	2843.6	3006.5		2677.7	2578.5	2749.2		1.91	1.29	1.19	
FP				13.0				6092.0				5758.2				0.88
LSD	2.30				718.33				728.18				0.35			
Cv (%)	10.96				8.35				8.89				10.97			

FP=farmer irrigation scheduling practice

Table 6. Effects of depth and frequency on pod length, pod diameter, plant height, canopy diameter and unmarketable yield on Abergelle.

Treatment	Pod length (cm)	Pod diameter (cm)	Plant height (cm)	Canopy diameter (cm)	Unmarketable yield (kg/ha)
Depth					
75%	8.41a	0.80ab	69.90a	39.48a	311.62ab
100%	8.21a	0.85a	69.02a	37.91ab	258.07b
125%	8.24a	0.86a	68.95a	38.05ab	341.85a
FP	7.41a	0.65b	68.00a	32.26b	333.58ab
LSD	1.67	0.15	9.66	6.90	80.56
Cv (%)	15.28	13.94	10.49	13.68	19.72
Frequency					
5 days	9.46a	0.93a	72.22a	41.82a	354.23a
7 days	8.83ab	0.90a	70.87a	41.65a	272.38b
9 days	6.58c	0.67b	64.77a	31.97b	284.93ab
FP	7.41bc	0.65b	68.00a	32.26b	333.58ab
LSD	1.67	0.15	9.66	6.90	80.56
Cv (%)	15.28	13.94	10.49	13.68	19.72

FP=farmer irrigation scheduling practice,

The correlation coefficient analysis such as revealed in Table 7 indicated that marketable yield was significantly correlated ($r \geq 0.9$) with total yield, and also water productivity was significantly correlated through marketable yield and total yield ($r \geq 0.8$), but negatively correlated with unmarketable yield. The t-test analysis for correlation coefficient with 95% confidence interval showed that there was a significant difference in all the parameters except unmarketable yield.

Table 7. Correlation coefficient of different parameters (number of pods per plant, marketable yield, unmarketable yield, total yield and water productivity) from the study data.

parameters	number of pods per plant	marketable yield	unmarketable yield	total yield	water productivity
number of pods per plant	1				
marketable yield	0.78*	1			
unmarketable yield	0.04ns	0.09 ns	1		
total yield	0.78*	0.99***	0.12 ns	1	
water productivity	0.73*	0.81**	-0.08ns	0.80 **	1

($P \leq 0.05$) *** *Very highly significant*, ** *Very significant*, * *significant*, ^{ns} *none significant*

Conclusions and Recommendations

The results of the experiment at both locations indicated the importance of research interventions to improve hot pepper production by saving a significant amount of water for irrigating additional land. Application of irrigation depth at specific irrigation interval has shown a significant effect on yield and water productivity when compared with farmers' scheduling practices. Irrigation application of 75% and 100% CROPWAT generated depth at 5 and 7 days irrigation intervals provided a relatively significant and higher value in terms of marketable yield, total yield and water productivity both at Ziqualla and Abergelle. Comparing with the farmers' practices, 75% depth at 5 days interval as well as 100% depth at 7 days interval saved irrigation water that would irrigate an additional land of about 2.2 ha and 1.5 ha at Ziqualla, and 2.4 ha and 1.8 ha at Abergelle, respectively. However, in addition to saving 25% irrigation water without yield penalty, 75 % generated depth at 5 days gave 5781 kg ha^{-1} marketable yield advantage and 3.42 kg m^{-3} water productivity at Ziqualla and 3098 kg ha^{-1} marketable yield and 3.1 kg m^{-3} water productivity at Abregelle over the farmers practices. The main agricultural water management strategy for dry land and water scarce areas like Wag Himira is primarily to improve the agricultural productivity and hence improve the income of the farmers by applying optimum amount of water and saving significant amount of water to cultivate additional cropland by the saved irrigation water. Considering this, application of 75% CROPWAT generated depth at 5 days interval was found economically feasible and is recommended to be used by the farmers and other water users in Ziqualla and Abergelle woreda and other similar agro-ecologies. Furthermore, further research on fertilizer rate for hot pepper under irrigation is suggested.

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Evaluation of the potentials of supplementary irrigation for improvement of sorghum yield in Wag-Himra, North Eastern, Amhara, Ethiopia.

Aemro Wale1*, Workat Sebnie, Gebrehana Girmay, and Gashaw Beza

Sekota Dry Land Agricultural Research Center; P.O. Box 62; Sekota, Ethiopia

*Corresponding author: Aemro Wale; email: aemrowale@gmail.com

Abstract

Rainfall variability and drought has been accounted to have a major effect on crop production in Ethiopia. However, supplemental irrigation plays a major role in increasing water use efficiency and yields of rain-fed crops. The experiment was conducted for two cropping seasons (2014 to 2015) at Aybra on farmer's plot in Sekota, Eastern Amhara. This paper tries to determine the net irrigation requirement and schedule of supplementary water application during moisture stress period and to improve crop water productivity of sorghum yield. The design of the experiment was random complete block design and seven treatments (C1, C2, FMSO, S1, S2, S3 and S4) with three replications were tested. The analysis of variance for both years showed that there was significant interaction effect between treatments across years on head weight, grain yield, and water productivity. Supplementing sorghum with the CROPWAT generated depth (100%) (219.4mm) irrigation water during moisture stress at the development and mid-season stage at eight days interval gave better head weight, grain yield, water productivity and stem diameter. Similarly, supplementary application of CROPWAT generated depth (100%) (328.4mm) irrigation water during moisture stress starting from the development stage (development up to harvesting) at eight days interval also gave good sorghum grain yield and yield related parameters. Therefore, this research finding recommended that supplementing rain-fed for sorghum production starting from the development stage (20 days after sowing down to harvesting) based on inidcators. However, if the water is scarce or a limiting factor for crop production, supplementing during development and mid-season stage at eight days interval is recommended.

Keywords: Irrigation requirement, Sorghum, Supplementary irrigation, Wag-himra, Water use efficiency

Introduction

Agriculture is a fundamental part of rural livelihoods of Ethiopia although there are many instances when farmers in water-scarce areas are unable to succeed in their agricultural scheme due to the unavailability of required quantities of water at the correct time. The Ethiopian economy is based on rain-fed agriculture. Rainfall is the major source of water for agriculture. However, farmers' yield gain in rain-fed regions in developing countries is low largely due to low rainwater use efficiency because of non-optimal soil, water, nutrient and pest management options, as well as a shortage of seeds from improved cultivars (Rockström and Barron, 2007; Wani *et al.*, 2008). There are three primary ways to develop rain-fed agricultural production, namely: (i) enhance the effective rainfall use through improved water management; (ii) increase crop yields in rain-fed areas through agricultural research; and (iii) transform policies and improved investment in rain-fed areas.

As the Amhara Regional State Government is emphasizing developing irrigation-based agriculture to attain food security at the household level, it is important that appropriate technologies are available for adoption by farmers. This focuses on the first way, in which supplemental irrigation plays a major role in increasing water use efficiency and yields of rain-fed crops. For instance, a supplemental irrigation study (Rockström *et al.*, 2002) carried out in Burkina Faso (seasonal rainfall of 418-667mm) and Kenya (seasonal rainfall of 196-557mm) reported 37-38% increase in sorghum grain yield by supplemental irrigation alone. However, when supplemental irrigation was combined with a fertilizer application of what nutrient rates, loading rate and timing, the crop yield of irrigated land increased to 70-300% when compared to the rainfed system.

Estimating seasonal rainfall characteristics based on the past records is important to assess drought risk and to improve drought mitigation strategies such as supplementary irrigation. Rainfall inconsistency has been accounted to have a major effect on Ethiopia's economy and food production for the last three decades. There have been reported of rainfall variability and drought associated food shortage (Tilahun, 1999; Bewket and Conway, 2007). Unreliable and poor distribution of rainfall is one of the major causes of low yield of sorghum in Ethiopia and it is a staple food crop for millions of people who live in the dry land areas of the country. So, farmers and private sales are now opting for the production of this crop under supplemental and/or full irrigation (Shenkut *et al.*, 2013). In most cases, what determines crop production in semiarid areas of Africa is the distribution of seasonal rainfall rather than the total amount of rainfall because dry wonderful strongly slow down the yield (Barron *et al.*, 2003; Segele and Lamb, 2005). Water scarcity is a feature of Northern Ethiopia; particularly in Wag-himra water scarcity is severe (Bekele, 2006; Araya *et al.*, 2011; Feyisa, 2016). Due to this, moisture stress is the major limiting factor for crop production which highly reduces the crop yield in these areas. Sorghum is an important food cereal crop and the major crop in rain-fed agriculture in Wag-himra.

One of the approaches taken as a countermeasure to the unpredictability of rain and to overcoming such problems is using supplementary irrigation during the growing season. Supplemental irrigation (SI) is a highly efficient option to achieve this strategic goal by providing the crop with the needed amount of water at the required time (Oweis, 1997). Supplemental irrigation is defined as “the addition of a limited amount of water to otherwise rain-fed crops, when rainfall fails to provide essential moisture for normal plant growth, in order to improve and stabilize productivity”. Unlike full irrigation, the timing and amount of supplemental irrigation cannot be determined in advance, because it is supplementary to rainfall, which is variable in amount and distribution and difficult to predict (Oweis *et al.*, 1999). In northern Syria, it was found that applying 50% of full supplemental irrigation requirements would reduce yield by 10-15% while applying the saved water to lands otherwise rain-fed increased the total farm production by 38% (Oweis, 1997; Oweis and Hachum, 2006).

Alleviating soil moisture stress during the critical crop growth stages is the key to improved production. It was concluded by the authors that avoiding drought, through early flowering and maturity, was the main factor underlying higher seed yield under severe drought conditions (Li *et al.*, 2000; Wang *et al.*, 2005; Ghanbari-Malidarreh, 2010). In this area, supplementary irrigation is necessary for the increment of sorghum grain yield and yield components and enhancement of food security. However, the additional amount of water alone may be inadequate for crop production, as irrigation timing relative to critical crop growth stages is critical. Therefore, this research was conducted to compute and set the net irrigation requirement (depth of water) to be Supplemented in the moisture deficit period and the timing of the water application (irrigation interval) and to improve crop and water productivity.

Material and Methods

Description of the study area

The experiment was conducted for two cropping seasons (2014 to 2015) at Fikire Selam Kebele on a farmer's plot in Sekota woreda, Wag-himra, North Eastern Amhara, 12.680N Latitude, and 39.010E Longitude and at an altitude of 1976 m.a.s.l (Fig. 1). The mean maximum and minimum temperatures are 26.5 and 12.1^{o}c respectively and the mean annual rainfall in the area was 275.7 mm with a considerable year-to-year variation. But this amount of rainfall didn't fulfill the crop water requirement in the growing season. Such rainfall variation results in a range of conditions under which the use of supplemental irrigation is a useful option to improve and stabilize yields. The soil textural class of the experimental area is clay loam with a pH of 6.7-7.1

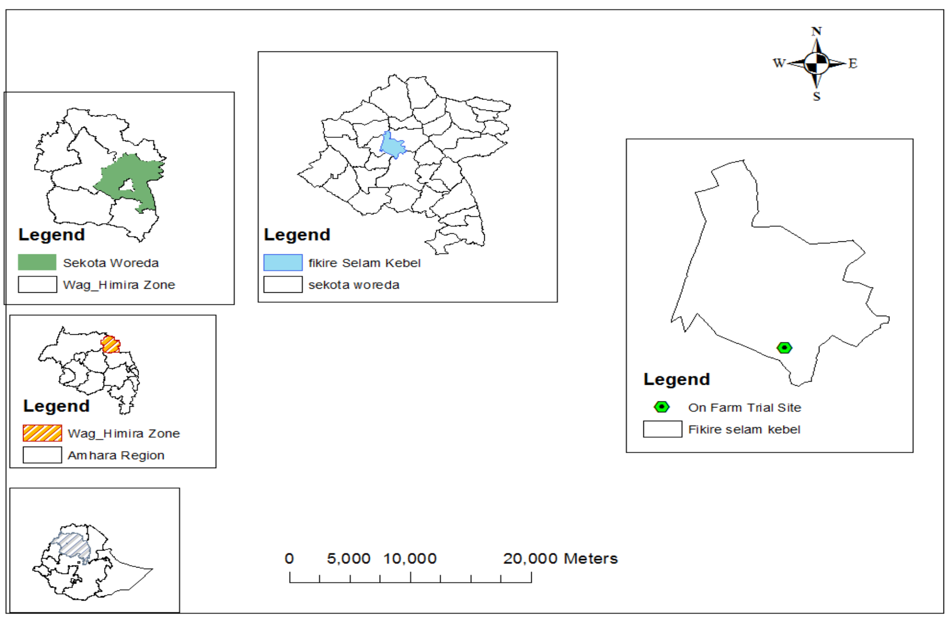

Figure 1. Map of the study area

Soil and Water Sample Collection and Analysis

The collected soil samples were composited into three samples based on the soil depth. The composite soil samples were collected and air dried, thoroughly mixed. The samples were properly labeled, packed and transported to the laboratory. After that, the samples were dispersed after testing and for pH, and soil organic matter (SOM). Soil textures were analyzed at Sekota dry land Agricultural research center Soil Laboratory. The soil pH was measured in the supernatant suspension of a 1: 2.5 using a Standard glass electrode pH meter (Carter and Gregorich, 2008). The soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The water sample was taken from the site which was used for the irrigation application. The plastic bottle was used to collect the water samples from the experimental site. The sample was labeled carefully and transported to the laboratory and analyzed for their selected chemical composition of pH and ECw. Laboratory analyses were done at Sekota dry land Agricultural research center soil laboratory for selected chemical composition /only for their pH and ECw. ECw of the water samples were measured using conductivity meter. Field capacity and permanent wilting point of the experimental site was done.

Experimental design and Crop

The experiment was conducted using a simple random complete block design. Plots were 3m X 5m. There were a total of seven treatments and three replications in 2014 and 2015. Two control treatments (C1 and C2) with no supplementary irrigation. One treatment supplemented when the crop was under water stress through field observation (FMSO) and Four treatments (S1, S2, S3, and S4) having supplementary irrigation levels at development, mid-season, and late season growing stages were determined using the CROPWAT computer model (Version 8.0). Irrigation water was applied by using a hand-held watering cane having fixed volume water Conveyed to the furrow (Table 1). Sorghum (Miskre variety) which has a relative maturity of 125 days was used as a test crop. Fertilizer was applied at the rate of 100 kg/ha for Diammonium phosphate (DAP) at planting and 50 kg/ha of urea (applied in two splits, half at planting and a half at 45 days after sowing). The crop data, crop type, planting date, growth stage in day, maximum rooting depth, Kc values, depletion fraction and yield reduction coefficient were used as inputs to the CROPWAT computer model.

Table 16. Length of growing season and other factors of sorghum

parameters	Crop growth stage				Total growing period
	initial	development	Mid-season	Late season	
Length of growing season (days)	20	35	40	30	125
Crop coefficient (kc)	0.50	0.83	1.15	0.6	
Rooting depth (cm)	30	50	100	100	
Depletion level (p)	0.5	0.50	0.5	0.8	
Yield response factor (ky)	0.6	0.6	1.2	0.8	

Source: FAO CROPWAT model (Smith *et al.*, 2002)

Determination of reference evapotranspiration

Reference evapotranspiration (ETo) on a daily basis was calculated by applying the modified FAO Penman-Monteith equation and based on a daily time step (Allen *et al.*, 1998) using FAO CROPWAT software version 8.0. The input data for the CROPWAT software includes location i.e. altitude, latitude, and longitude of the meteorological station, daily values of maximum and minimum air temperatures, air humidity, sunshine duration, and wind speed were used from a 10km meteorological station located on the experimental field.

Supplementary irrigation water requirement

The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and sorghum crop coefficient (Kc) given by Allen *et al.* (1998) as 0.5 for the initial stage, $0.5 < Kc < 1.15$ for the crop development stage, 1.15 for the mid-season stage and 0.6 for the late season stage. Calculation of crop water requirement (ETc) using CROPWAT software over the growing season was from ETo and crop coefficient (Kc) equation 1.1.

$$ETc = ETo*Kc \quad (1.1)$$

Where, ETc = actual evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day). The net irrigation requirement was calculated using the CROPWAT software based on Allen *et al.* (1998) as follows equation 1.2.

IRn = ETc - Pe 1.2

Where, IRn =Net irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (pe) was estimated using the method given by Allen *et al.* (1998) as equation 1.3 and 1.4.

Pe = 0.6 * P – 10/3 for P month <= 70 mm or 1.3

Pe = 0.8 * P – 24/3 for P month > 70 mm 1.4

Where, Pe (mm) = effective rainfall and P (mm) = total rain fall.

Water productivity, also known as water use efficiency, was determined as the ratio of grain yield per unit area divided by the total seasonal water use of the crop (rainfall + supplemental irrigation) (Irmak *et al.*, 2011). Statistical analysis of the data included analysis of variance (ANOVA), using SAS, to test the effects that season, supplemental irrigation had on grain yield, head weight, stem diameter, and water productivity in the two cropping seasons of 2014 and 2015.

Table 2. the treatment setup of supplementary irrigation on the experiment in Wag-himra area.

	2014 Year			2015 Year			Mean of the two Years		
Treatment	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)	Total crop water requirement (mm/season)	Measured rainfall (mm/season)	Actual Seasonal irrigation requirements (mm/season)
C1	351.7	351.7	0	199.7	199.7	0	275.7	275.7	0
C2	351.7	351.7	0	199.7	199.7	0	275.7	275.7	0
FMSO	481.7	351.7	130.0	656.3	199.7	456.6	569.0	275.7	293.3
S1	687.7	351.7	336.0	520.6	199.7	320.9	604.1	275.7	328.4
S2	650.3	351.7	298.6	453.7	199.7	254.0	552.0	275.7	276.3
S3	567.0	351.7	215.3	423.2	199.7	223.5	495.1	275.7	219.4
S4	529.6	351.7	177.9	356.3	199.7	156.6	443.0	275.7	167.3

Where, Treatments, C1=rain-fed without furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during mid-season stage at eight days interval at moisture stress.

Result and Discussion

Soil properties of the experimental field

Analysis of soil samples for the major soil physical and chemical properties before planting was carried out at soil laboratories of Sekota Dry-Land Agricultural research center and Mekelle Soil Research Center. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil. The organic matter (OM) was considered to improve water-holding capacity, nutrient release and soil structure and is rated low as shown in (Table 3). This was in agreement with the findings of Okalebo *et al.* (2002) who reported that soils having OM value in the range of 0.86-2.59% are considered low. Thus, it needs additional materials or nutrients that increase the amount of organic matter in the soils. In agreement with Hazelton and Murphy, (2016), the experimental soils had ECe less than 4dS m^{-1} and are non-saline and suitable for crop production. Moreover, according to the ratings of Chimdi *et al.* (2012), the pH value of the experimental soils is neutral. The topsoil surface had a slightly lower bulk density (1.2g/cm^3) than the subsurface (1.26g/cm^3) which might be due to the relatively higher organic matter contents in the top soil and the compaction level increased in the lower part. In general, the average soil bulk density (1.24 g/cm^3) was suitable for crop root growth. The average soil moisture content values at field capacity of the experimental site were 39.26, 33, and 18% at 0-30, 30-85, and 85- 105cm soil depths, respectively. The moisture content at the permanent wilting point also showed variation with depth and increasing from the surface to the lower depth. The total available water (TAW) that is the amount of water that a crop can extract from its root zone is directly related to variation in FC and PWP and its root depth.

Table 3. Soil physical and chemical characteristics of the experimental site

Depth (cm)	Texture				Bulk density (g/cm3)	Organic matter (%)	pH	EC (ds/m)	FC (%)	PWP (%)
	Sand (%)	Clay (%)	Silt (%)							
0-30	37.7	31.3	31.0	clay loam	1.2	1.55	6.9	0.15	39.26	13.12
30-85	51.2	25.0	23.8	sandy clay loam	1.25	1.18	6.7	0.27	33	13
85-105	35.0	36.3	28.7	clay loam	1.26	1.38	7.1	0.20	18	7

Clear year -to -year variations were seen due to treatment effects. Although the actual rainfall amount which occurred in the second year was less than the long-term mean value, more rainfall was measured at the initial stage of sorghum affecting its growth and resulted in stunted growth. Moreover, the grain yield in the second year was highly affected by the damage of birds during the mid-season stage (at about maturity time).

Table 4. Analysis of variance

Source of variation	Degree of freedom	Mean square			
		Head weight (kg/ha)	Grain yield (kg/ha)	Stem diameter (cm)	Water productivity (kg/m^3)
Treatment	6	1999756.88**	1085183.42**	0.0509**	1.2614**
Replication	2	11680.88	27131.67	0.0003	0.0108*
Year	1	1233387.59**	1268295.10**	0.3547**	0.0288*
Treatment*year	6	223083.12**	50553.40**	0.0156	0.2160**
Error	26	21995.56	8674.62	0.0066	0.0026

***=Significant at (0.01) level of significance, *=Significant at (0.05) level of significance*

The analysis of variance for both years showed that there was a significant interaction effect between treatments across years on head weight, grain yield, and water productivity (Table 4). The results of 2014 and 2015 indicated that head weight, grain yield, stem diameter, and water productivity were statistically significant other than plant height didn't (Table 5). According to the result supplementing the crop with treatment S3 and S1 application of 219.4mm and 328.4mm of irrigation water respectively at eight days interval at moisture stress obtained better head weight, grain yield, water productivity, and stem diameter as compared to other treatments.

But there was a statistically significant difference in grain yield and water productivity of sorghum. The result was in agreement with the finding of Feyisa (2016) who reported that supplementing the crop with S3 and S1 at eight days interval obtained good sorghum yield and yield related parameters. The result was in line with Ziadat (2015) which reported that full supplementary irrigation of green pepper yield improvement of 32.6 kg/ha compared with the none supplemented irrigation of green pepper in Gumara-Maksegnit watershed. Similar to our result, the research conducted in India indicated that supplementary irrigation early during the vegetative growth stage and early reproductive stage on clay soils contributed to increased yield (Singh and Das, 1987). Sorghum grain yield under rain-fed condition control treatment constantly had a low yield in both experimental seasons 2014 and 2015. The production potential of the crop was particularly affected by rainfall amount and distribution pattern.

The seasonal water use (rainfall and supplemental irrigation) was used to calculate the water productivity of crops. The experimental results in water productivity of sorghum grain yield to improve from 0.75kg/m^3 of water for rain-fed and 1.77kg/m^3 of water at supplementary irrigation. The result was in line with the finding of Zhang and Oweis (1999) water productivity was about 0.96 kg of wheat grain m^{-3} of water under rain-fed conditions and 1.36 kg of wheat grain m^{-3} under supplemental irrigation. The result also was similarly that the finding of Oweis and Hachum (2009) reported supplemental irrigation caused rainwater productivity in northwest Syria to increase from 0.84kg/m^3 of water for rain-fed and 1.06 kg/m^3 of water at full supplemental irrigation. From our finding supplementing the crop with S3 at 2194m^3/ha irrigation water application at eight days interval at the moisture stress period evaluated to supplementing the 3284m^3/ha of water irrigated S1 at eight days interval at moisture stress was achieved 1090m^3/ha of water saved. This amount of applying the saved water also 0.49 hectares of additional lands was irrigated.

Table 5. Mean separation result of the effects of supplementary irrigation on head weight, grain yield, plant height, stem diameter and water productivity.

Treatments	2014 Year					2015 Year					Combined over Year			
	Head weight (kg/ha)	Grain yield (kg/ha)	plant height (cm)	Stem diameter(cm)	Water productivity(kg/m^3)	Head weight (kg/ha)	Grain yield (kg/ha)	plant height (cm)	Stem diameter(cm)	Water productivity(kg /m^3)	Head weight (kg/ha)	Grain yield (kg/ha)	Stem diameter(cm)	Water productivity(kg/m^3)
C1	2084.4d	1404.4d	152.4a	1.21c	0.43e	1911.1cd	1405.1c	139.6a	1.01b	1.04b	1997.7d	1404.7d	0.74e	1.11d
C2	2823.7c	1649.8c	155.3a	1.2c	0.51d	1688.9d	1339.1c	142.6a	1.16ab	0.99b	2256.3c	1494.4d	1.19dc	0.75e
FMSO	2137.8d	1346.6d	156.9a	1.37b	0.32f	2222.2c	1002.1d	148.7a	1.16ab	0.29d	2180.0c	1174.3e	1.26bc	0.30f
S1	3383.7ab	2463.1a	158.8a	1.47a	0.97c	3295.8a	1999.8a	138.8a	1.30a	0.77c	3208.5ba	2239.9a	1.31ba	0.86d
S2	3281.0b	2229.8b	156.6a	1.22c	0.98c	2900.0b	1896.0a	140.4a	1.18ab	0.84c	3090.5b	2062.9cb	1.20dc	0.99c
S3	3410.4a	2389.8ab	151.2a	1.47a	1.48b	3004.2ab	1658.0b	140.4a	1.16ab	0.98b	3314.5a	2132.9b	1.38a	1.77a
S4	3333.3ab	2266.0b	164.0a	1.46a	1.69a	3033.4ab	2016.8a	145.3a	1.16ab	1.4a	3207.2ba	2023.9c	1.31ba	1.23b
CV(%)	2.36	4.67	6.94	3.32	4.62	7.72	5.15	6.60	9.13	5.56	5.42	4.89	6.49	5.13
LSD (0.05)	122.71	163.22	19.34	0.07	0.07	354.68	148.29	16.71	0.18	0.08	177.76	104.45	0.09	0.05
Grand mean	2922.10	1964.26	156.50	1.34	0.91	2579.36	1616.71	142.30	1.16	0.91	2750.73	1790.49	1.25	0.95

Where; Treatments ,C1=rain-fed without furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during mid-season stage at eight days interval at moisture stress.

Conclusions and Recommendations

Supplemental irrigation is a viable irrigation management scheme that can be used by farmers in a dry-land area like Wag-himra to enhance and stabilize their rain-fed grain sorghum production. Supplemental irrigation using a limited amount of water, if applied during the critical crop growth stages of vegetative and early reproductive, can result in a substantial improvement on yield and water productivity. The application of supplemental irrigation can also assist the crop to escape critical stages particularly terminal drought or moisture deficit. In rain-fed dry areas, where water is the most limiting factor, the priority should be to maximize yield per unit of water rather than yield per unit of land.

As a result it can be concluded that dry-land areas like wag-himra which has problems of rainfall distribution and amount and having an access to irrigation water can increase their yield advantage 835.2 kg ha^{-1} by supplementary irrigation starting from the crop development stage up to harvesting stage at eight days interval following moisture deficiency indicators like crop physiological indicator and soil moisture stress with amount of 328.4mm seasonal irrigation water requirement for improving variety of sorghum (Miskre) from the analysis of the two year results.

As an option, if water is the restraining factor during the sorghum growing season, applying supplementary irrigation only during development and mid-season stages at eight days intervals on moisture stress or rainfall ceased can give a reasonable good grain yield, head weight and water productivity and it had grain yield improvement of 728.5kg ha^{-1} in 2014 and 2015. Therefore, this research recommended that supplementing rain-fed for sorghum production starting from development stage (20 days after sowing down to harvesting) whenever there is deficit following indicators.

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Determination of Irrigation Regime for Onion at Jari, North Eastern Amhara, Ethiopia

Solomon Wondatir* and Zeleke Belay

Sirinka Agricultural Research Center, P.O.Box 74, Woldia, Ethiopia

*Corresponding author: Solomon Wondatir; email: solwondatir@gmail.com

Abstract

*Proper amount and timing of irrigation 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. This experiment was conducted to determine the crop water requirement of onion (Adama Red variety) in Tehuledere District from 2011 to 2012. The experiment was conducted in RCBD design with 3 replications on a gross plot size of 3m*3m. The experimental treatments are nine with a factorial combination of three irrigation depths (19, 25 and 35mm) and three irrigation intervals (5, 8 and 10days). Irrigation water use efficiency function was used for the comparison of water to yield response factors. There was no interaction effect among the treatments across each year in bulb weight, bulb yield, and water productivity. There was significant difference in average bulb weight, marketable yield, total yield, and water productivity among the treatments. The application of 35mm depth of water with 5 days irrigation interval (770mm as seasonal water requirement) gave maximum marketable bulb yield. While the maximum water productivity of 7.366 kg m^{-3} was obtained from the application of 25mm irrigation depth in 10 days irrigation interval (seasonal irrigation demand of 280mm). In this experiment, optimum yield and optimum water productivity were observed from the application of 19 mm irrigation application depth at 5 days irrigation interval with a total seasonal irrigation demand of 418 mm. Hence, irrigators can irrigate onion with 5 days irrigation interval with irrigation application depth of 19 mm (75% of the CROPWAT generated depth) for onion for Tehuledere district and similar agro-ecologies.*

Keywords: *Crop water requirement; irrigation depth, irrigation interval, water productivity*

Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably lead to increased food demand. To maintain self-sufficiency in the food supply, one viable option is to raise the production and productivity per unit of land through agriculture, mainly through irrigation. Agriculture is the main water user but information on agricultural water use is nonexistent. Predominantly no reliable data on the area of small-scale irrigation is available and most irrigation infrastructures are not effectively used. The study site, Jare small scale irrigation scheme /SSI/ is located within Upper Mile River sub-basin, which is a tributary to Awash River basin. According to the Agricultural and Rural Development Office annual report, Tehuledere district has a cultivable land of 16,133ha and an irrigable land of 7,300ha and from this 6,670ha was irrigated in the irrigation season; included household level water storage ponds; but due to data collection and recording gaps the reliability of the figure exaggerated (Annual report of ARDO, 2014).

Irrigated agriculture is a complex that is influenced by weather, labor, irrigation scheduling, on-farm water management, farming practices/ agronomic, crop selection, cropping pattern, soil fertility/, the availability and management of inputs /fertilizers, chemicals, etc.…), equity, cost recovery, marketing, and organizational aspects. Poor management of available water for irrigation, both at system and farm level has led to a range of problems and further aggravated water availability and has reduced the benefits of irrigation investments (Food and Nations, 1996). Awulachew (2019), reported that improving low-performing schemes specifically small-scale irrigation schemes requires incorporating applied research on irrigated agriculture.

Among the common irrigated vegetables, onion (*Allium cepa* L.) shares the largest in both area coverage and local consumption in Ethiopia. Particularly, it is the popular vegetable grown under irrigation in most of the traditional and the recent modern irrigation schemes in the Amhara region. However, the largest producer of onion is not supported with improved water management practices to improve its productivity and bulb quality. Onions need frequent irrigation to maintain high soil moisture. Irrigation scheduling highly matters in onion production. This is because; onions are extremely sensitive to water stress. Regardless of the type of irrigation system used, both yield and quality can suffer if irrigation is delayed and available soil moisture is allowed to drop too low (Shock *et al.,* 2010). Studies made in Turkey gave clear proof that the bulb and dry matter production of onion were highly dependent on appropriate water supply (Ayas and Demirtaş, 2009).

The study area is endowed with different water sources from irrigation schemes and water harvesting ponds, which can have a capacity to irrigate large amounts of land. However, in most of the irrigation schemes whether traditional or modern, the irrigation water management practices followed by farmers are traditional and poor in water management and utilization. In Jare irrigation scheme most of the time the irrigation system is a rigid type of rotation and it takes around 15 days for a cycle. As a result, it has been affecting the production of vegetable crops in the irrigation scheme, particularly on onion crop. Although the area is reached in water resources, due to poor cropping patterns and lack of appropriate water resource management techniques, the scheme has not been giving the expected production services.

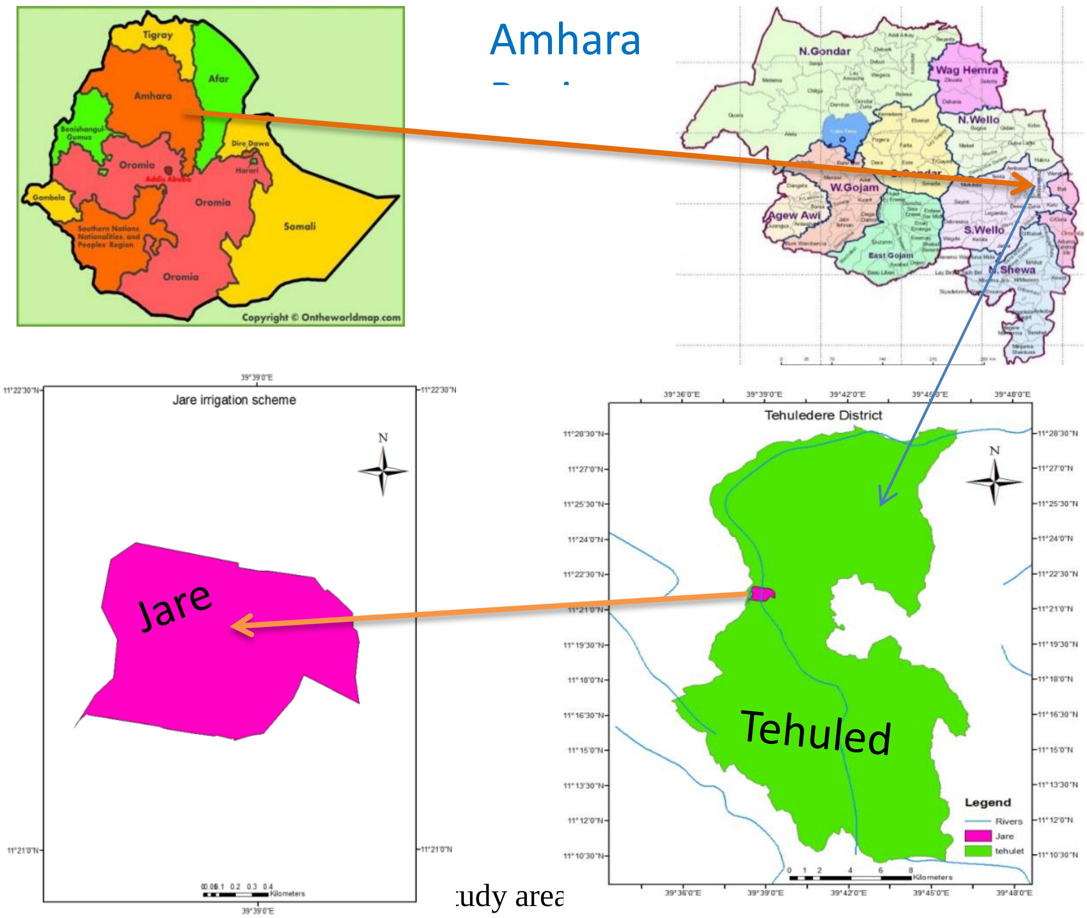
Proper amount and timing of irrigation water application is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources (Allen *et al.*, 1998). There is a lack of location-specific research results of how much water and when to irrigate onion. Therefore, this research was conducted to determine the irrigation water requirement and irrigation scheduling of onion under irrigation in specific localities of Tehuldere areas.

Materials and Methods

Description of the Study Area

The experiment was conducted for two consecutive years from 2011 to 2012 in the South Wollo zone of Tehuledere district at Jare sub center research farm. The study area is located at 437km from Addis Abeba and 7km from Haik town nearby the main asphalt road. Geographically, the area lies in the global positioning from 11^{o}21'N, latitude to 39^{o}38'E, longitude and at an altitude of 1680m above sea level. According to CSA (2007) report, the district has a total population of 117,877; of whom 59,300 are men and 58,577 are women. It covers an area of 405.37 square kilometers and contains notable landmarks include the monasteries of Debre Egziabeher and Hayk Istifanos. The mean annual rainfall is 1020.8mm and average annual temperature ranges from 12.20^{0}c to 26.70^{o}c respectively. The area is categorized under sub-moist cool 'weinadega' agro-ecological zone. The soil in the experimental site is texturally clay loam.

The soil has a pH of 6.8. Average daily pan evaporation amount is around 3.98mm/day. Jare small scale irrigation scheme is a check basin type of diversion system; the head work has no water flow control gates.



:udy area

The irrigation scheme has total household beneficiaries of 537 (446 Male and 91 Female). The initial total command (nominal) area was 168 ha but currently, it is declined to 146 ha. The slope of the area ranges up to 50% in the downhill of the watershed and 2% in the lower part of the scheme. The primary soil type in the study area is the tropical plateau black clay soil with some distribution of brown soil and new alluvial, and the soil is sticky and hardened with poor content of organic matter and nutrients, lower capacity of holding moisture, soil and fertilizer (ORDA, 2005).

Jari Small Scale Irrigation Scheme's, main water source is Mile River and some additional minimum flow comes from the surrounding areas, the bottom hill of the upper watershed, (Kezikaze River, Tirngo, Wulko, and Muk Wuha springs). The irrigation system was constructed for demonstration purpose, so as to serve as a sample model of demonstration for a wide range of the agricultural area, by the regional government; 'Agricultural Comprehensive Development and Programming in Jari-Ful Wuha Watershed in Upper Mile River'

Generally, the scheme has an advanced design and structural systems of night storage and rainwater harvesting ponds connected with the irrigation canal networks, but currently, it is not as such satisfactory in services. The implementation of water harvesting ponds with irrigation system in the watershed was initiated by South-South Cooperation agreement signed among the Ethiopian government, FAO and the Chinese government. Prior to the implementation of the project, feasibility studies supported by FAO were carried out in the watershed by Chinese and Ethiopian experts in 2002 and 2005. The total investment budget for the construction of engineering, biological and other measures was 7,192,611ETH birr; the engineering cost covers 84.74% of the total (ORDA, 2005). Currently, the operation and management of the scheme have been led by WUAs.

Methodology

The test crop onion (Adma Red variety) was selected from secondary data sources of farming system survey reports and by preliminary assessments of field surveys on major irrigation schemes that found in the South Wollo zone. Meteorological data was taken from a local climate estimator of New- LocClim software program. The trial was conducted in two phases;

First phase: Net Irrigation Requirements and optimal scheduling were estimated

Calculations of crop water requirements and irrigation scheduling were carried out by CROPWAT4W Smith (1992) with inputs of climatic, crop and soil data. Firstly, crop water requirement was determined by inserting Crop data: crop type, planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction); a set of typical crop coefficient data files that are default in the program were also used. Climatic data: average 10 years meteorological data of (1) maximum and minimum temperature; (2) wind speed; (3) sunshine hours; (4) relative humidity; and (5) rainfall were used. Soil data: total available moisture (TMA), maximum infiltration rate (8mm/hr), maximum rooting depth (70cm) and 40% soil moisture depletion fraction were used for determination of irrigation scheduling. Canning irrigation application method was used in bounded flatbed plots and considering 80% irrigation application efficiency was used for gross irrigation calculation.

Second phase: Validating the irrigation Result on Field

For the determination of optimal irrigation scheduling, CROPWAT by default used the options; irrigation timing: irrigate when 100% of readily available moisture occurs and application depth: refill to 100% of readily available moisture, this irrigation scheduling theoretically gives no yield reduction. By adjusting 25% up and down from optimal irrigation scheduling, nine treatments which were the combination of 3 irrigation depths and 3 irrigation intervals were set.

Table 1. Experimental treatments combination

No	Treatments	Irrigation depth (mm)	Seasonal irrigation requirements (mm)
1	CWGD and OPT of application	25mm*,8days*	350
2	CWGD at 5 days interval	25mm*,5days	550
3	CWGD at 10 days interval	25mm*,10 days	280
4	Application of 75% of CWGD and OPT of application	19mm, 8days	266
5	Application of 75% of CWGD at 5 days interval	19mm,5days	418
6	Application of 75% of CWGD at 10 days interval	19mm,10days	209
7	Application of 125 % of CWGD and OPT of application	35mm, 8days	490
8	Application of 125 %of CWGD at 5 days interval	35mm,5days	770
9	Application of 125 % of CWGD at 10 days interval	35mm,10days	385

*CWGD-cropwat generated depth *OPT- optimum time of applications

For the verification of the results, a field trial was carried out for two years. The experiment was conducted in RCBD design with 3 replications in an experimental gross plot size of 3m*3m. The spacing between plants and rows were 10cm and 20cm respectively. The onion was grown from starting February, 19 to June, 05; taken 110days total length of the growing period. Blanket fertilizer recommendation of urea100kg/ha split application and Dap50kg/ha were applied. Prior to planting, all plots were irrigated with an equal amount of water up to the field capacity and continued irrigating up to 2 weeks to increase the survival rate of transplant onion plants.

Irrigation water productivity function was used for the comparison of water to yield response. Irrigation water productivity (IWP) is generally defined as crop yield per water used to produce the yield (Howell, 1996; Viets, 1962). Thus, IWP was calculated as fresh weight (kg) obtained per volume of irrigation water applied (m^3).

$$IWP = \frac{\textbf{Yield}}{\textbf{Water applied}}$$

IWP is an important factor when considering irrigation systems and water management, and probably will become more important as access to water becomes more limited (Shdeed, 2001). For statistical analysis Gen Stat Release 13.3 statistical software at $p<0.05$ was used to evaluate the effects of treatments on the yield and yield components of onion.

Results and Discussions

Analysis of rainfall occurrences

The model expected rainfall value was estimated at 95% probability of occurrence. The total model expected rainfall value was 210mm, which was lower than the actual rainfall existed in 2011year (i.e. 221.1mm). While in 2012 the expected rainfall was higher than from the actual rainfall, which was 171mm. However, the monthly distribution variability was more indicative instead of the total rainfall; to observe how much the existed rainfall was matching with the expected. The only larger variation of the actual rainfall by 55mm occurred during the 2011 year at the month of May. On the other hand, except in 2012 in April, the expected values were compatible with the actual rainfall occurred during both years. As a result, the total crop water requirement of onion would be the summation of both rainfalls occurred and irrigation applied.

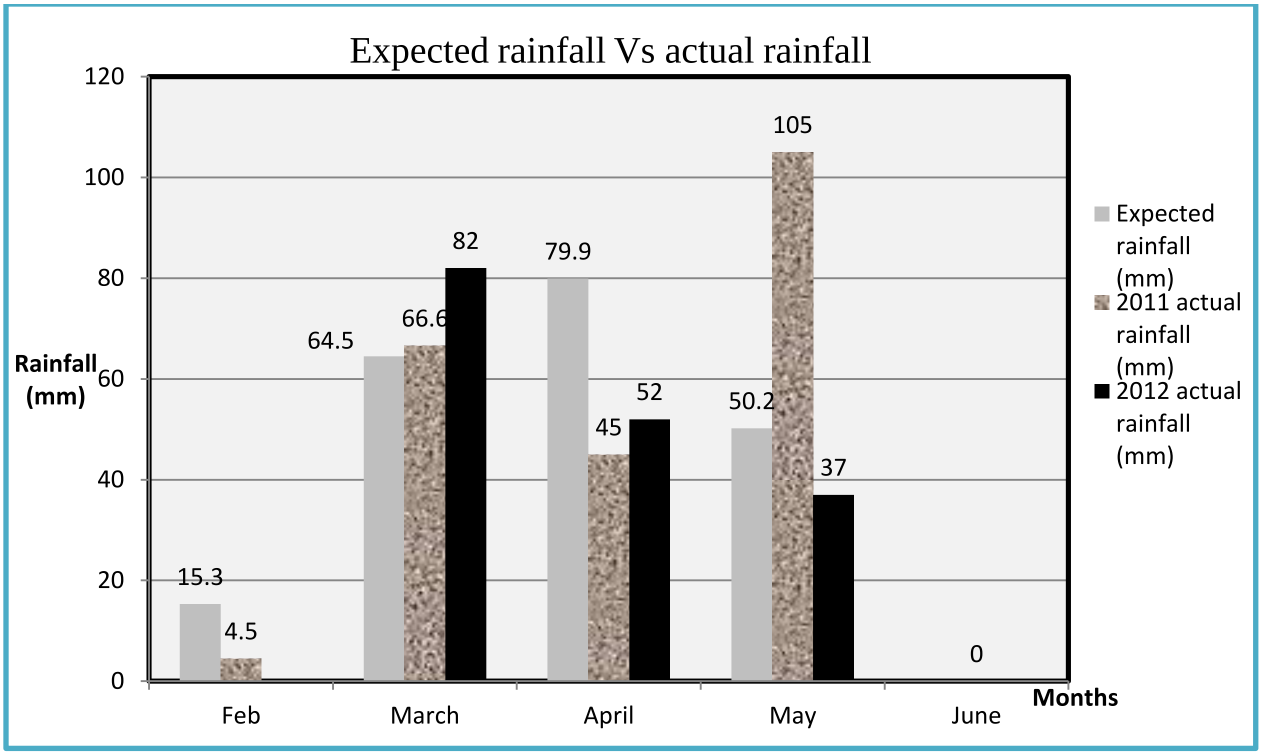


Figure 2. Expected rainfall VS actual rainfall occurrences

Results of yield and yield components

In an average bulb weight, marketable yield and water productivity; there was no significant difference between treatments across years. However, there was a significant difference in total yield.

Treatment effects on average bulb weight, marketable yield and water productivity

The combined effect of the two years result showed that there was a significant difference between treatments in average bulb weight. The maximum and minimum average bulb weight of 70.07gm and 51.37gm were obtained due to the application of 35mm in 10 days irrigation interval and 19mm in 10days irrigation interval respectively. It indicated that bulb weight was affected by the depth of application. As observed in table 2, there was a highly significant difference between treatments in marketable yield. Application of 35mm depth with 5days of irrigation interval (770mm a seasonal water requirement) which needs 22 irrigation cycles gave a maximum yield of 19.46 ton ha^{-1}. On the other hand, the lowest marketable yield of 9.58 ton ha^{-1} was obtained due to the application of 19 mm irrigation depth with 10days irrigation interval. Treatments which have similar irrigation interval of 5 days with irrigation depths of 25mm and

19 mm didn't show a significant difference in marketable yield. Relatively, treatments of 5 days irrigation interval with different irrigation depths gave maximum marketable yields. The effect of treatments in both years in total bulb yield was varied. In the first year, the maximum total bulb yield of 16.66 ton ha^{-1} was obtained due to the application of 25 mm irrigation depth with 5 days irrigation interval. While in the second-year application of 35mm irrigation depth in 5 days irrigation interval gave the maximum total bulb yield of 26.56 ton ha^{-1}. The combined result of the two years was 21.12 ton ha^{-1} due to the application of 35 mm irrigation depth with 5days irrigation interval.

Table 2. Effects of treatments on bulb weight, marketable yield and water productivity

Treatments	Bulb weight (gm.)	Marketable yield (ton ha^{-1})	Water productivity (kg m^{-3})
25mm, 8days	58.33ab	12.12c	3.60d
25mm, 5days	63.30ab	18.19ab	3.45d
25mm, 10 days	64.17ab	16.26b	7.37a
19mm, 8days	51.57b	13.03c	5.04b
19mm, 5days	59.40ab	17.28ab	4.32c
19mm,10days	51.37b	9.58d	4.76bc
35mm, 8days	62.70ab	15.96b	3.39d
35mm,5days	66.87 a	19.46a	2.74e
35mm,10days	70.07a	16.12b	4.29c
CV (%)	18.2	12.7	12.3
Grand mean	60.9	15.33	4.329

The same letters are not significantly different (P <0.05),

Table 3. Effects of treatments on total bulb yield

Treatments	Total bulb yield (ton/ha)		
	2010/11	2011/12	Combined
25mm,8days	11.87	13.32	12.59
25mm,5days	16.66	21.3	18.98
25mm,10 days	16.25	16.90	16.57
19mm, 8days	12.89	13.93	13.41
19mm,5days	17.12	19.02	18.07
19mm,10days	8.82	11.08	9.95
35mm, 8days	13.85	19.35	16.60
35mm,5days	15.69	26.56	21.12
35mm,10days	14.98	18.03	16.50
CV (%)	7.23	21.74	12.5
Grand mean	14.24	17.72	15.98

The marketable yield slightly increased as the amount of seasonal irrigation water increased but the irrigation interval was affecting the consistency. However, the determined total seasonal irrigation amount couldn't full fill the crop water demand in the growing period. The optimum seasonal irrigation amount estimated by a crop watt model was 350mm but the field experiment verified that the seasonal irrigation amount can be reached up to 770m. The yield increment was not yet reached at the maximum level and not turned as the amount of irrigation increases. Water productivity can be increased by increasing the yield per unit of land area. In, water management strategies and practices should be considered in order to produce more crops with less water. The highest water productivity of 7.37kg/m^3 was observed due to the application of 25mm irrigation depth with 10 days irrigation interval (seasonal irrigation demand of 280mm), and the lowest was found due to the effect of application depth of 35mm with 5 days irrigation interval which required 770mm seasonal irrigation amount. However, the only bulb yield increment was 3.2ton/ha by adding an extra amount of 490mm.

There were no significant differences between treatments in marketable bulb yields due to the application of 19, 25, 35mm application depths with 5days irrigation interval. However, the application of 19mm depth of application with 5 days irrigation interval had the highest water productivity of 4.32kg m^{-3} than the two treatments. It had optimum water productivity and could save about 352 mm seasonal irrigation water with 2.18 ton ha^{-1} yield reduction from treatment 8. The saved amount of irrigation water can irrigate an additional irrigable land of 84% and 46% of treatments 5 and 8 respectively.

In this experiment, frequent irrigation was more productive than prolonged irrigation application intervals. Research results conducted at Werer and Melkasa Agricultural Research Centers showed that onion was found to respond better at frequent rather than prolonged intervals of irrigation which is 50mm water at 3-6 days interval (Michael, 2001; Lemma and Hearth 1992). According to Zeleke and Solomon 2013, research finding in Kobo area application of 125% of CROPWAT generated depth which is about 38 mm at 7 days interval gave the highest marketable yield of 28.0 ton ha^{-1}. As a result, relatively application of 19mm irrigation depth with 5 days irrigation interval is advisable in areas like Jare which has water resource management utilization problems.

Conclusions and Recommendations

In this experiment, optimum yield and functional water productivity were existed due to the application of 19mm irrigation application depth at 5 days interval with around a total seasonal irrigation demand of 418mm which could save irrigation water to irrigate additional irrigation land. Crop watt generated depth (25mm) of application and optimum time of application (8 days) are not recommendable but further research is necessary for specific depths of application in 5 days irrigation interval. As a result, in the study area around Tehuledere and areas which have similar agro-ecology and soil characteristics, irrigators can irrigate onion with a frequent 5 days irrigation interval with irrigation application depth of 19mm (75% of the CROPWAT generated depth).

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Effect of Drip Lateral Spacing and Irrigation Amount on Tomato and Onion Crops Water Productivity at Kobo Girrana Valley, Ethiopia.

Solomon Wondatir*[1], Zeleke Belay[2], Abera Getnet[1]

[1]Sirinka Agricultural Research Center, P.O. Box.74, Woldia, Ethiopia

[2]Amhara Region Agricultural Research Institute (ARARI), P.O.Box 527, Bahir Dar, Ethiopia

*Corresponding author: email: solwondatir@gmail.com

Abstract

Irrigation system in Kobo-Girrana valley is extensively developed into modern drip irrigation using groundwater sources. Tomato and onion are among the major vegetables grown under drip irrigation. However, the drip lateral spacing is fixed to 1m for all irrigated crops. This leads to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. An on-station experiment was conducted to determine the effect of drip line spacing and irrigation amount on yield, irrigation water use efficiency and net return income. The experiment was carried out for two consecutive irrigation seasons in 2010/11 and 2011/12 at Kobo irrigation research station. The experimental treatments were: two laterals spacing of single (1m) row and double (2m) row corresponding to each test crop and three irrigation amounts (pan coefficients /PC/ = 0.8, 1.0 and 1.2). The experimental design was factorially arranged in RCBD. The experimental results revealed that there was an interaction effect between the lateral spacing and irrigation amounts on marketable yield and water productivity of the test crops. Application of 0.8 PC with 2m lateral spacing and 1.2 PC with 1m lateral spacing provided a relatively higher marketable yield of tomato and onion respectively. Similarly, high water productivity was recorded with the same irrigation depths and spacing. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion and tomato. An optimized production and irrigation efficiency can be attained by applying irrigation depth adjusted by the given pan coefficients and drip lateral spacing in Kobo areas.

Keywords: *Drip irrigation, irrigation schedule, lateral spacing, marketable yield, water productivity*

Introduction

Irrigation water plays a main role for agricultural growth, which enhances the cropping intensity of high value crops and also increasing the productivity of crops. Hence irrigation water plays a great contribute to sustain reduction of rural poverty too. Ethiopia is the country which endowed with abundant water resources and huge irrigable lands for irrigation agriculture (Awualchew *et al.*, 2010; EPCC, 2015).

Despite this, much of the available irrigation water is applied through the conventional surface irrigation method, where the efficiency of water is very low. The low irrigation water-use efficiency not only reduces the anticipated outcomes from investments in the water resources sector of the country, but also creates environmental problems, such as lowering of the water table due to over-exploitation of sub-surface water resources, water logging and soil salinity, thereby affecting the yields adversely.

In order to reduce the water stress in agricultural sector and to improve the efficiency of existing irrigation systems, various initiatives have been taken in Ethiopia in recent years. Of these, drip irrigation has been practiced relatively in large scale in Amhara region; specifically, in Kobo Girana Valley. Since moisture stress is completely absent in drip irrigation, the productivity of crops is found to be significantly higher than those cultivated under flood irrigation (Namara *et al.*, 2005; Narayanamoorthy, 2004; Shah and Keller, 2014).

Drip irrigation has a multiple advantage; it offers improved yields, requires less water, and decreases the cost of tillage, and reduces the amount of fertilizer and other chemicals to be applied to the crop. Because drip irrigation makes it possible to place water precisely where it is needed and to apply it with a high degree of uniformity at very low flow rates, it decreases both surface runoff and deep percolation. These features make drip irrigation potentially much more efficient than other irrigation methods, which can translate to significant water savings (Hanson *et al.*, 1996).

Thus, in Kobo Girana Valley use of drip irrigation for vegetable crops has increased through government assisted ground water resources development program. Currently significant area is under drip irrigation development. Onion and Tomato are among the major vegetable crops grown in Kobo Girana valley.

However, the drip lateral spacing is fixed to 1m for all irrigated crops. This leads to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. Lateral spacing is always a compromise between optimal water distribution and lateral cost.

So, it is imperative to investigate whether spacing adjustment and using one lateral pipe between two plant rows is effective and economical in terms of initial investment cost and irrigation management efficiency. As a result, this study was conducted to determine the effect of drip line spacing and irrigation amount on yield, net return, and irrigation water use efficiency.

Materials and Methods

The experiment was carried out at Kobo irrigation site for two consecutive years of 2011 and 2012 for onion and tomato. Kobo research station is situated at 12.08^0 N latitude and 39.28^0 E longitudes at an altitude of 1470 m above sea level. The 15 years mean annual rainfall is about 630mm and average daily reference evapo-transpiration rate of 5.94 mm. The soil type in the experimental site is silty clay loam which has average infiltration rate of 8 mm/hr., pH value of 7.8, average FC and PWP of 11.5% and 3.2% on volume basis respectively.

The drip system was the gravitational type which stands 1.5m head difference from the ground and consisted of PE laterals of 16mm in diameter and PE manifold pipeline of 32mm diameter. The discharge rates of the emitters were calculated as 0.9l/hr. and emitter spacing was chosen as 0.50m. The experimental design was factorial RCBD with 4 replications. Six treatments were composed of two factors: lateral spacing (single and double) and three irrigation depths (80%, 100%, and 120%). For tomato and onion, 1m & 2m lateral spacing and 0.5 & 1m lateral spacing were used respectively. The amounts of irrigation water applied (I m^3) in the irrigation treatments were determined by Class-A pan evaporation using the equation given below:

$$I = A * E_p * K_p * P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where;

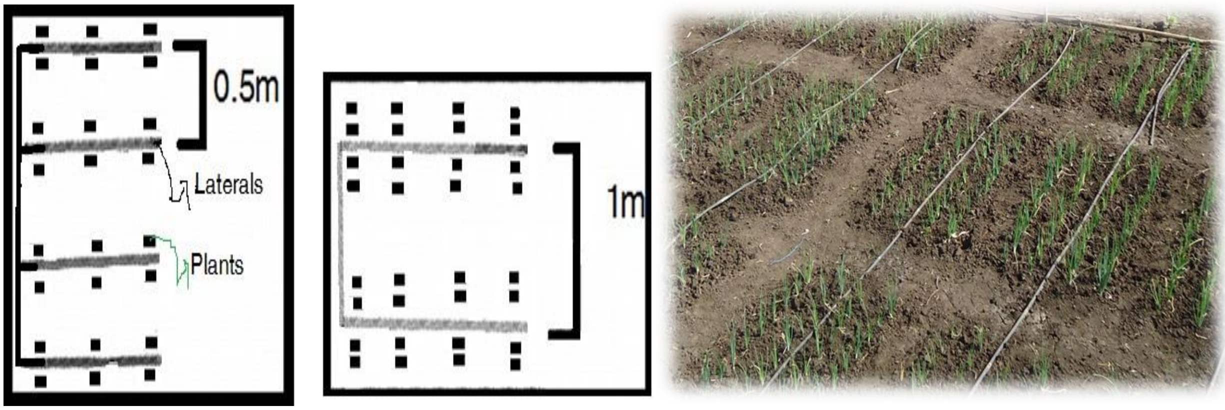
I = is the plot area (m^2),

Ep = is the cumulative pan evaporation amount for the 4-days irrigation interval,

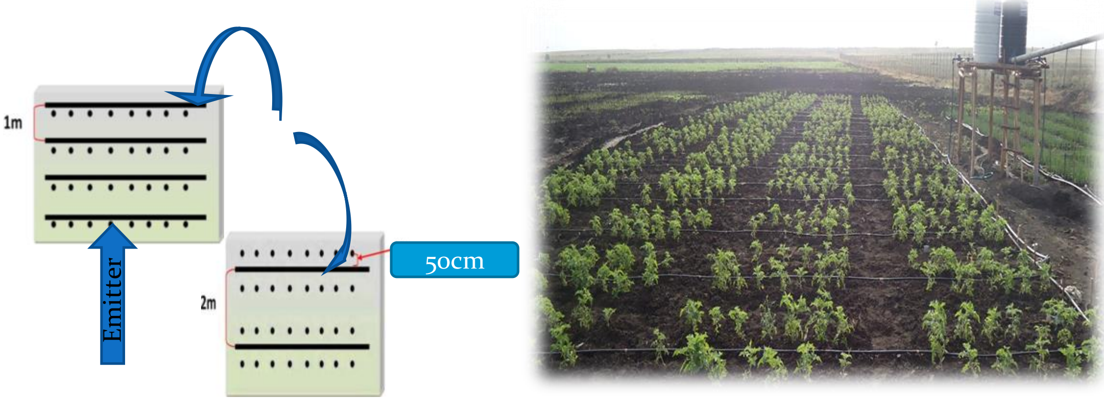
Kp = is the coefficient of pan evaporation (i.e. Kp =0.8, 1.0 & 1.2) and

P = is the percentage of wetted area (P) or percentage

The spacing between plants was 30 and 10cm for tomato and onion respectively.



(a) Onion



(b) Tomato

Figure 1. Schematic layout of laterals and plants in the experimental plots for onion and tomato

The percentages of the wetted area (P) were determined by methods from Keller and Bliesner (1990) and Yildirim (2003). The P was the average horizontal area wetted in the top 15–30 cm of the crop root zone as a percentage of each lateral line area. Thus, the percentages of wetted area measured in the experimental site were 90% or 45% for the lateral spacing of single or double, respectively. The first irrigation for all plots was based on water deficit that would be needed to bring the 0–60 cm layer of soil to field capacity. Subsequent irrigations were applied considering the 4-days irrigation interval. Irrigation water use efficiency (IWUE) is generally defined as crop yield per water used to produce the yield (Viets, 1962; Howell, 1996). Thus, IWUE was calculated as fresh fruit weight (kg) obtained per unit volume of irrigation water applied (m^3).

The economic analysis was carried out through the net benefit investment method; i.e. by subtracting total annual costs from total annual benefits. The other economic analysis parameter cost-benefit ratio couldn't be computed, because there was no continuous production and other operating costs in the project life periods. The total production cost was calculated from the results of investment, operation and production costs. The market price of each vegetable crop in the production year was used for the estimation of total income.

Result and Discussion

Results

There was an interaction effect between drip lateral spacing and irrigation depths on water productivity of onion and tomato. While there were no interaction effects on bulb yield of onion and tomato.

Table 1. Main effects of lateral spacing and irrigation depth on marketable bulb yield and water productivity of onion and tomato

Lateral spacing	Marketable yield (tone/ha)		Water productivity (kg/m^3)		Irrigation regime	Marketable yield (tone/ha)		Water productivity (kg/m^3)	
	Onion	Tomato	Onion	Tomato		Onion	Tomato	Onion	Tomato
Single	19.01	17.21	3.48	1.997	80%	20.01	20.48	6.93	3.87
double	22.45	21.53	8.13	4.935	100%	20.14	20.03	5.5	3.81
					120%	22.04	17.60	4.99	2.72
LSD (0.05)	1.24**	2.06**	0.38**	0.244**		1.515*	NS	0.46**	0.299**
CV(%)	10.2	18.1	11	12		10.2	18.1	11	12

Table 2. Interaction effects of lateral spacing and irrigation amounts on marketable yield and water productivity of onion and tomato.

Lateral spacing and Irrigation depth	Seasonal irrigation amount (mm)		Marketable yield (ton ha^{-1})		Water productivity (kg m^{-3})	
	Onion	Tomato	Onion	Tomato	Onion	Tomato
Single row, 80% PC	461.5	449.79	18.26	17.55	4.02	1.601
Single row, 100% PC	576.9	562.24	18.21	18.21	3.36	2.293
Single row, 120% PC	692.3	674.69	20.55	15.88	3.06	2.098
Double row, 80% PC	230.8	224.9	21.76	23.41	6.91	6.130
Double row, 100% PC	288.5	281.12	22.06	21.85	9.85	5.330
Double row, 120% PC	346.1	337.35	23.54	19.33	7.63	3.343
LSD(0.05)			ns	ns	0.65**	0.4230**
CV (%)			10.2	18.1	11	12

*-significant difference NS= non-significant at 5% **-high significant difference PC- pan coefficient

Table 3. Economic analysis of drip lateral spacing for onion crop

Treatments	Amount of irrigation water (mm) (1)	Irrigation water (m^3 ha^{-1}) (2)	Irrigation duration for the irrigation season (h) (3)	Labor cost for irrigation (birr h^{-1}) (4)	Total cost for irrigation labor (birr) (5)= (3*4)	Pump cost (birr) (6) (irrigation cycle*unit pump cost) (2*3)	Crop production cost (birr ha^{-1}) (7)	Irrigation system cost for 1ha (birr ha^{-1}) (8)	Yearly cost of the irrigation system (birr/ha) (9)=(8/7years)	Total cost for 1 year (birr ha^{-1}) (10)=(5+6+7+9)	Yield (kg ha^{-1}) (11)	Sale price (birr kg^{-1}) (12)	Gross income per ha (birr $ha^{-1}year^{-1}$) (13)=(11*12)	Net income (birr $ha^{-1}year^{-1}$) (14)=(13-10)
1	461.5	4615	90.25	3	270.75	384.58	10000	21444.05	3063.44	13718.77	18260	4	73040	59321.23
2	576.9	5769	112.82	3	338.46	480.75	10000	21444.05	3063.44	13882.65	18210	4	72840	58957.35
3	692.3	6923	135.38	3	406.14	576.92	10000	21444.05	3063.44	14046.50	20550	4	82200	68153.50
4	230.8	2308	45.13	3	135.39	192.33	10000	15768.3	2252.61	12580.33	21760	4	87040	74459.67
5	288.5	2885	56.42	3	169.26	240.42	10000	15768.3	2252.61	13718.77	22060	4	88240	75577.71
6	346.1	3461	67.68	3	203.04	288.42	10000	15768.3	2252.61	13882.65	23540	4	94160	81415.93

Table 4. Economic analysis of drip lateral spacing for tomato crop

Treatment	Amount of irrigation water (mm) (1)	Irrigation water (m^3 ha^{-1}) (2)	Irrigation duration for the irrigation season (h) (3)	Labor cost for irrigation (birrh^{-1}) (4)	Total cost for irrigation labor (birr) (5)=(3*4))	Pump cost (birr) (6)	Crop production cost (birr ha^{-1}) (7)	Irrigation system cost for 1ha (birr ha^{-1}) (8)	Yearly cost of the irrigation system (birr/ha) (9)=(8/7years)	Total cost for 1 year (birr ha^{-1}) (10)=(5+6+7+9)	Yield (kg ha^{-1}) (11)	Sale price (birr kg^{-1}) (12)	Gross income (birr ha^{-1} $year^{-1}$) (13)=(11*12)	Net income (birr ha^{-1} $year^{-1}$) (14)=(13-10)
1	449.79	4498	250	3	750	374.83	7000	15768.3	2252.61	10377.44	17550	2.5	43875	33498
2	562.24	5622	312	3	937	468.5	7000	15768.3	2252.61	10658.11	18210	2.5	45524	34867
3	674.69	6747	375	3	1124	562.25	7000	15768.3	2252.61	10938.86	15880	2.5	39700	28761
4	224.9	2249	125	3	375	187.42	7000	12513.8	1787.69	9350.11	23410	2.5	58525	49175
5	281.12	2811	156	3	469	234.25	7000	12513.8	1787.69	9490.94	21850	2.5	54625	45134
6	337.35	3374	187	3	562	281.17	7000	12513.8	1787.69	9630.86	19330	2.5	48325	38694

Discussion

Onion

Effects of lateral spacing and irrigation depths on onion bulb yield and water productivity

As observed in table 1; lateral spacing and different irrigation depths had a separate significant effect on marketable yield of onion. However, there was no interaction effect between different lateral spacing and irrigation depths on marketable yield of onion. The highest and the lowest marketable bulb yield of 23.54 and 18.21 ton/ha were obtained due to the effects of 1m lateral spacing with 120% of irrigation depth and 0.5m with 100% of irrigation depth respectively. In table 2 above, lateral spacing and different irrigation depths separately affects water productivity and had an interaction effect on water productivity of onion. Maximum 9.85 and minimum 3.06kg/m^3 water productivity were existed due to the effects of a double row with 100% irrigation depth and single row with 120% irrigation depth respectively. The value of water productivity was decreased as the amount of irrigation amount increased.

Economic analysis and evaluation of onion

As showed in table 3 and 4 above; Economic analysis and evaluation were computed by using the results of this study based on investment, operation, and production costs. Based on the irrigation amount of each treatment in the growing season irrigation duration, labor cost for irrigation and pump cost were estimated. The production costs were computed by considering all production inputs (i.e. costs of seeds, plowing of land, transplanting, hoeing, weeding, pesticide, fertilizer, harvesting, etc.) for onion and tomato. The production costs were similar for each treatment and calculated as 10,000.00birr/ha for onion and 7,000birr/ha for tomato in the production season. On the other hand, drip irrigation system costs can vary greatly, depending on the crop (plant, and therefore, emitter spacing and hose) (Solomon, 1988).

Thus, based on lateral length, connections, tapes, and drippers for the treatment in which the lateral spacing was 1m and the investment costs were 26% less than in the treatment in which the lateral spacing was 0.5 m for onion. And for tomato, 2m lateral spacing had 20.64% less investment cost than 1m lateral spacing. The investment cost of a drip system was calculated with 7 years life period (Enciso *et al.*, 2005).

According to the calculation for onion 1m lateral spacing with 120% irrigation amount gave the maximum yearly net income of 81,415.93birr. On the other hand, less net income of 58,957.35birr was obtained in 0.5m lateral spacing with 80% irrigation amount. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion.

Tomato

Effects of lateral spacing and irrigation depths on tomato fruit yield and water productivity

There was a highly significant difference in marketable tomato yield due to different lateral spacing. There was no significant difference in marketable fruit yield of tomato among different irrigation amounts. A maximum of 21.53ton/ha marketable fruit yield was obtained due to the effect of double lateral spacing. There was no interaction effect in marketable fruit yield of tomato due to lateral spacing and irrigation amounts. The amount of marketable yields was slightly decreasing as the amount of irrigation water applied increased. The maximum (23.41tone/ha) and minimum (15.88tone/ha) marketable yield of tomato were obtained due to effects of double row spacing with 80% irrigation depth and single row spacing with 120% irrigation depth.

For tomato crops, the irrigation water use efficiencies range from 1.6 - 6.13kg/m^3 depending upon treatments. The maximum irrigation water use efficiency of 6.13kg/m^3 was obtained from double lateral spacing (2m) with 80% irrigation depth. This might be related to the wider lateral spacing and low depth of application; which used a low amount of total irrigation water. Similarly, Hao *et al.* (2013) showed that IWUE was greatest with double rows in the tomatoes grown in the greenhouse. Generally, the highest water use efficiencies occurred in double lateral spacing with small irrigation depth. Furthermore, IWUEs differ considerably among the treatments and generally tends to increase with a decline in irrigation (Howell, 2006). IWUE is an important factor when considering irrigation systems and water management, and probably will become more important as access to water becomes more limited (Shdeed, 2001). On the other hand, water productivity can be increased by increasing the yield per unit land area. In addition, water management strategies and practices should be considered in order to produce more crops with less water.

Economic analysis and evaluation of tomato

The production costs were similar for each treatment and calculated as 7,000birr/ha for tomato in the production season. Based on lateral length, connections, tapes, and drippers for the treatment in which the lateral spacing of 2m lateral spacing had 20.64% less investment cost than 1m lateral spacing. The investment cost of the drip system was calculated similarly with the above onion crop. The lowest 28,761.00birr and highest 49,175.00birr yearly net income were obtained due to treatments of single row spacing (1m) with 120% irrigation amount and double row spacing (2m) with 80% irrigation amount respectively. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of tomato.

Conclusion and Recommendation

In the experimental study of onion, 692mm irrigation water amount in 0.5m lateral spacing with 120% irrigation depth gave a marketable yield of 20.55ton/ha. However, the highest fresh marketable yield of onion (23.54tone/ha) was obtained by the effect of 1m lateral spacing with 120% pan coefficient which requires a total seasonal irrigation requirement of 346mm. A maximum water use efficiency of 9.85kg/m^3 was recorded by 1m lateral spacing with 100% irrigation depth followed by 7.1kg/m^3 water use efficiency of 1m lateral spacing with 120% irrigation depth for onion.

Investment costs in the design of one lateral for two crop rows were 27% less because the length of laterals, dripper numbers and connections were fewer than the design of one lateral for each crop row. Also, the yield obtained was high compared to the treatment with one lateral for each row. Consequently, economic analysis based on investment and production costs, yields obtained, amounts of irrigation water applied per ha, was done to compare these two treatments. As a result, 1m lateral spacing with 120% irrigation amount was given the highest as 81,415.93birr yearly net income return.

For tomato drip lateral spacing determination study, the maximum marketable yield 23.41tone/ha was obtained by treatment effects of 2m lateral spacing with 80% irrigation depth to which total seasonal irrigation water amount of 225mm. Similarly, 2m lateral spacing with 80% irrigation depth gave the maximum water use efficiency of 6.13kg/m^3. Fresh marketable yield slightly decreases as the irrigation amount increases. To get optimum tomato production using one lateral pipe for two plant rows and 80% pan coefficient of irrigation amount is recommendable. Drip irrigation cost of double row lateral spacing was 20.64% less than a single lateral spacing for each crop rows. A maximum marketable yield obtained in the treatment of 2m lateral spacing by 80% pan coefficient contributes for a high economical yearly net return income of 49,175birr.

An optimized production and irrigation efficiency can be attained by applying irrigation depth adjusted by the given pan coefficients and drip lateral spacing in Kobo areas. Generally, in kobo Girana area double lateral spacing is more economical than a single lateral spacing design for onion and tomato vegetables.

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III) Soil and Water Conservation

Developing GIS-Based Soil Erosion Map Using RUSLE for Andit Tid Watershed Central Highlands of Ethiopia

Ayele Desalegn*[1] Abraham Tezera[1] and Fikrey Tesfay[2]

[1]DebreBerhan Agricultural Research Center, P.o. Box: 112, Debre Birhan, Ethiopia

[2]DebreBerhan University, P.O. Box: 445, Debre Berhan, Ethiopia

*Corresponding author: Ayele Desalegn; email: ayeledesalegn5@gmail.com

Abstract

*Soil erosion is a common phenomenon and major threat in many parts of the Ethiopian highlands. It is difficult to quantify and measure the amount of soil erosion. When integrated with GIS, erosion models such as the Universal Soil Loss Equation (USLE) can be used to identify erosion potential areas and identify hotspots. This research was conducted in the Central Highlands of Ethiopia, Andit Tid watershed, North shoa, Ethiopia during 2014 and 2015 to estimate the annual soil loss from the watershed and to map the topographic and anthropogenic factors for the planning and implementations of sustainable soil conservation and management system in the watershed. The Revised Universal Soil Loss Equation (RUSLE) integrated with GIS was used to estimate soil losses and identify the potential effect of erosion factors. We employed inverse distance weight (IDW) - interpolation-to generate rainfall erosivity (R) factor and soil erodibility (K) factor surface maps. The slope length and steepness (LS) factor was derived from a 30m*30m Digital Elevation Model (DEM). The vegetation cover (C-factor) was derived from remotely sensed land use/cover map. The land use/cover map was also used to derive management practice (P) factor. We also made the long-term correlation matrix among discharge, sediment loss and rainfall of the watershed. The result revealed that the annual soil erosion potential of the watershed ranges between 0-29 ton $ha^{-1}yr^{-1}$with an average of 22.3 ton $ha^{-1}yr^{-1}$. Therefore, GIS-based soil erosion model is a cost-effective method to estimate soil erosion as well as to identify priority area for sustainable land management practices.*

Keywords: *Andit Tid, DEM, RUSLE, soil erosion*

Introduction

The Ethiopian highlands account 43% of the country and cover 95% of the cultivated land. According to FAO (1984) and Hurni (1993), the annual soil loss of the Ethiopian highlands ranges between 200 to 300 tons per hectare and have an impact on the loss of fertile soil. Soil erosion affects 50% of the agricultural area and 88% of the total population of the country (Sonneveld *et al.*, 1999). The situation is more prevalent and determinant in the study region (Amhara region). The influences of soil erosion on soil degradation, agricultural production, water quality, hydrological systems, and environments have been recognized (Lal, 1998). Different attempts were also made to assess the severity of soil loss. The methods of quantifying soil loss based on erosion plots possess many limitations in terms of cost, representativeness, and reliability of the resulting data. They cannot provide a spatial distribution of soil erosion loss due to the constraint of limited samples in complex environments for geospatial analysis of environmental complexity, contingency, and unpredictability (Simandan, 2011; Simandan, 2016).

Thus, mapping soil erosion in large areas is often very difficult using these traditional methods. On the other hand, model-based estimation of soil erosion is often difficult due to the complex interplay of many factors, such as climate, biophysical, social, economic, and political factors (Ananda and Herath, 2003). The soil's resistance to rainfall and runoff erosivity is, therefore, considered as the inherent susceptibility of soil to be detached and translocate by erosion processes, such as splash erosion, surface runoff and can be dignified as soil erodibility factor (K-factor) (Addis and Klik, 2015). In this regard, integrating soil erosion with geographical information system (GIS) is considered a vital tool to map the spatial variability of soil loss across space (De Roo, 1998).

Universal Soil Loss Equation (USLE) and later the Revised Universal Soil Loss Equation (RUSLE) has been the most widely used model in predicting soil loss (Wischmeier and Smith, 1978). RUSLE represents how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff (Renard *et al.*, 1997). It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions (Millward and Mersey, 1999; Boggs *et al.*, 2001). There are five major factors that are used to calculate soil loss for a given site (Equation 3**)**. Each parameter is the arithmetic estimate of a specific condition that affects the severity of soil erosion at a particular location. Thus, the erosion values obtained from the RUSLE more accurately represent long-term averages.

Therefore, the purposes of this research are: (1) develop a GIS-based soil erosion potential model of the AnditTid Watershed; (2) estimate soil erosion potential for the entire watershed and to identify high soil erosion potential areas; and (3) develop a correlation among recorded rainfall, discharge, and sediment loss. The paper is organized as: section two provides the material and methods used; section three reveals the results and discussions and finally, conclusion and remarks are provided in section four.

Materials and Methods

Description of the study area

Andit Tid watershed is one of the seven catchments of the Soil Conservation Research Programme (SCRP) of the Amhara Regional Agricultural Research Institute (ARARI). The SCRP was initiated in 1981 by the Institute of Geography of the University of Bern (Switzerland). Hence in the study area, there is a huge amount of collected and available data for the last 25-30 years. The watershed is situated on 39°43’E longitudes and 9°48’N latitudes (Figure 1) 180 km northeast of capital city Addis Ababa. The watershed covers a total area of 475 ha, and the altitude of the catchment ranges from 3040 to 3550 m.a.s.l. The mean annual rainfall is 1651mm, the minimum and maximum temperaturesare7°C and 17°C, respectively. The minimum and maximum average soil temperatures are 8°C and 20°C, respectively. The agro-climatic zone of the watershed is moist wurch.

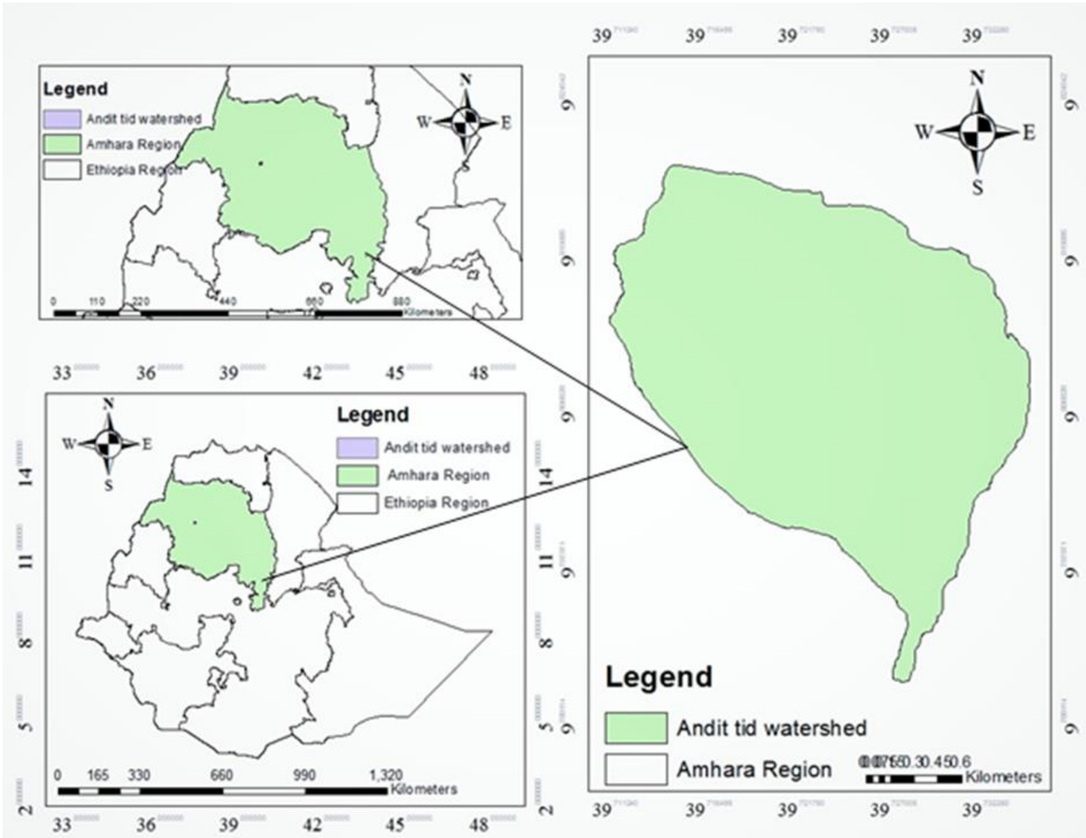

Figure 1. Map of Andit Tid watershed.

Data sources and analysis

The research has used both primary and secondary data. Satellite image, aerial photo, topographic map, meteorological data, and others were collected from different governmental and non-governmental organizations. In addition, a Global Positioning System (GPS) data collection was carried out to generate information for image classification and soil loss vulnerability verification. Data analysis and processing were made by digitizing, calculating and classifying the necessary information of each thematic layers using ArcGIS 10.1 software. Furthermore, some simple statistical methods, such as percentage, average and graphic tabulation were employed for analysis and interpretations. The following simplified flow chart (Figure 2) shows the basic methodological approach followed in RUSLE.

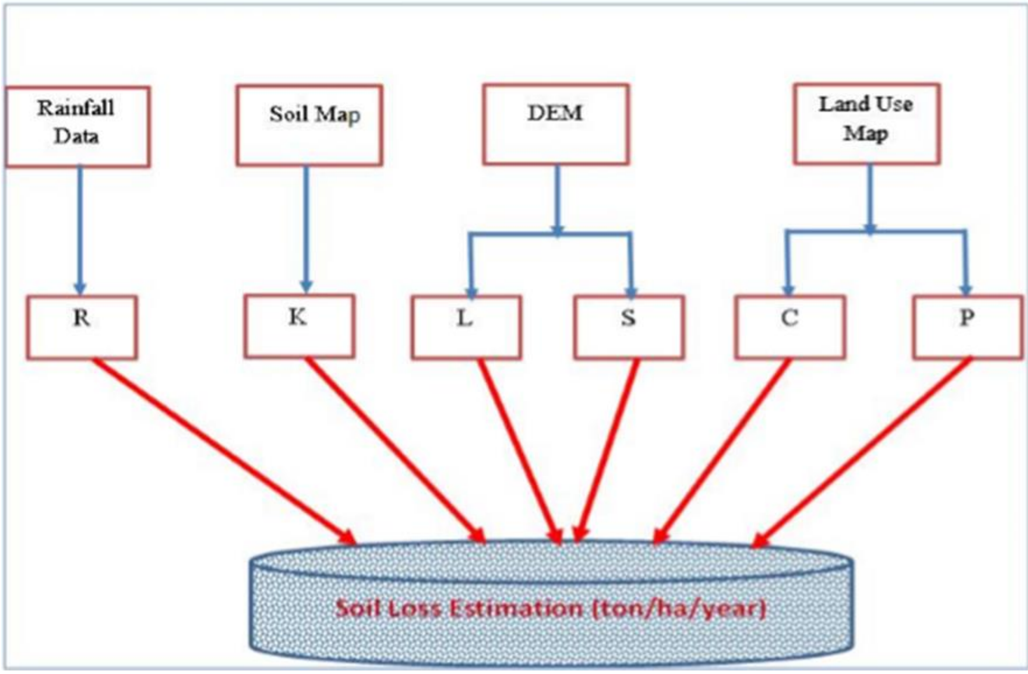

Figure 2. Conceptual framework of soil loss estimation (Authors developed).

Rainfall erosivity (R) factor

The soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff. The daily rainfall data records from the watershed rain gauge station covering the period 1985-2014 were used to calculate the rainfall erosivity (R). The mean annual rainfall from 4 rain gauge sites of the watershed was first generated (Table 2) to get continuous rainfall data for each grid cell. Then the R-value corresponds to the mean annual rainfall of the watershed was found using the R correlation established in (Hurni, 1985) to Ethiopia condition.

R= -8.12 + 0.562*P ……………………………..Equation (1)

Where R is the rainfall erosivity factor (MJmmha^{-1} h−1 yr^{-1}) and P is the mean annual precipitation (mm).

R-factor was computed using a conversion tool (Equation 1) in raster surface using IDW (Inverse Distance-Weighted) interpolation methods in ArcGIS software.

Soil erodibility (K) factor

The value of K ranges from 0 to 1. Spatial analysis tool extract by the mask in a GIS environment was used to obtain soil unit map of the study watershed. The soil erodibility (K) factor for the watershed was estimated based on soil unit types referred from (Nachtergaele *et al.*, 2010) soil database adapted to Ethiopia by Hurni (1985) and Helldén (1987). The soil unit map is presented as shapefile which was then converted to a raster with a cell size of 30x30 m. The raster map was then reclassified based on their erodibility value as shown in Table 1.

Table 1. Soil Types and their corresponding K value

Soil Type	Area (Ha)	K-value
Eutric leptosol	275	0.15
Eutric cambisol	30.5	0.15
Lithic leptosol	169.5	0.2

Slope length and (LS) factor

The topographic factor (ls) is used to adjust the erosion rate based upon the length and steepness of the slope. The erosivity of runoff increases with the velocity of the runoff water. Steep slopes produce high runoff velocities. Soil loss increases with increasing slope due to the greater volume of runoff accumulating on the longer slope lengths. The slope length is the distance from the point of origin of the runoff to the point where the slope steepness decreases sufficiently to cause deposition or to the point where runoff enters a well-defined channel. The slope length and slope steepness can be used as a single index ls, which expresses the ratio of soil loss as defined by Wischmeier and Smith (1978). Slope steepness has been considered as one of the most model parameters in RUSLE analysis due to the fact that the steeper the slope of a field, the more it is pushed downhill, the faster the water runs and the greater will be the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff.

In the case of this study 30m*30m spatial resolution digital elevation model (DEM) was employed to map the flow accumulation and slope gradient of the study watershed from Abay basin DEM data by using Arc GIS 10.1 software. Then the equation that was generated by Griffin *et al.* (1988) was used to calculate and map the slope length and steepness (ls) factor in Arc GIS as defined in (Equation 2).

LS = pow [(flow accumulation) * cell size/22.1, 0.6] * pow [sin (slope) * 0.01745/0.09,1.3]… Equation (2)

Where LS represents the slope length and steepness factor; flow accumulation is derived from the DEM after conducting fill, flow direction and flow accumulation processes in Arc GIS; Cell size is the size of the cells being used in the grid-based representation of the landscape. Finally, the LS factor map was derived using the above formula in Arc GIS spatial analysis raster calculator function (Figure 5).

Crop management (C) Factor

The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The land use map was used for analyzing the c-value. Land use and land cover types were classified so as to use the classified image as an input for generating crop management (C) factor. The land use and land cover map of the study watershed were prepared from LANDSAT through supervised digital image classification technique using ENVI 5.0 software. A ground truth effort was also made in order to collect actual information. The raster land use/land cover map was converted to a vector format and a corresponding C-value was assigned to each land use classes based on cover values proposed by Hurni (1985) (Table 4). Finally, using reclassification and vector to raster conversion the land use/ land cover map was converted to C factor map as mentioned in (Figure 6).

Management Practice Factor (P-value)

Erosion management practices are the practices that reduce the velocity of runoff and the tendency of runoff to flow directly down-slope reduce the P factor. In the study area, there is only a small area that has been treated with terracing through the agricultural extension program of the government and these are poorly maintained as implementation was performed without the participation of the local people. As data were lacking on permanent management factors and there were no management practices, the P-values suggested in (Bewket and Tefferi, 2009) were used. Thus, the agricultural lands are classified into five slope categories and assigned P-values while all non-agricultural lands are assigned a P-value of 1.00 (Figure 6). In general, the minimum p-value is 0.1 for the cultivated land with a slope of less than 5%. The P-factor was assessed using major land cover and slope interaction adopted by Wischmeier and Smith (1978) for Ethiopia condition. The corresponding P values were assigned to each land use/land cover and slope classes. The P factor map was then produced through analyst tool, extract and the intersection of land use and slope class map in ArcGIS environment.

Total annual soil loss analysis

Average annual soil loss rate was determined by a cell-by-cell analysis of the soil loss surface by superimposing and multiplying the respective RUSLE factor values (R, K, LS, C, and P) interactively by using “Spatial Analyst Tool- Map Algebra -Raster Calculator” in ArcGIS 10.1 environment as shown in equation (3).

A= R* K* LS* C* P ……………………………………………………………..Equation (3)

Where A is the average annual potential soil loss in ton.ha^{-1}yr^{-1}; R is the rainfall-runoff erosivity (MJmmha^{-1} h−1 yr^{-1}) factor; K is the soil erodibility (MghMJ^{-1} mm^{-1}) factor; LS is the slope length and steepness factor; C is the land-cover management factor; P is the management practice factor.

Correlation among rainfall, discharge and sediment loss

Since Andit Tid watershed is one of the SCRP model watersheds in Ethiopia the rainfall, river discharge, sediment loss and other climatic and hydrologic data were collected, organized and encoded in Debre Brehan Agricultural Research centre and WLRC project office since 1982. So long as this study accessed the data of selected parameters from Andit Tid station. The average monthly relationship between rainfall and discharge, rainfall and sediment loss, and discharge and sediment loss were done using Stata 22.0 statistical software.

Result and discussion

Rainfall erosivity (R) factor

As shown in the map below the maximum R-value is 949 whereas the minimum R-value is 839. Hence the watershed is dominated with maximum and near maximum R-factor value except for the northwestern parts of the watershed. The erosivity factor result is presented in (Figure 3).

Table 2. Mean annual rainfall and erosivity factor (R) result.

Rain gauge station	Coordinate points			Mean Annual Rainfall (mm)	R-value
	X(m)	Y(m)	Z(m)		
1	577951	1084936	3050	1656.4	922.78
2	579049	1084944	3221	1703.1	949.03
3	579488	1083468	3403	1651.8	920.19
4	577928	1084868	3031	1508.3	839.2

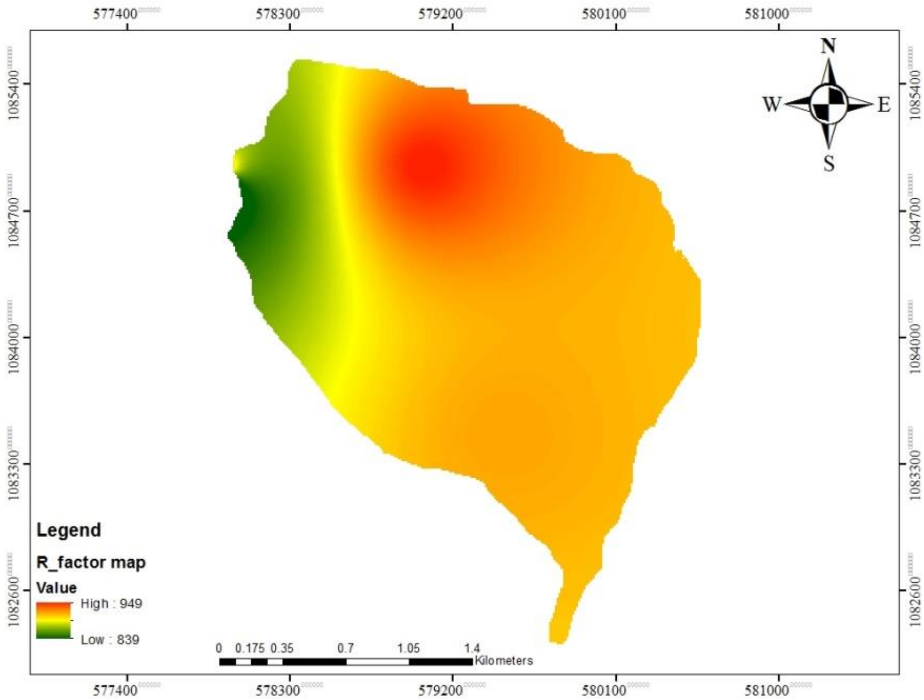

Figure 3. Rainfall erosivity factor (R value) map.

Soil erodibility (K) factor

The results indicated that soil erodibility value in the study watershed is 0.15 for Eutric Leptosols and Eutric Cambisols whereas 0.2 (Lithic Leptosols). From the following map (Figure 4). We could conclude that the larger area of the watershed has the K value of 0.15 in the North, Northeastern and Northwest parts of the watershed whereas the South and Southeastern part has the K value of 0.2.

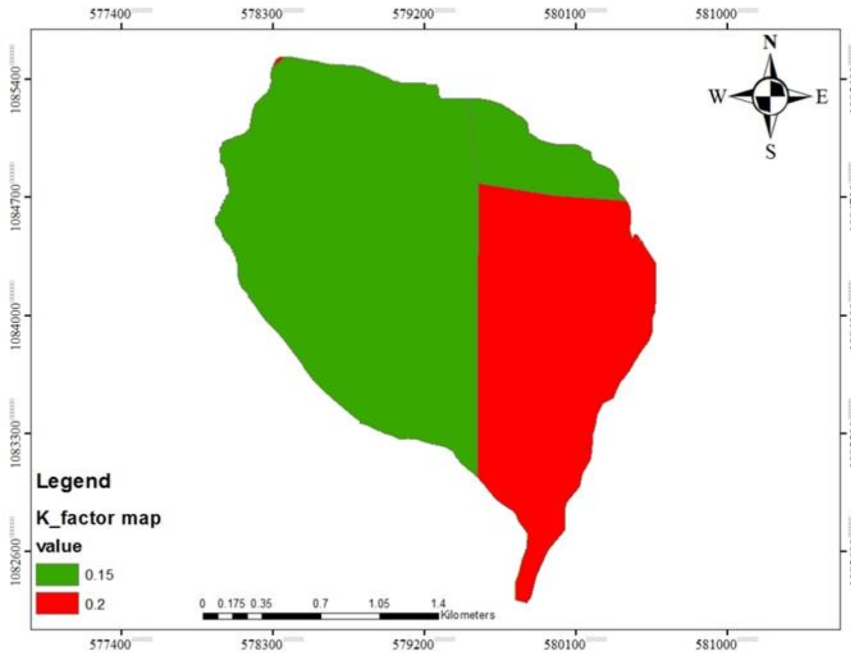

Figure 4. Soil erodibility (K) factor map

Slope length and steepness (LS) factor

The maximum LS value is 7.46 and the minimum value is 0 in the plain parts of the watershed, it was calculated after generating flow accumulation and slope class map from DEM and by using Raster Calculator through applying (Equation 2).

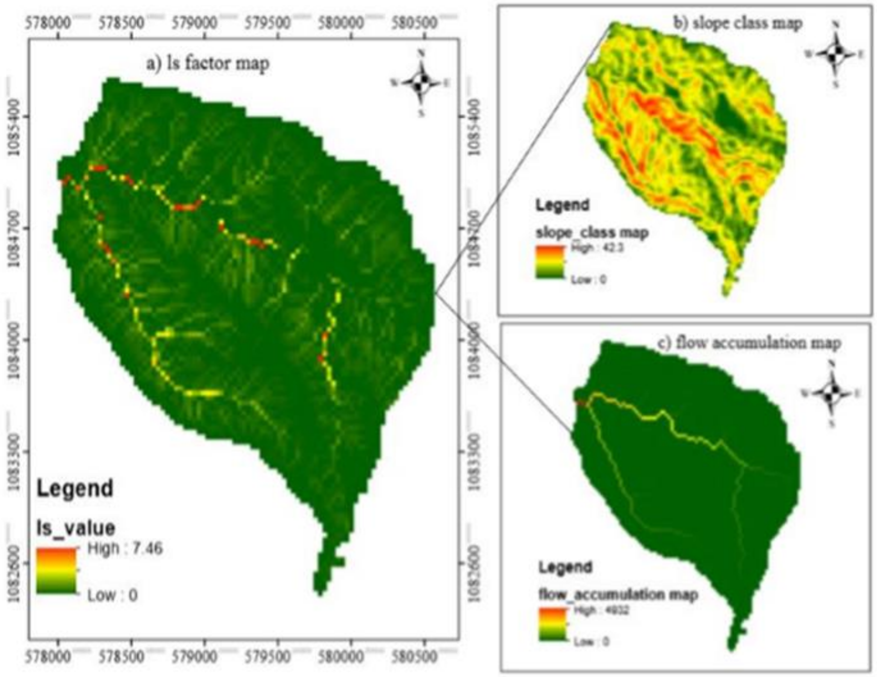

Figure 5. LS factor, slope class, and flow accumulation map.

Cover management (C) factor

The result indicated that five land use and land-cover classes were recognized in the watershed, dominantly by cultivated land (35.49%) followed by dense grassland (25.65%). Crop management C factor values of the study watershed were ranging from 0.001 for dense forest land to 0.40 to the open grassland/bad land soft.

Table 4. The land use land cover class and their corresponding C-values

Land use type	Area (ha)	C-value
Cultivated land	169.1	0.1
Open grassland	73.7	0.4
Degraded land	92.3	0.15
Dense forest	17.6	0.001
Dense grassland	122.3	0.01
Total area	475	

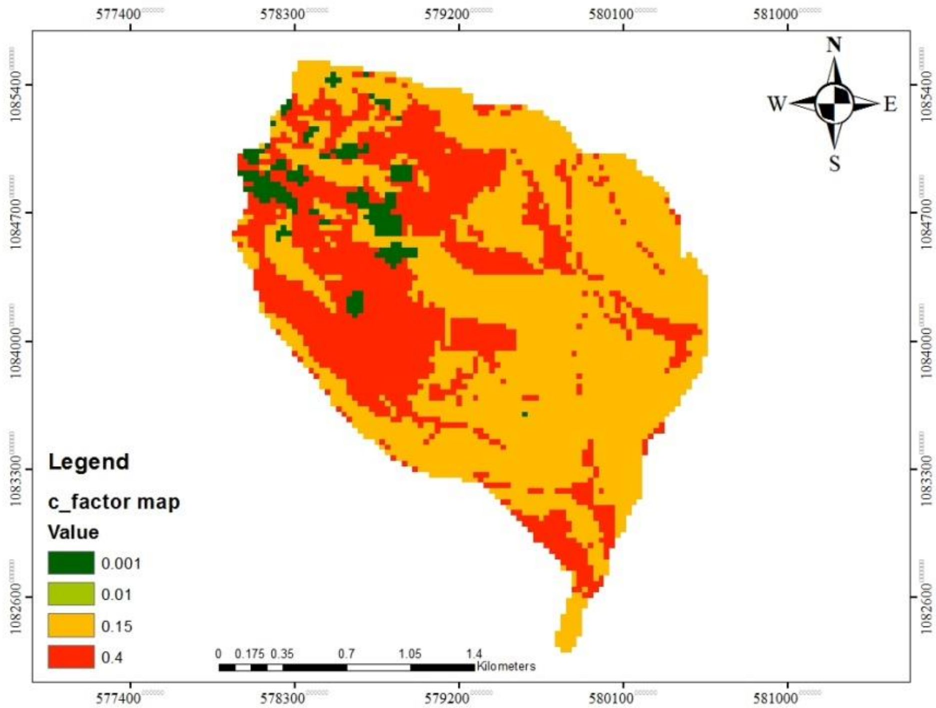

Figure 6. Land use and Cover management (C) factor map

Management practice (P) factor

The maximum P-value was 1; it was the value for all land use types excluding cultivated land, whereas the P-values were varied for cultivated land of different slope class as shown in the table below.

Table 5. P-value of different land use types

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other Land	All	1.00

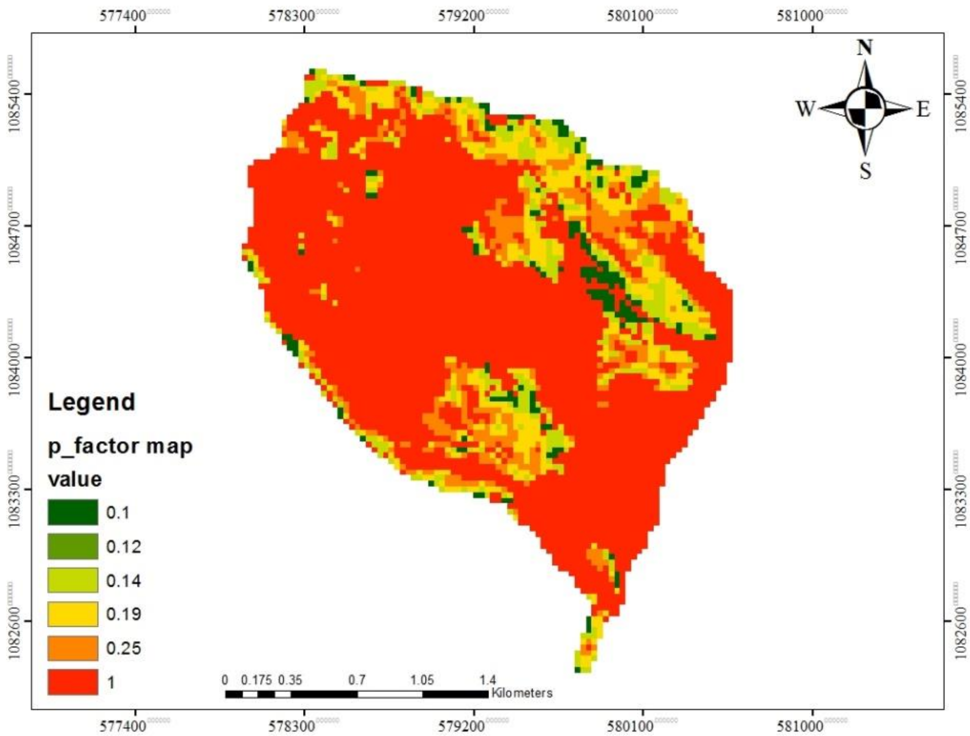

Figure 7. Management practice (P) factor map

Total annual average soil loss

The Revised Universal Soil Loss Equation (RUSLE) has been used widely all over the world (Mellerowicz *et al.*, 1994) including Ethiopia (Kaltenrieder, 2007; Bewket and Tefferi, 2009; Tiruneh and Ayalew, 2015) because of its simplicity and limited data requirement. The spatial distributions of the amount of soil loss in the study area are quite different and range nearly insignificant 0 t/ha/yr. in the North, East and Central parts of the study area to extremely high 291.3 ton $ha^{-1}yr^{-1}$ in the West and Northwest parts of the catchment (Figure 8). The mean annual soil loss from the area is 22.3 ton $ha^{-1}yr^{-1}$ and a total soil loss of 10, 601 ton yr^{-1} from the entire 475 ha area of the watershed. Since the West and Northeast parts of the catchments are dominated by steeply sloping areas, an estimated soil loss in this area is almost in the range of the soil loss estimation of the Ethiopian highlands.

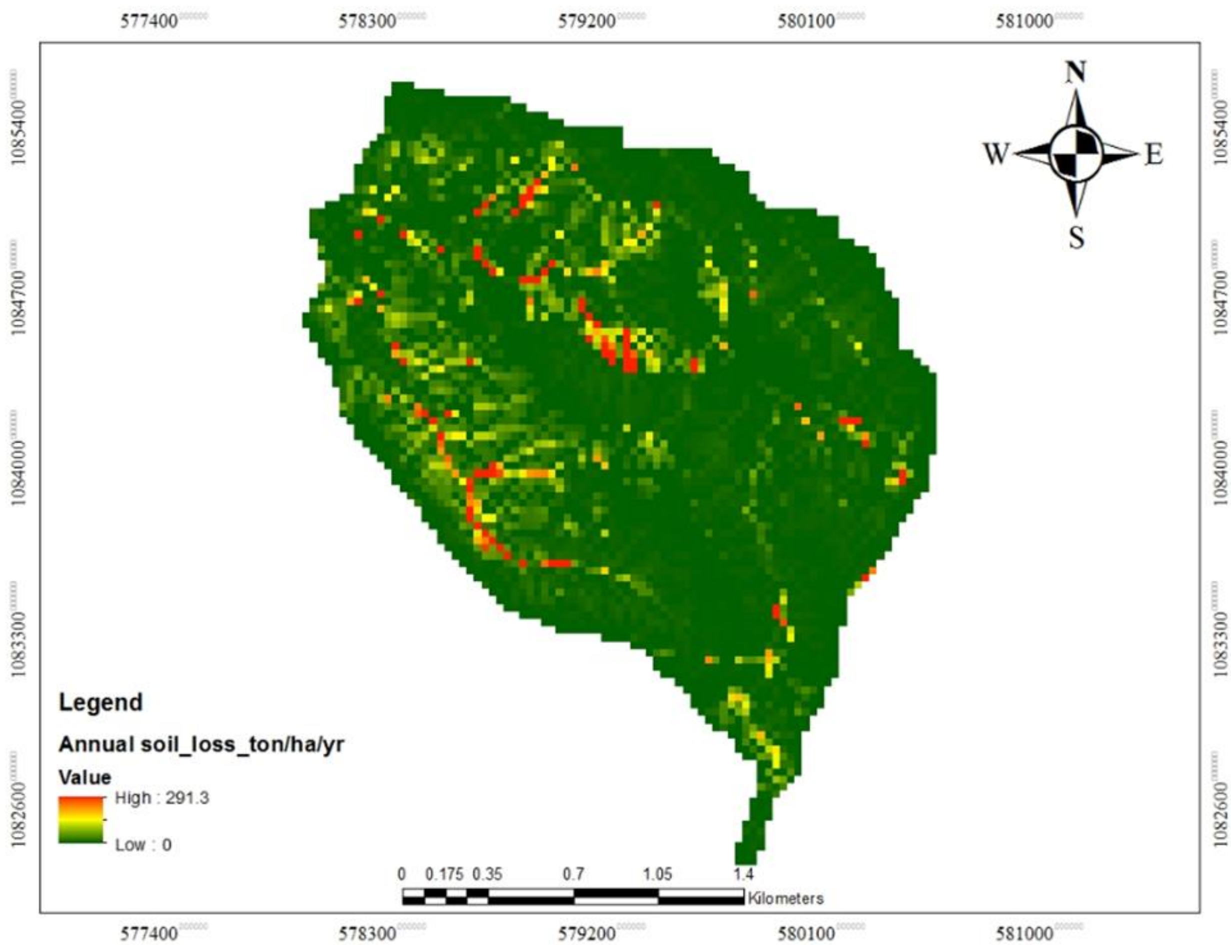

Figure 8. Total annual soil loss map of AnditTid watershed

Based on the analysis the average soil loss rate estimated for the study/ AnditTid watershed is 22.3 ton $ha^{-1}yr^{-1}$, which is relatively consistent with the average soil loss rate reported by other studies such as Hurni (1985) 18 ton.$ha^{-1}yr^{-1}$for Ethiopia highlands, Ayalew (2014) 24.95 ton.$ha^{-1}yr^{-1}$for Zingin watershed, northwestern Ethiopia and Amsalu and Mengaw (2014) 30.6 ton $ha^{-1}yr^{-1}$ for a JabiTehinan watershed in the North Western Highlands of Ethiopia. In contrast, FAO 1986 reported that an average soil erosion rate of 35 ton $ha^{-1}yr^{-1}$for the Central and Northern Highlands of Ethiopia. Similarly, the annual average soil loss rate of Koga watershed was 47 ton ha^{-1} yr^{-1} (Gelagay and Minale, 2016). However, Bewket and Tefferi (2009) found an average soil loss rate of 93 ton $ha^{-1}yr^{-1}$ in Chemoga watershed of the Blue Nile basin in the Northwestern highlands of Ethiopia. The other study reported by Tiruneh and Ayalew (2015) stated that the average amount of soil loss estimated by RUSLE from Enfraz watershed was 4.81 tons ha^{-1} year-

[1], which was a small amount that was the result of the contribution of the implemented soil and water conservation measures in the watershed.

Correlation among rainfall, river discharge, and sediment loss

The hydrology relationship between rainfall, discharge and sediment loss is presented in figure 9. The result showed that the relationship between rainfall and river discharge in the watershed is 90.7%. The result demonstrated that increasing the rainfall amount in the watershed by 1mm will increase by 3.25 m^3. On the other hand, the relationship between rainfall and sediment loss is 89.4%. The result revealed that increasing the rainfall amount in the watershed by 1mm will cause 2.6kg of soil. Furthermore, the relationship between river discharge and sediment loss in Andit Tid watershed is 66.5%. The result indicated that as the river discharge increased by 10 m^3 the sediment loss increased by 7kg of sediment.

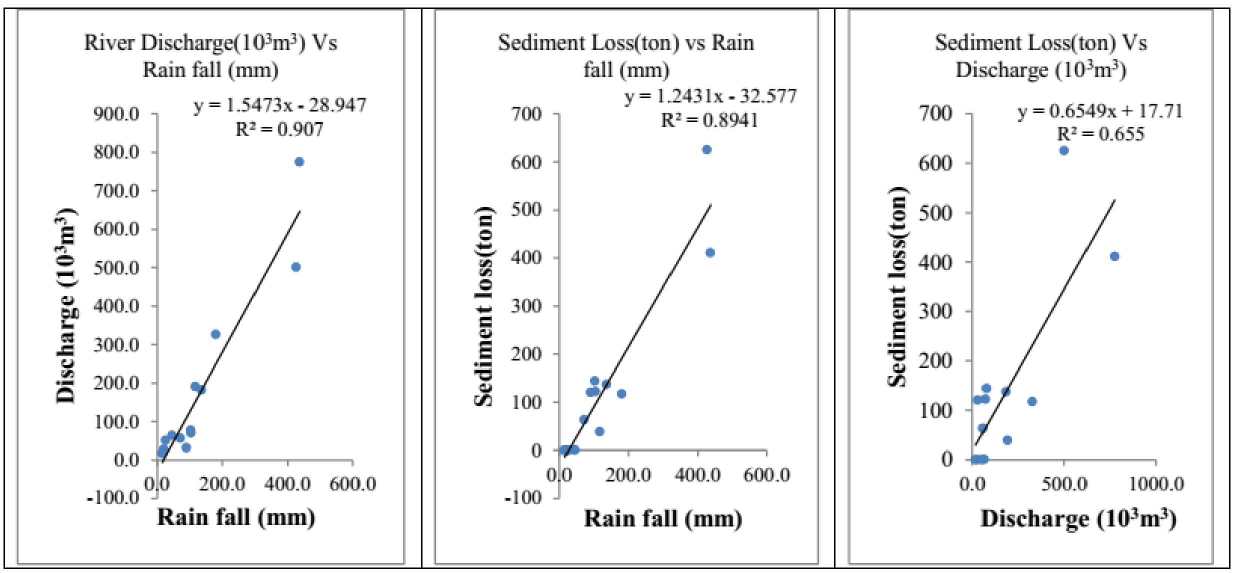

Figure 9. Monthly average rainfall, discharge, sediment loss graphs (from 1994-2014).

Conclusions

The study demonstrates that the RUSLE together with GIS and RS provides a great advantage to estimate soil loss rate over areas. However, the accuracy of results obtained is largely a function of the accuracy of input data such as topography (LS-factor), support practices (P-factor) and cover parameters (C-factor) which are location specific and need to be calibrated. In connection with land use/land cover types, there is no distinct pattern observed but soil erosion vulnerability potential increases in bare and cultivated lands. The increase in vegetation protects the soil surface from the erosive power of rainfall. The estimated values of soil erosion have a direct relationship with slope gradients, even the highest soil erosion occurs on the steep slope area according to the soil loss map of the study watershed. Since the relation between rainfall and sediment loss is around 90.5%, we can conclude that rainfall is the main driving force for the formation of erosion. The hydrology relationship between rainfall, discharge, and sediment is very strong. The soil loss can be used as one of the main inputs for decision-maker of soil resource management and it may influence policy decisions of land use planning in the study area. Based on our findings we recommended that (1) Soil erosion hotspot areas which were being identified in the soil erosion map should be given a serious attention and priorities for implementing soil conservation activities before the areas reached to irreversible soil degradations; (2) The local communities should implement immediate soil conservation measures in their communal and cultivated lands through applying different soil protective methods like mulching, strip cropping, terracing, contour plowing, cover crops and other indigenous means of soil conservation; (3) Currently, there is no C factor defined specifically for local vegetation species but in order to use the RUSLE as a sustainable and accurate resource management tool, additional research to determine the C-factor for specific Andit Tid watershed trees and plants are so as to be needed.

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Effect of Vetch Cover Crop and Green Manure on Runoff and Nutrient Loss and Yield of Chickpea in Gumara-Maksegnit Watershed

Legese Abebaw*[1], Atikilt Abera[1] and Hailu Kendie Addis[2]

[1]Gondar Agricultural Research Center, P.O.Box. 37, Gondar, Ethiopia

[2]Amhara Regional Agricultural Research Institute

[*]Corresponding author: email: legeseabebaw08@gmail.com

Abstract

Cover crops play an important role in reducing runoff, soil loss, and nutrient loss. Farmers in Gumara-Maksegnit practices fallow during the rainy season for the preceding chickpea production system. A field experiment was conducted in 2014-2016 during the rainy season to evaluate the effect of vetch cover crop and green manure on runoff, soil and nutrient loss and yield of chickpea. The experiment contained four treatments including: 1) control plot (Farmers' practice: fallowing- without cover crop), 2) planting chickpea after removing vetch (Vicia sativa L.) with recommended DAP fertilizer, 3) planting chickpea after incorporating vetch as green manure to the soil without DAP fertilizer, 4) planting chickpea after incorporating vetch green manure to with the soil with half recommended DAP. The experiment was arranged in Randomized Complete Block Design with three replications. Each plot with an area of 36 m² was equipped with a runoff monitoring system. Vetch was planted as a cover crop at the onset of the rain in June and used as green manure. The analyses of variance showed that vetch cover crop reduced runoff volume by 18.9-27.3% and soil loss by 29-38.1% compared to fallowing (farmers practice). Vetch also reduced the nutrient loss (TN loss by 35.5-39%, available P by 34.5-50.42% and OM by 32.12-38.555%) compared to fallowing (farmers practice). Planting chickpea after incorporating vetch as green manure reduced runoff volume from 33.7-24.49 m^3 ha^{-1}, soil loss from 290.61-180.04 kg ha^{-1}, TN loss from 0.31-0.189 kg ha^{-1}, phosphorus loss from 1.19-0.59 g ha^{-1} and OM loss from 7.47-4.59 kg ha^{-1} and increased crop yield by 9-24% compared to the control. Furthermore 4.62 to 18.44 t ha^{-1} vetch biomass can be produced compared to fallowing. Therefore, vetch cover incorporated to the soil as green manure is recommended for chickpea production system for the aforementioned benefits.

Keywords: *cover crop, green manure, runoff, soil loss, vetch*

Introduction

Plant residues reduce the impact of raindrops that otherwise would detach soil particles and make them prone to erosion. A cover crop is a crop planted primarily to manage soil fertility, soil quality, water, weeds, pests, and diseases in an agro-ecosystem (Lu *et al*., 2000). Farmers choose to grow and manage specific cover crop types based on their own needs and goals, influenced by the biological, environmental, social, cultural, and economic factors of the food system in which farmers operate (Snapp *et al.*, 2005). One of the primary use of cover crops when incorporated as green manure is to increase soil fertility. Often, green manure crops are grown for a specific period, and then plowed under before reaching full maturity in order to improve soil fertility and quality. They are used to manage a range of soil macronutrients and micronutrients. Of the various nutrients, the impact that covers crops has on nitrogen management has received the most attention from researchers and farmers, because nitrogen is often the most limiting nutrient in crop production (Sutton *et al.*, 2011).

Cover crops can also improve soil quality by increasing soil organic matter levels through the input of cover crop biomass over time. Increased soil organic matter enhances soil structure, as well as the water and nutrient holding and buffering capacity of the soil (Patrick *et al.*, 1957). Although cover crops can perform multiple functions in an agro ecosystem simultaneously, they are often grown for the sole purpose of preventing soil erosion. Dense cover crop stands physically slow down the velocity of rainfall before it contacts the soil surface, preventing soil splashing and erosive surface runoff (Römkens *et al.*, 1990). Cover crop biomass acts as a physical barrier between rainfall and the soil surface, allowing raindrops to steadily trickle down through the soil profile. The protective canopy formed by a cover crop reduces the impact of raindrops on the soil surface thereby decreasing the breakdown of soils aggregates. This greatly reduces soil erosion and runoff and increases infiltration. Decreased soil loss and runoff translate to reduced transport of valuable nutrients, pesticides, herbicides, and harmful pathogens associated with manure from farmland that degrades the quality of streams, rivers and water bodies and poses a threat to human health.

By reducing soil erosion, cover crops often also reduce both the rate and quantity of water that drains off the field, which would normally pose environmental risks to waterways and ecosystems downstream (Dabney *et al.*, 2001). Gómez *et al.* (2009) and Joyce *et al.* (2002)

reported that cover crops have a significant impact on increasing infiltration capacity and subsequently it reducing the amount of runoff and soil loss. Cover crops are generally included in cropping systems as nutrient management tools (Ruffo and Bollero, 2003). Cover crops can be leguminous or non-leguminous. As vetch is one of legume cover crops, it is used as a source of nitrogen (N) for the following cash crop (Smith *et al.*, 1987) while grasses are mainly used to reduce NO3 leaching and erosion (Meisinger *et al.*, 1991). Biological fixation by leguminous crops offers the potential to reduce the need for N fertilizers for the succeeding crop (Ladha *et al.*, 2004). A bicultural of a legume and grass is used with the intention of providing both benefits simultaneously (Ranells and Wagger, 1996).

When a cover crop is managed for its contribution to soil nitrogen, the application of nitrogen fertilizer for the subsequent crop may be less, thereby lowering costs of production, reduced nitrogen losses to the environment and reducing the use of purchased nitrogen fertilizer that is produced using fossil fuels. Planting cover crops before or between main crops can improve soil physical, chemical, and biological properties and consequently lead to improved soil health and yield of principal crops. Leaving cover crops as surface mulches in no-till crop production systems has the advantage of increasing nitrogen economy (Smith *et al.*, 1987; Frye *et al.*, 1988) conserving soil moisture (Morse, 1993), reducing soil erosion (Langdale *et al.*, 1991), improving soil physical properties (Blevins and Frye, 1993), increasing nutrient retention (Staver and Brinsfield, 1998; Dinnes *et al.*, 2002), increasing soil fertility (Cavigelli and Thien, 2003), suppressing weeds (Creamer *et al.*, 1996; Creamer and Baldwin, 2000), reducing diseases and insects (Ristaino *et al.*, 1996), reducing global warming potential (Robertson *et al.*, 2000), and increasing crop yields (Triplett *et al.*, 1996). Planting cover crop during the fallow period in Gumara-Maksegnit watershed is an unconventional or precious activity that needed to introduce and adopt for farmers. It is better to cover the land with the cover crop as compared to leaving the land fallowing. There was no finding or it is a site-specific related to the impact of vetch cover crop on runoff, soil loss and nutrient loss in the experimental area. Therefore, this study was conducted to evaluate the effect of vetch cover crop and green manure on runoff, soil loss, soil chemical properties and yield of chickpea in North Gondar zone, Gumara-Maksegnit watershed. The main objective of the research activity was to evaluate the effect of cover crop and green manure on runoff, soil loss, soil nutrient loss and yield of chickpea in the study area.

Materials and Methods

Description of the study Area

The study area is located in the northwest part of Amhara National Regional State; North Gondar zone at Gumara-Makegnit watershed. The watershed is located at about 45 km southwest of Gondar near Makegnit town. It covers an area of 53.7 square kilometers and located at 12^0 23’ 53” to 12^0 30’ 49” north latitude and 37^0 33’ 39” to 37^0 37’ 14” east longitude (Figure 1). This study was conducted in a farmer’s field in the 2014-2016 cropping season. The altitude of the experimental site ranges from 1923 to 2851 m above mean sea level. The mean annual rainfall in the area is about 1052 mm and it is seasonal, erratic and uneven in distribution (Addis and Klik, 2015). The mean maximum temperature of the area is about 28.5 °C and while the mean minimum temperature is about 13.3°C. The soil types are predominately Cambisol and Leptosol which are found in the upper and central part of the watershed, whereas Vertisol is found in the lower catchment near the main outlet in which the experiment was undertaken (Addis *et al.*, 2015).

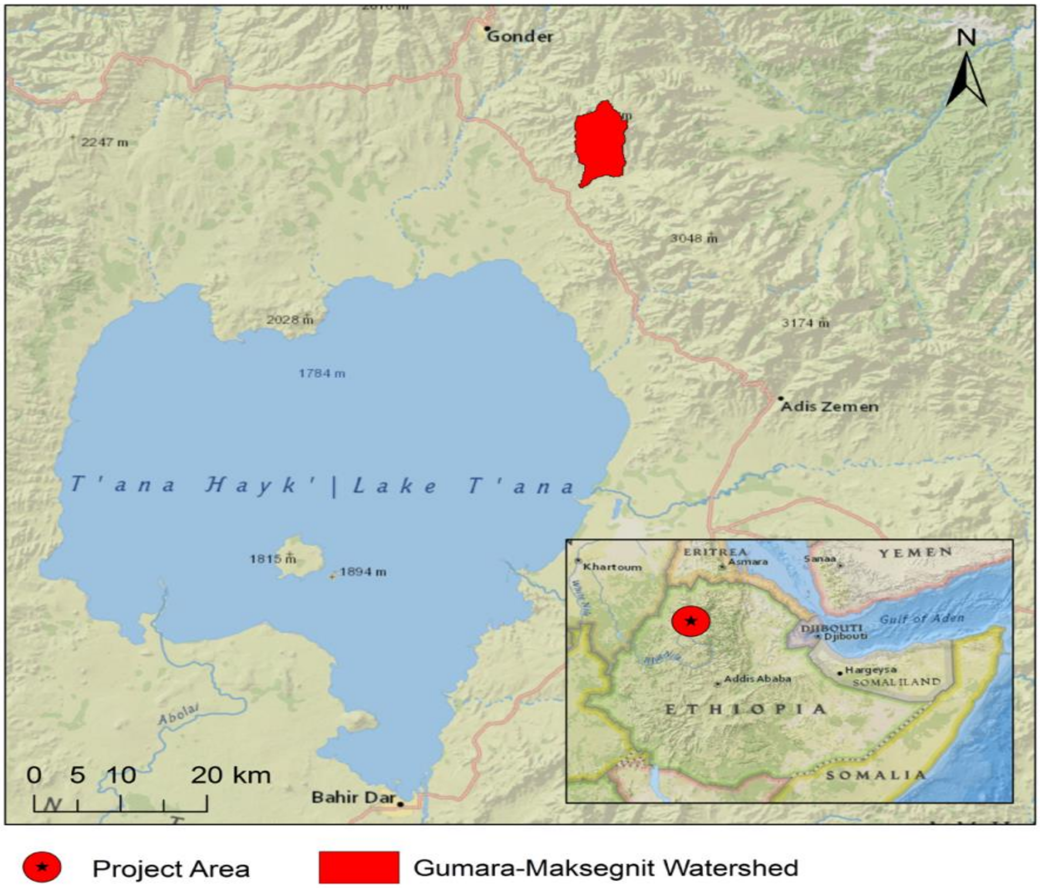

Figure 1. Location of the study area (Addis et al., 2015)

Experimental setup

The experiment was conducted on farmer's field on 12m long and 3m wide runoff plots that have 7.2% slope. The Four treatments were arranged in a randomized complete block design with three replications (Figure 2). The treatments were:

1. Control plot or farmers' practice: fallowing without cover crop,
2. Chickpea planted with recommended Di-ammonium phosphate (DAP) fertilizer after the harvesting of vetch cover crop,
3. Chickpea planted after vetch cover crop was incorporated with the soil as green manure and
4. Chickpea planted after vetch cover crop was incorporated with the soil as green manure and with half Di-ammonium Phosphate (DAP) application.

The test crop was chickpea planted in early September. Before planting chickpea, vetch was planted in June as cover and green manure crop during the rainy season by substituting the fallow practice of farmers. Vetch was planted in rows at the seed rate of 25 kg ha^{-1}. Later it was plowed under and incorporated as green manure a week before planting chickpea. Vetch was selected as cover and green manure crop because it has a greater surface cover and it is the leguminous type for green manure in order to increase soil fertility. It has also greater fodder value for cattle.

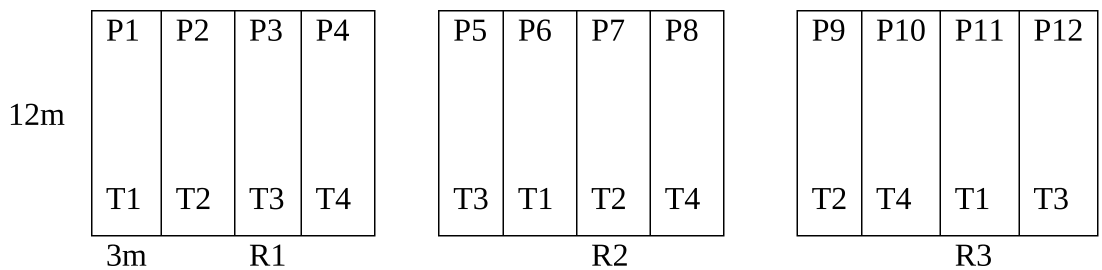

Figure 2. Treatment layout with site replication

Runoff, Soil loss and Nutrient loss sampling

Each runoff plots were bounded by the iron sheet. The overland flow was guided and channeled using PVC tube into a metal tanker to collect and measure the runoff during the selected rain fall events. The average of selected 5 rainfall events in 2014 and 9 rainfall events in 2015 and 2016 was taken for analyzing the soil and nutrient loss from plots. Hence the rainfall and runoff events were small and that can't be representing the whole annual rainfall and runoff, the values of all rainfall runoff and events was changed into one representative rainfall and runoff event for the analysis of all needed parameters. So, all the analysis was made per unit (1) event which was the mean of different events in each experimental year. 5.5 liters volume of runoff sample was taken during each event and then filtered and weighed for sediment and nutrient analysis. Two-liter volume of runoff sample was used for sediment analysis and the rest 3.5 litter was used for nutrient analysis. All soil loss and nutrient loss data obtained from laboratory analysis by using this sample were compiled and inferred to the whole soil and nutrient loss data collected from each runoff plots. Organic matter was determined from organic carbon according to Walkley & Black method (Schnitzer, 1982) and the OC result obtained from laboratory analysis was multiplied by 1.724 to provide organic matter. Available P was measured in Parts per million (ppm). Total nitrogen was analyzed by the Kjeldahl method (Bremner and Mulvaney, 1982). The other volume of runoff collected in a metal tanker was measured and drained away from the tanker and clean the tanker for the sampling of the next day. The total volume of runoff in each plot that was averaged from different events and assumed in one event is shown in Table 1 below.

(A) (B)

Figure 2. Design and layout of experiment on the ground: (A) before planting and (B) after planting

(A) (B)

Figure 3. (A) fallow versus , (B) dense vetch cover crop plots

Table 1. Mean runoff, soil loss and nutrient loss in 2015 and 2016 rainy season)

Sampling year	Runoff plots	Rainfall (mm)	Total volume (liter)	Runoff depth (mm)	Runoff coefficient (C)	Sediment loss g/l	% Total N	Available P/PPM	% O.M
2014	RP-1	36.98	122.42	3.40	0.09	13.95	0.13	0.91	2.14
	RP-2	36.98	125.52	3.49	0.09	10.39	0.10	2.07	2.46
	RP-3	36.98	113.44	3.15	0.09	12.00	0.12	1.58	2.49
	RP-4	36.98	115.19	3.20	0.09	6.23	0.11	1.10	2.29
	RP-5	36.98	104.71	2.91	0.08	7.59	0.11	1.34	2.75
	RP-6	36.98	110.78	3.08	0.08	12.15	0.12	2.36	2.50
	RP-7	36.98	105.78	2.94	0.08	10.98	0.12	2.06	2.53
	RP-8	36.98	83.42	2.32	0.06	7.50	0.12	2.02	2.73
	RP-9	36.98	100.82	2.80	0.08	7.45	0.14	2.08	2.61
	RP-10	36.98	123.13	3.42	0.09	12.79	0.12	1.99	2.92
	RP-11	36.98	157.43	4.37	0.12	8.23	0.10	2.13	2.98
	RP-12	36.98	125.56	3.49	0.09	4.14	0.15	1.05	2.19
2015	RP-1	29.11	61.72	1.71	0.06	5.46	0.10	6.16	2.38
	RP-2	29.11	56.89	1.58	0.05	5.63	0.09	5.92	2.37
	RP-3	29.11	55.83	1.55	0.05	6.55	0.09	5.18	2.29
	RP-4	29.11	48.94	1.36	0.05	7.96	0.08	5.54	2.15
	RP-5	29.11	57.33	1.59	0.05	6.15	0.09	5.18	2.31
	RP-6	29.11	68.89	1.91	0.07	9.77	0.10	6.16	1.90
	RP-7	29.11	69.28	1.92	0.07	6.01	0.09	5.41	2.18
	RP-8	29.11	56.72	1.58	0.05	8.02	0.08	5.54	1.98
	RP-9	29.11	63.43	1.76	0.06	6.82	0.09	5.33	2.11
	RP-10	29.11	65.67	1.82	0.06	7.60	0.08	5.54	2.42
	RP-11	29.11	70.67	1.96	0.07	6.72	0.10	6.18	2.11
	RP-12	29.11	56.28	1.56	0.05	7.05	0.09	5.21	2.16
2016	RP-1	44.75	151.72	4.21	0.09	5.46	0.07	5.73	2.75
	RP-2	44.75	123.87	3.44	0.08	5.63	0.08	4.88	2.23
	RP-3	44.75	84.17	2.34	0.05	6.55	0.10	3.13	2.54
	RP-4	44.75	99.94	2.78	0.06	7.96	0.09	5.39	2.50
	RP-5	44.75	97.22	2.70	0.06	8.15	0.11	4.89	3.03
	RP-6	44.75	188.11	5.23	0.12	9.77	0.09	6.85	3.11
	RP-7	44.75	127.00	3.53	0.08	6.58	0.08	6.07	2.22
	RP-8	44.75	118.67	3.30	0.07	9.02	0.09	5.64	2.37
	RP-9	44.75	112.67	3.13	0.07	6.82	0.07	4.99	2.21
	RP-10	44.75	110.00	3.06	0.07	4.26	0.08	4.82	2.18
	RP-11	44.75	160.11	4.45	0.10	5.72	0.12	4.99	2.44
	RP-12	44.75	98.94	2.75	0.06	7.05	0.07	5.11	2.66

Crop yield measurement

Chickpea was planted in 2014 and 2015 cropping seasons but not in 2016. To investigate the effects of vetch cover crop on crop response, chickpea yield was collected and measured from 18 m^2 harvestable sizes at the middle of each runoff plots at the end of the growing season. Vetch biomass also collected and measured to compare the cover crop treatment with non-cover crop (fallow) treatment, because the cover crop has an additional fodder value for cattle.

Data Analysis Procedures

As explained earlier in the experimental setup, the sampling plots were arranged in randomized complete block design replicated three times. The data obtained from field measurement and laboratory analysis were analyzed by SAS software version 9.0. The soil and nutrient loss and crop yield were subjected to analysis of variance using the general linear model procedure of the statistical analysis system. When the analysis of variance (ANOVA) showed significant differences (at $p \leq 0.05$) due to cover crop and fallowed treatments, a mean separation for each parameter was made using the least significant difference (LSD). A simple graphical representation also used to explain the difference in vetch biomass of cover crop treatments.

Result and Discussions

Effect of Vetch Cover Crop on Runoff and Soil loss

In 2014, runoff and soil loss didn't show any significant differences ($p>0.05$) between treatments (Table 2). But numerically, the higher runoff and soil loss was observed in the control plot as compared to vetch cover crop treatments. The control plot produced higher runoff volume (36.17 m^3 ha^{-1}) and the cover crop treatments produced lower runoff volume which ranges from 29.79-31.83 m^3 ha^{-1}. The higher soil loss 402.6 kg ha^{-1} also observed in fallow treatment as compared to the vetch covered treatments which range from 247.82-297.86 kg ha^{-1}. This implies that vetch cover crop reduced runoff volume by 14.9% and soil loss by 32.47% relative to the fallow treatment. As shown in Table 3 below in 2015, runoff volume and depth was showed significant variation at $p \leq 0.05$ with respect to treatments, but it didn't show any significant variation between treatments with respect to soil loss. As shown in Table 7, the higher runoff volume (18.64 m^3 ha^{-1}) was observed in the control plot, while the cover crop treatments were recorded lower (16.37 m^3 ha^{-1} on average) runoff volume. Absolutely, higher sediment (137.46 kg ha^{-1}) was lost in control treatment and lower sediment (on average, 111.96 kg ha^{-1}) was lost in treatments covered by vetch. In 2016, there were highly significant $P \leq 0.01$) variation between treatments in runoff volume and depth, but didn't show any significant variation among treatments with respect to soil loss. However, 37.9% soil loss reduction was observed numerically (Table 8). The higher runoff volume (46.29 m^3 ha^{-1}) was removed in the fallow plot, while lower runoff volume (25.96-33.66 m^3 ha^{-1}) was lost in vetch cover crop treatments. This resulted in vetch reduce runoff volume by 35.2% as compared to fallowed land during the fallow season as shown in Table 6 to 9. In all the three years and the combined result showed that runoff depth was higher in the control plot as compared to treatments covered by vetch.

Table 2. The ANOVA for runoff volume (m3/ha), runoff depth (mm), sediment loss (kg/ha), and nutrient loss (N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha) in 2014

		Q		Runoff (mm)		Sediment		TN		Available P		OM	
Sources	**DF**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**
Treatment	3	23.78	0.31	0.24	0.31	14081.30	0.42	0.020	0.44	0.07	0.53	8.01	0.58
Replication	2	53.22	0.11	0.53	0.11	7397.58	0.59	0.008	0.68	0.00	0.96	1.54	0.88
Error	6	15.99		0.16		12735.65		0.019		0.083		11.34	

MS= means of squares, DF= degree of freedom, P= probability (indicator of significances), Q=runoff volume, TN=total nitrogen, P phosphorus, and OM=organic matter.

Table 3. The ANOVA for runoff volume (m^3/ha), runoff depth (mm), sediment loss (kg/ha), and nutrient loss (N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha)) for the average of 9 events in 2015

		Runoff volume		Runoff depth		Sediment		TN		Available P		OM	
Sources	**DF**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**
Treatment	3	5.98	0.05	0.06	0.05	732.01	0.31	0.001	0.17	0.05	0.12	0.20	0.38
Replication	2	6.14	0.06	0.06	0.06	1273.29	0.16	0.001	0.27	0.04	0.22	0.32	0.22
Error	6	1.32		0.013		496.38		0.001		0.018		0.16	

MS= means of squares, DF= degree of freedom, and P= probability (indicator of significances)

Table 4. The ANOVA for runoff volume (m^3/ha), runoff depth (mm), sediment loss (kg/ha), and N loss (kg/ha), *Phosphorus loss (g/ha) and OM loss (kg/ha)) in 2016*

		Runoff volume		**Runoff depth**		**Sediment**		**TN**		**Available P**		**OM**	
Sources	**DF**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**
Treatment	3	228.67	<0.001	2.28	<0.001	12271.40	0.15	0.013	0.10	0.78	0.15	14.91	0.16
Replication	2	25.69	0.07	0.26	0.07	18049.05	0.09	0.016	0.07	1.16	0.08	19.48	0.11
Error	6	6.15		0.062		4869.58		0.004		0.3		5.99	

Where, MS= means of squares, DF= degree of freedom, and P= probability (indicator of significances)

Table 5. The overall combined ANOVA for runoff volume (m^3/ha), runoff depth (mm), sediment loss (kg/ha), and N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha).

		Runoff volume		**Runoff depth**		**Sediment**		**TN**		**Available P**		**OM**	
Sources	**DF**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**	**MS**	**P**
Treatment	3	155.76	<0.0001	1.55	<0.0001	21120.00	0.04	0.027	0.04	0.59	0.02	15.82	0.08
Year	2	1057.61	<0.0001	10.62	<0.0001	106802.61	<0.0001	0.190	<0.0001	1.99	0.00	85.31	0.00
Error (year)	6	28.35	0.016	0.28	0.016	8906.64	0.24	0.009	0.39	0.40	0.033	7.11	0.34
year*Treatment	6	51.34	0.0008	0.51	0.0008	2982.36	0.8	0.003	0.85	0.16	0.369	3.65	0.71
Error	18	7.83		0.08		6033.87		0.008		0.13		5.83	

MS= means of squares, DF= degree of freedom, Q=runoff volume, TN=total nitrogen, P phosphorus, and OM=organic matter.

In the combined analysis, all runoff volume, depth, and soil loss showed significant variation at $p<0.05$ among the treatment means. Runoff volume and runoff depth also showed highly significant variation among treatment means (Table 5). As shown in table 9, higher runoff volume (33.7 $m^3\ ha^{-1}$) and soil loss (290.61 kg ha^{-1}) were lost in control plot, while the lower runoff volume on average about 25.72 $m^3\ ha^{-1}$ and soil on average about 196.65 kg ha-1 was lost in vetch covered treatments. In overall combined means surprisingly higher reduction (38.05%) of soil loss was observed in third treatment (Chickpea is planted after vetch cover crop incorporated with the soil as green manure). As indicated by Römkens *et al.* (1990), dense stands of vetch cover crops in treatment two to four slow down the velocity of rainfall drops before it contacts the soil surfaces and then preventing soil splashing and reduces erosive surface runoff. This experiment showed that covering the land using vetch cover crop was the effective way to reduce the surface runoff and soil loss during the fallow season and fallowing the land without cover crop enhances runoff and soil loss.

Table 6. Mean runoff depth (mm), sediment loss (kg/ha), and nutrient loss in 2014

Treatment	Q ($m^3\ ha^{-1}$)	Runoff (mm)	Sediment (kg ha^{-1})	TN (kg ha^{-1})	Available P (g ha^{-1})	OM (kg ha^{-1})
T1	36.17	3.62	402.69	0.48	0.69	10.08
T2	30.75	3.08	297.86	0.34	0.61	7.51
T3	31.83	3.18	247.82	0.30	0.35	6.21
T4	29.79	2.98	270.11	0.31	0.48	7.36
$CV_{(\%)}$	12.44	12.44	37.05	38.30	54.01	43.22
$LSD_{(0.05)}$	ns	ns	ns	ns	ns	ns

ns=non-significant, T1=Control plot or farmers' practice: fallowing without cover crop, T2=Chick pea planted with recommended Di-ammonium phosphate (DAP) fertilizer after the harvesting of vetch cover crop, T3=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and T4=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and with half Di-ammonium Phosphate (DAP) application. This is considered for all tables.

Table 7. Mean runoff depth (mm), sediment loss (kg/ha), N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha)) in 2015

Treatment	Q (m^3 ha^{-1})	Runoff (mm)	Sediment (kg ha^{-1})	TN (kg ha^{-1})	Available P (g ha^{-1})	OM (kg ha^{-1})
T1	18.64^{a}	1.86^{a}	137.49	0.13	0.85	2.85
T2	17.55^{ab}	1.75^{ab}	108.25	0.10	0.60	2.39
T3	15.69^{b}	1.57^{b}	103.26	0.09	0.54	2.32
T4	15.87^{b}	1.59^{b}	124.36	0.10	0.69	2.73
CV $_{(\%)}$	6.80	6.74	18.83	21.76	20.52	15.61
LSD $_{(0.05)}$	*	*	ns	ns	ns	ns

**=significant variation at (p≤0.05) and ns=non-significant (p >0.05). Values with different letters within the same column showed significant variation between treatments at (p≤0.05) significant level.*

Table 8. Mean runoff depth (mm), sediment loss (kg/ha), N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha) in 2016

Treatment	Q (m^3 ha^{-1})	Runoff (mm)	Sediment (kg ha^{-1})	TN (kg ha^{-1})	Available P (g ha^{-1})	OM (kg ha^{-1})
T1	46.29^{a}	4.63^{a}	331.66	0.31	2.03	9.47
T2	33.66^{b}	3.37^{b}	213.03	0.17	1.14	4.73
T3	25.96^{c}	2.60^{c}	189.03	0.18	0.85	5.24
T4	30.43^{bc}	3.05^{bc}	216.14	0.19	1.17	5.13
CV $_{(\%)}$	7.28	7.32	29.39	29.61	42.32	39.85
LSD $_{(0.05)}$	**	**	ns	ns	ns	ns

***=significant variation at (p≤0.05) and ns=non-significant (p >0.05). Values with different letters within the same column showed significant variation between treatments at (p≤0.05) significant level.*

Table 9. Mean runoff depth (mm), sediment loss (kg/ha), N loss (kg/ha), Phosphorus loss (g/ha) and OM loss (kg/ha) combined over years.

Treatment	Q (m^3 ha^{-1})	Runoff (mm)	Sediment (kg ha^{-1})	TN (kg ha^{-1})	Available P (g ha^{-1})	OM (kg ha^{-1})
1	33.70^{a}	3.37^{a}	290.61^{a}	0.31^{a}	1.19^{a}	7.47
2	27.32^{ab}	2.73^{ab}	206.38^{b}	0.202^{b}	0.78^{ab}	4.88
3	24.49^{b}	2.45^{b}	180.04^{b}	0.187^{b}	0.59^{b}	4.59
4	25.36^{b}	2.54^{b}	203.54^{b}	0.20^{b}	0.78^{ab}	5.07
CV $_{(\%)}$	10.09	10.10	35.28	39.22	44.00	43.88
LSD $_{(0.05)}$	**	**	*	*	*	ns

***=highly significant variation (p≤0.01), *=significant variation at (p≤0.05) and ns=non-significant (p >0.05). Values with different letters within the same column showed significant variation between treatments at (p≤0.05) significant level.*

Effect of Vetch Cover Crop on Nutrient Loss

Nutrient didn't show any significant variation ($p \geq 0.05$) between treatment means in each year. However, numerical or absolute variation was observed between treatment means in all three years. As shown in table 6, 7 and 8, the higher TN (0.48, 0.13, and 0.31 kg ha^{-1}) loss was recorded in fallowed (control) plot as compared to vetch cover crop treatments which range from 0.3-0.34, 0.09-0.10 and 0.17-0.19 kg ha^{-1} in the consecutive three years respectively. The loss of available phosphorus in the control plot was ranged from 0.69-2.03 g ha^{-1}, while in the treatments covered by vetch it was ranged from 0.35-1.17 g ha^{-1} in all the three years. Organic matter loss also higher in control plot like other nutrient parameters. For example, in 2016, OM loss in control plot was about 9.47 kg ha^{-1}, while in the vetch covered treatments it reduced on average to 5.03 kg ha^{-1} which means reducing OM loss by 46.9% relative to control plot. When coming to the overall combined means, TN and available P showed significant ($p<0.05$) variation among treatment means. But OM didn't show any significant ($p>0.05$) variation between treatment means. The higher (0.31 kg ha^{-1} per event) mean values of TN loss was recorded in control plot and vetch cover crop treatments resulted in 0.2, 0.18, and 0.2 kg ha^{-1} per event for T2, T3, and T4 respectively. As explained above in runoff and soil loss, the third treatment (Chickpea is planted after vetch cover crop incorporated with the soil as green manure) was the winner of all other treatments. It reduced TN loss 61%, available P loss by 50% and OM loss by 61.5% as it compared to the fallow practices in a unit rainfall event.

As explained by different findings (Blevins and Frye, 1993; Staver and Brinsfield, 1998; Ladha *et al.*, 2004), vetch cover crop is the effective way increasing nutrient retention, improving soil chemical properties and it also reduces the need of nitrogen and phosphorus fertilizers. (Mitchell and Tell, 1977) and (Ebelhar *et al.*, 1984) reported that cultivation of hairy vetch as a cover crop and green manure could reduce the use of chemical fertilizers. On the opposite side, leaving the land for fallowing during the rainy season exposed available nutrients to erosion through runoff. Reduction in soil erosion by cover crops is associated with increases in soil organic matter content which improve soil water infiltration and holding capacity. With more infiltration and less runoff from each rainfall event, soil erosion and nutrient loss are significantly reduced. Cover crops growing before chickpea planting increased surface cover, and anchor residue, and reduced rill erosion and subsequently prevent nutrients from leaching and erosion (Kaspar *et al.*, 2001).

Effect of Vetch Cover Crop on chickpea yield

As the yield data was collected for the first two experimental years, chickpea yield didn't show any significant ($p>0.05$) variation among the treatment means (table10). However, vetch cover crop treatments increased the yield of chickpea about 9-24% as compared to the control plot. Unfortunately, the yield of chickpea in both the two years was low, because there was a known shortage of rainfall during the experimental years in northwestern region site especially in 2015. The automatic and manual rain gauge recorded about 632 mm rainfall in 2014 and 533 mm rainfall in 2015 starting from June to September. Due to this shortage of rainfall, the crop was exposed to series drought. Normally, the second treatment (Chickpea planted with recommended Di-ammonium phosphate (DAP) fertilizer after the harvesting of vetch cover crop) was the winner according to the yield of chickpea, especially in 2014 cropping season. This might be occurred based on the fact that during the first year there was no significant variation between treatments because it is the start time. The higher yield in treatment to occur might be the result of the addition of recommended fertilizer. The real treatment variation was shown in the third treatment that had the appreciable result as compared to the control. Indicating that cover crop and green manure gradually enhanced crop yield.

Table 10. Mean chickpea grain yield combined over years (2014 and 2015)

	Grain Yield (kg ha-1)		
Treatment	**2014**	**2015**	**Combined**
T1	742.5	421.0	581.75
T2	768.7	671.0	719.85
T3	675.4	598.0	636.70
T4	600.2	665.7	632.95
CV $_{(\%)}$	27	23.25	25.13
LSD $_{(0.05)}$	ns	ns	ns

ns=non-significant (P>0.05), T1=Control plot or farmers' practice: fallowing without cover crop, T2=Chick pea planted with recommended Di-ammonium phosphate (DAP) fertilizer after the harvesting of vetch cover crop, T3=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and T4=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and with half Di-ammonium Phosphate (DAP) application. This is considered for all tables.

Biomass of vetch cover crop also used as fodder value for cattle. As shown in fig. 4 below, the fourth treatment was observed the appreciable vetch biomass as compared to the other treatments. After protecting runoff, soil and nutrient loss, the vetch could be harvested and properly settled for cattle fodder during the winter season. This is more preferable than leaving the land for fallowing and exposing the soil and nutrient for erosion. It can be produced from 4.62-18.44 ton ha^{-1} of vetch biomass during the fallow season.

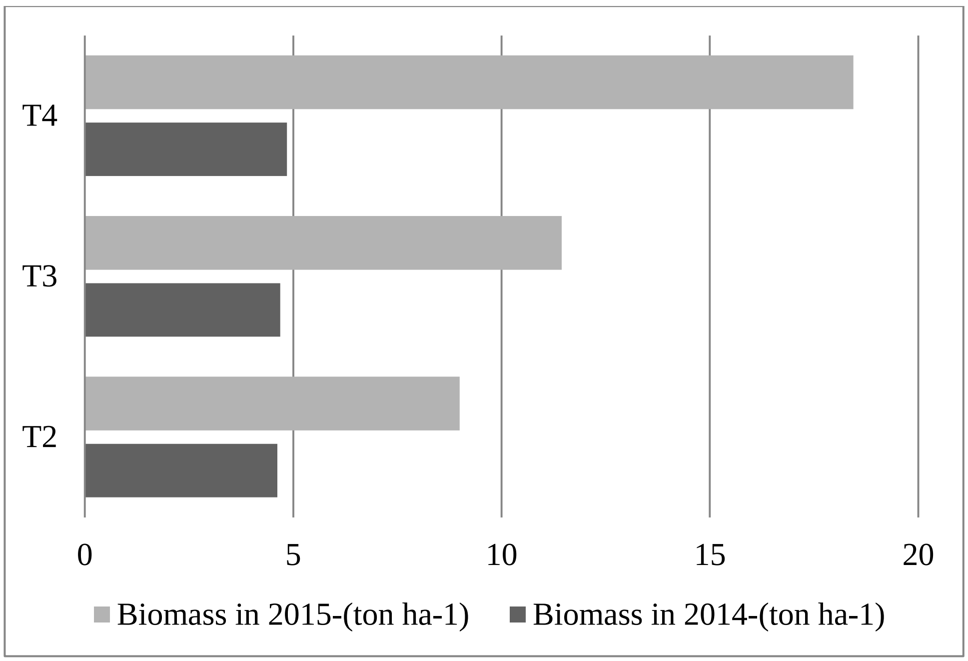

Figure 4. *Biomass of vetch in 2014 and 2015 rainy season. Where, T2=Chick pea planted with recommended Di-ammonium phosphate (DAP) fertilizer after the harvesting of vetch cover crop, T3=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and T4=Chickpea planted after vetch cover crop was incorporated with the soil as green manure and with half Di-ammonium Phosphate (DAP) application. This is considered for all tables.*

Conclusions and Recommendations

The field study results indicated that the percentage of vetch cover crop increased to 92% in the growing period which had a clear impact on runoff volume and sediment loss. In this experiment, the overall combined ANOVA showed that except organic matter content, the other parameters resulted in significant ($p \leq 0.05$) variation among treatments. Vetch cover crop reduced runoff volume by 18.93-27.33% and soil loss by 28.98-38.05% with relative to the fallowed plot. Vetch also reduced the nutrient loss (total nitrogen loss by 35.5-39%, available phosphorus loss by 34.5-50.42% and organic matter content by 32.12-38.555 as compared to the control fallow practices. From vetch cover crop treatments, the third treatment (Chickpea planted after vetch cover crop was incorporated with the soil as green manure) was the winner to reduce runoff volume, soil loss and nutrient loss as it compared to the other three treatments. This treatment also reduced runoff volume from 33.7-24.49 m^3 ha^{-1}, soil loss from 290.61-180.04 kg ha^{-1}, TN loss from 0.31-0.189 kg ha^{-1}, phosphorus loss from1.19-0.59 g ha^{-1} and OM loss from 7.47-4.59 kg ha^{-1} as compared to fallow practices within a unit rainfall event. Chickpea yield didn't show any significant variation among the treatment means. However, there was an absolute increment in yield of vetch cover crop treatments by 9-24 % an as compared to the control plot. It can also produce about 4.62 to 18.44 t ha^{-1} vetch biomass as compared to leave the land for fallowing. Based on this experiment vetch cover crop incorporated with the soil as green manure crop was the most outshine treatment in order to reduce runoff, soil loss, and nutrient loss, in which it is recommended to practice in similar agro-ecology. Although the finding in this experiment was very interesting, it could be needed to show each treatment separately with its economic analysis or cost-benefit analysis.

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Impact of Stone Bunds on Soil Physical and Chemical Properties and Crop Yield: Case Study at Gumara-Maksegnit Watershed

Legese Abebaw*[1], Atikilt Abera[1] and Hailu Kendie Addis[2]

[1]Gondar Agricultural Research Center, Gondar, P.O.Box 37, Gondar, Ethiopia

[2]Amhara Regional Agricultural Research Institute

[*]Corresponding author: email: legeseabebaw08@gmail.com

Abstract

Soil erosion is one of the principal environmental problems in Ethiopia resulting in a reduction of productivity of agricultural lands through removal of the most fertile portion of the soil. The study was performed at Gumara-Maksegnit Watershed, in Northwestern Ethiopia with the objective to evaluate the effect of stone bunds on the distribution of soil properties and crop productivity. Three consecutive stone bunds in two sites (54 representative plots) and untreated site (9 plots) were used to evaluate some physical and chemical properties of soil and crop productivity. The evaluation was made in two factors (three intra-bund positions includes lower A, middle B, and upper C part of the stone bund, and three consecutive bunds, lower middle, and upper bunds). Split-plot design (consecutive stone bunds in the main-plot and intra-bund positions in the sub-plot) with three replications was used for experiment. Paired sample t-test was also used to evaluate the mean comparison of treated versus untreated farm plots for the parameters of crop yield, moisture content and soil nutrients. There were significant differences ($p<0.05$) among the intra bund positions (A, B, and C part of the stone bund) in grain yield, available p and organic matter.While CEC, pH, and K^+ showed significant difference among the consecutive bunds. The study showed that the position immediately above the stone bund accumulates more moisture and soil nutrients and becomes more productive as compared to the middle and upper (loss zone) positions of the stone bunds. The higher soil moisture content, grain yield and soil nutrients (OM and CEC) were obtained from the treated farms compared to untreated farms.

Keywords: *Gumara-Maksegnit watershed, moisture content, stone bund, Soil properties*

Introduction

Land degradation, in the form of soil erosion and nutrient depletion, threatens food security and the sustainability of agricultural production in Sub-Saharan Africa (Kassie *et al.*, 2007; Hurni, 1985; Hurni, 1988; Nyssen *et al.*, 2004). Soil erosion is one of the principal environmental problems in Ethiopia resulting in a reduction of productivity of arable lands through removals of the most productive portion of the soil, that is, the chemically active part such as organic matter and clay fractions (Alemu *et al.*, 2013; Amdemariam *et al.*, 2011). It also causes deterioration of soil structure, moisture holding capacity through lowering soil depth, increasing bulk density, soil crusting, and reducing water infiltration.

Soil and water conservation practices in upland areas can foster the production of various kinds of ecosystem services that have both upstream and downstream benefits (Alemu *et al.*, 2013). By implementing practices that maintain or restore the capacity of soil to retain water along with nutrients and organic matter, farmers can dramatically reduce agricultural water demand, reduce vulnerability to climate extremes of drought and flooding, and also increase soil carbon storage, as well as productivity. Soil productivity is the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specified management system. Generally, soil productivity is determined by the response of crop yield (Larson *et al.*, 1985).

Soil erosion rates are partially controlled by soil and water conservation structures such as stone bunds and soil bunds, which are installed along the contour lines. Sediment accumulates behind these structures, which results in the development of progressive terraces (Hudson, 1992; Gebrernichael *et al.*, 2005). In response, governments and development agencies have invested substantial resources in promoting soil and water conservation practices such as stone bunds and soil bunds as part of efforts to improve environmental conditions and ensure sustainable and increased agricultural production.

This type of terrace is often associated with high spatial variability in soil fertility and crop response, due to soil erosion and sediment accumulation processes (Figure 1). Stone bunds and soil bunds act not only as a partial barrier for water-induced soil erosion, but at the same time form a total barrier to tillage translocation (Turkelboom *et al.*, 1997; Govers *et al.*, 1999), causing colluviation behind the lower stone bund and truncation of soil profiles at the foot of the upper stone bund (Herweg and Ludi, 1999; Nyssen *et al.*, 2000).

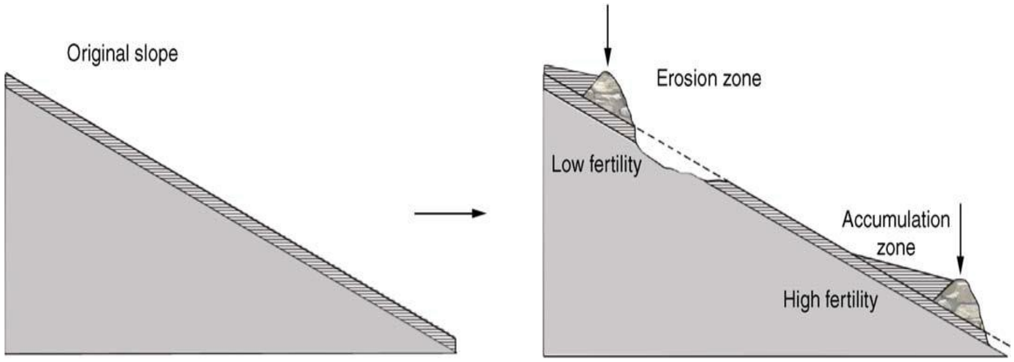

Figure 1. Sketch to illustrate the development of an erosion zone and an accumulation zone on plots between two stone bunds (indicated by vertical arrows). If soil fertility is concentrated near the surface, the development of a progressive terrace results in a spatial gradient of soil properties based on (Turkelboom *et al.*, 1997).

In Tigray (Vancampenhout *et al.*, 2006) observed a yield increase of 7% on land treated with stone bunds compared to untreated areas. The purpose of soil conservation is not merely to preserve the soil but to maintain its productive capacity while using it, (Troeh *et al.*, 1980). In Gumara-Maksegnit watershed, the most commonly practiced soil and water conservation measure that communities early accepted and experienced are stone terraces (Ziadat and Bayu, 2015). In the study watershed, large-scale stone bund building programs are implemented to curb severe soil erosion.

There are many studies regarding the effect stone bunds on control of soil loss, nutrient depletion and control of runoff at watershed and plot level. However, there is no visible study regarding the impacts of stone bunds on soil moisture content, nutrient distribution, and crop yield within the intra-terrace based, or it is site specific. Therefore, it's important to study the performance of stone bunds which is constructed by community mobilization on soil physical and chemical properties and crop yield within the intra-terrace based and comparing the treated versus untreated farmland at Gumara-Maksegnit watershed. Therefore, the objectives of this study were to evaluate the magnitude of soil properties on consecutive terraces between intra-bund areas and to assess their influences on crop yield. The main objective of the study was to evaluate the effect of the stone bund on moisture retention, soil nutrient and yield improvement in Gumara-Maksegnit watershed.

Materials and methods

Description of the study area

A field experiment was conducted for two years, in 2015 and 2016 at Gumara-Maksegnit watershed in the highland area of northern Ethiopia. The watershed is found in north Gondar Administrative zone and located at about 45 km southwest of Gondar town. It covers an area of 53.7 square kilometers and located between $12^0$23’ 53” to 12^0 30’ 49” North latitude and 37^0 33’ 39” to 37^0 37’ 14” East longitude (Figure 2). The study watershed is characterized by diverse topographic features with an altitude ranges from 1933 to 2852 m.a.s.l. (Klik et al., 2018).The study area is characterized by a Uni-modal rainfall with intermittent and poor uniform distribution (Ziadat and Bayu, 2015) and the annual mean value is 1052 mm of which more than 90% occurs in the rainy season (June to September). The mean minimum and maximum temperatures are 13.6 and 28.5 °C respectively (Addis *et al.*, 2015).

The soil types are predominately Cambisols and Leptosols which are found in the upper and central part of the watershed, whereas Vertisols is found in the lower catchment where the experiment was undertaken (Addis *et al.*, 2015; Ziadat, 2015) major soil texture types in the watershed are sandy clay loam, sandy loam, clay loam, loam and clay (Ziadat and Bayu, 2015). The watershed is characterized by a mixed crop-livestock subsistence farming system. The land is the most valuable and scarce asset in the watershed where most farms are owner operated while some modalities of land exchange also exist (Ziadat and Bayu, 2015). The slope of the study watershed ranges from nearly flat (less than 2%) to exceptionally steep (greater than 70%) in the northern part of the watershed and the mean watershed slope is 22.06%. The study watershed was mainly covered by agricultural land (63.5%) followed by forest (24.3%) and grassland 12.2%. The major crops grown in the agricultural land includes sorghum, Tefff (*Eragrostis Tefff*), faba bean, lentil, wheat, chickpea, linseed, fenugreek, and barley. *Eragrostis Tefff* and sorghum were the main staple crops, whereas chickpea was grown at residual moisture in the lower regions of the watershed where clay soil textural classes were dominant and this crop cannot grow at higher altitudes (Addis *et al.*, 2015).

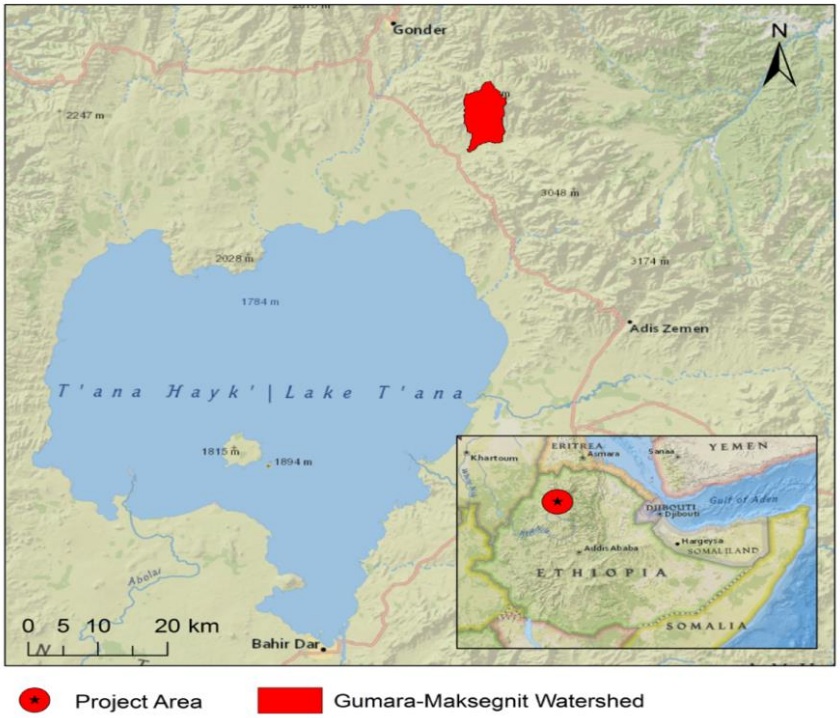

Figure 2. Location of the study area (Addis *et al.*, 2015)

Experimental setup

An experiment was set on 6.5 to 8.5% slope fields treated with and without stone bunds. Two treated sites (for the accuracy of results) and one untreated site were selected for an experiment. On the treated sites, three consecutive bunds (lower, middle, and upper) along the bottom-sequence were taken for evaluating the effect of stone bunds on crop yield, moisture availability and soil nutrient distribution within the intra-bund area. The bunds are characterized by the average spacing between bunds and height of 17.5m and 0.45m, respectively. A total of 54 sampling sites for the treated field (27 each for the two sites) and 9 sampling plots for the untreated site were used for soil and crop sampling within the intra-bund areas. Within the intra-bund area, three sampling positions were used: immediately above the bund (sediment accumulation zone, A), the middle area between two bunds (B), and immediately under the bund (erosion zone, C). These zones were determined in the field by the characteristic changes in local slope gradient on consecutive bunds (Table 1 and Figure 3), which can easily be observed in the field.

Soil sampling and analysis

Surface soil samples were taken at depth of 0-20 cm from each sampling plot (three positions within the conductive bunds) before planting and after harvesting by using sharp knife and metal round circular auger for moisture content determination and nutrient analysis (Nations and Organization, 1998). Soil samples for nutrient analysis were taken from three sampling points from each sampling plot and mixed thoroughly in a clean plastic bucket to form a composite sample for analysis of various soil properties. Each soil samples were air-dried at room temperature, homogenized and passed through a 2 mm sieve before laboratory analysis for different soil parameters including OM content, CEC, available P and soil PH. Organic matter was determined from organic carbon according to Walkley & Black method (Schnitzer et al, 1982*)* and the OC result obtained from laboratory analysis was multiplied by 1.724 to get organic matter. CEC was measured by using 1M Ammonium acetate, and pH was measured in distilled water using a 1:2.5(soil: water) suspension. Available P was measured in Parts per million (ppm).

Soil moisture content sample was collected from each sampling plot for 5 different days (20 days after planting, 45 days after planting, 62 days after planting, and 80 days after planting and 100 days after planting) by using core and determined by the gravimetric method (Klute, 1986). Soil samples taken for moisture content determination were measured immediately on the field and dried by oven at 105^{o}C for 24 hours. Then the soil moisture was the difference of initial soil sample and the oven dried soil. The soil moisture content that collected in different days was averaged by the same plot and subjected to analysis of variance. As the number of sampling dates for the two years was the same, the mean of two-year moisture data was used for data analysis for each site separately.

Crop yield measurement

To investigate the effects of stone bund implementation on crop response, crop harvest sample using 1 m^2 quadrant was collected at the erosion (C) zone, the central (B) zone and the accumulation (A) zone of the 63 sampling plots (54 treated and 9 untreated sampling plots) at the end of the growing season (Figure 3). A total of 27 crop samples in each site (3 bunds, 3 positions within the bund area and 3 replications) were measured for each crop type. Whereas, a total of 9 samples (with a transect parallel to site-1) were used for the untreated site. The crop yields were Tefff, Sorghum and Chick pea.

Data analysis procedures

The sampling plots for treated sites were arranged in split plot design replicated three times. Two factors (consecutive bunds and intra-bund positions (A, B, and C)) were considered as treatments.

The lower, middle and upper bunds were assigned in the main plot and intra-bund positions (A, B, and C) were assigned on sub-plots. Sampling plots for the untreated site was sited parallel to site-1and all the investigated results of the untreated site were compared to site-1, because the slope and other soil surfaces characteristics are similar. The data obtained from field measurement and laboratory analysis were analyzed by agricultural policy/environmental extender (APEX) model. The soil moisture content and chemical properties (pH, OM, available P, and CEC) were subjected to analysis of variance using the general linear model procedure of the statistical analysis system (SAS, version 9.0). When the analysis of variance (ANOVA) showed significant differences (at $p \leq 0.05$) due to consecutive stone bunds and intra-bund sampling positions, a mean separation for each parameter was made using the least significant difference (LSD). The data obtained from treated site-1 and untreated site were subjected to t-test by using SPSS software.

Table 1. Experimental design and layout with in different crop type: A=lower terrace position, B= center between two terraces and C=Upper terrace position (loss zone).

bunds from bottom to up	SITES																	
	Site-1									Site-2								
	Replication1			Replication 2			Replication 3			Replication 1			Replication 2			Replication 3		
Bund 1	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Bund 2	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Bund 3	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*

Where: A=lower terrace position (accumulation zone), B= center between two terraces and C=Upper terrace position (loss zone).

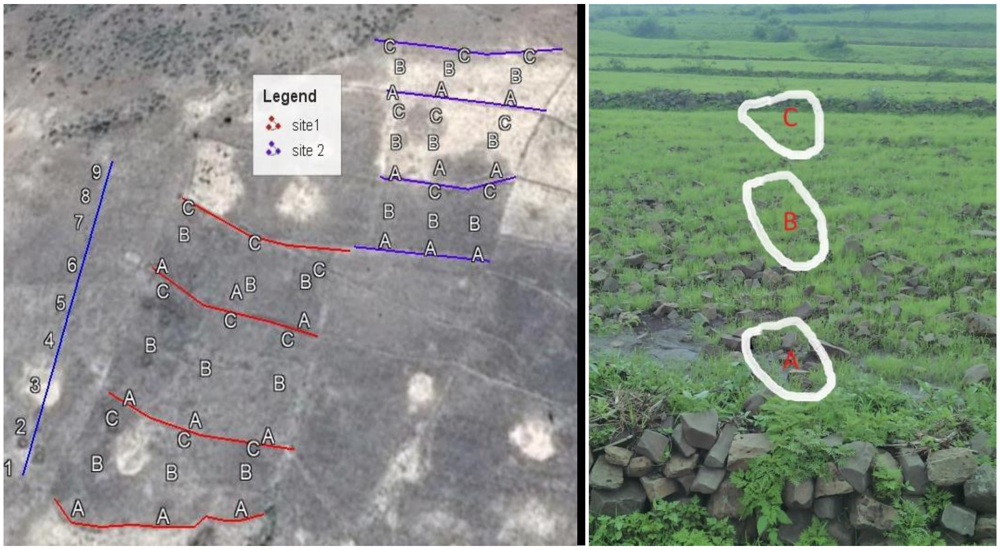

Figure 3. Layouts of point of data collection: A = the deposition zone of stone bund, B = middle part between consecutive stone bunds and C = the loses zone of stone bund.

Result and Discussions

Effect of stone bund on soil moisture content

Soil moisture showed significant variation at ($p \leq 0.05$) with respect to the main plot and subplot treatments in both sites (Table 2). In respect to main plot on site-1, higher soil MC (25.20±0.34%) was observed in lower bunds as compared to the middle (24.48±0.40%) and upper (23.59±0.23%) bunds (Table 3). In site-2 there was no significant variation ($p \leq 0.05$) between lower (24.03±0.28%) and middle (23.80±0.21%) bunds, but there was a significant variation ($p \leq 0.05$) between lower and upper bunds.

In respect to subplots or Intra-bund positions, in both sites, the higher soil moisture content was observed in data point A (immediately above the bunds) as compared to the middle (B) and loss (C) zone (Table 3B). But the main plot-subplot interaction effect didn't show any significant variation at ($p \leq 0.05$). The results revealed that stone bund significantly improved the soil moisture content. In respect to the variation between stone bunds, there is a numerical difference between lower middle and upper part of the bund. The result revealed that data point "A" from subplot and lower bund from main plot do have more soil moisture content. It seems that the lower zone (A) receives higher amounts of additional moisture from upper positions compared with the middle and upper zones. This may be associated with the relative amounts of the soil and slope position. The fertile topsoil moved down the slope by water erosion processes and sediment deposition took place around 2m above stone bund positions, which in turn might have contributed to increased soil depth and consequently improved the water content of the soil. These increases in soil MC also may be attributed to an additional water supply from upslope to downslope as catchment area increase.

Soil moisture content showed highly significant variation ($p<0.01$) between farm plots with stone bund practices and non-conserved farm plots (Table 4). The higher soil moisture content (24.42%) was observed in farm plots conserved with stone bunds as compared to non-conserved (22.88%) farm plot (Table 5). This could be attributed to the presence of significantly higher organic matter and reduced runoff velocity and enhanced infiltration as a result of stone bund barrier than the faster runoff flow down the slope for non-conserved farm plots. Since the soil textural class of the study site is of clay type, we can say that the only variable that is affecting the soil moisture content is the stone bund construction. Soil nutrients improve the soil structure and thus affect the stocking of the soil water reserves. In this study soil, MC showed that correlation to that of soil organic carbon contents, total nitrogen, and cation exchange capacity.

Table 2. Summary of ANOVA table for moisture content of site1 and site 2

		Average MC of site-1		Average MC of site-2	
Sources	DF	MS	P	MS	P
Replication	2	1.69	0.0031	0.19	0.32
bunds	2	5.88	<.0001	1.44	0.0034
Error (bunds)	4	0.20		0.03	
Intra-positions	2	7.76	<.0001	5.18	<0.0001
bunds*Intra-positions	4	0.41	0.11	0.20	0.33
Error (Intra-positions)	12	0.17		0.15	

Where, DF=degree of freedom, MC= moisture content and MS=mean squares

Table 3. The mean ± SE values of soil moisture content of site-1 and 2 in which A-main plot and B-sub plot treatments.

Bunds (main-plots)	Moisture content of site-1	Moisture content of site-2	*Intra-bund positions*	Moisture content of site-1	Moisture content of site-2
lower bund	25.20±0.34[a]	24.03±0.28[a]	A	25.49±0.36[a]	24.55±0.17[a]
middle bund	24.48±0.40[b]	23.80±0.21[a]	B	23.79±0.29[b]	23.10±0.22[b]
upper bund	23.59±0.23[c]	23.25±0.25[b]	C	23.98±0.24[b]	23.43±0.10[b]
CV (%)	1.83	0.74	CV (%)	1.71	1.65
LSD (0.05)	0.59	0.23	LSD (0.05)	0.43	0.40
	A			*B*	

Mean values followed by different small letters along the same column are significantly different at ($p < 0.05$).

Effect of stone bund on nutrient availability

Soil Organic Matter

Soil organic matter showed a significant variation at (0.05) with respect to sub-plot treatments (lower, middle and upper intra-bund areas) in site-1 and didn't show any significant differences in site-2 (Table 6 and 7). Higher organic matter (2.97±0.11) was observed in the accumulation zone (A) as compared to the middle (2.44±0.07) and upper (2.86±0.13) loss zone (Table 8 and 11). This could probably be attributed to accumulated and retained organic matter due to bund construction. Upper positions had the lowest OM that may indicate the severity of soil erosion on these sites and transported to the lower point in the landscape through runoff and erosion. The organic matter didn't show any significant variation in the main-plot treatments (consecutive bunds) in both site-1 and 2. Numerically higher soil organic matter was observed in the upper bund positions than the middle and lower bund positions.

Table 4. Paired sample T- test of nutrient, soil moisture content and crop yield treated versus untreated farm.

Parameters		Paired Differences			t	DF	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
PH	treated - untreated	0.27	0.17	0.099	2.681	2	0.115
Available P	treated - untreated	0.92	1.0	0.595	1.541	2	0.263
OM (%)	treated - untreated	0.69	0.14	0.079	5.054	2	0.037
CEC (coml./kg)	treated - untreated	9.71	0.26	0.147	66.024	2	<0.001
K+ (coml./kg)	treated - untreated	-0.11	0.43	0.249	-0.437	2	0.705
Moisture content	treated - untreated	1.55	1.13	0.375	4.125	8	0.003
Sorghum	Treated-untreated	177.96	181.12	60.373	2.948	8	0.018
Chickpea	treated-untreated	410.929	286.405	95.468	4.304	8	0.003

Where DF= degree of freedom, P=available phosphorus, OM=organic matter content, CEC=cat ion exchange capacity and K+=potassium ion.

According to Bot and Benites (2005), organic matter accumulation is often favored at the bottom of hills for two reasons: one is they are wetter than at mid or upper slope positions, and the other is OM would be transported to the lowest point in the landscape through runoff and erosion. The same holds true for conserved land where soils are actively eroded from the soil loss zone and deposited to the soil Accumulation zone, creating spatial variability in terms of moisture and nutrient availability within the inter-conserved space. As shown in table 4, Soil OM content also showed a significant difference at ($p<0.05$) with respect to conserved and non-conserved farm lands which directly related to available soil moisture content. The higher (2.76) organic matter was observed in the farm conserved with stone bunds as compared to non-conserved (2.07) bare land (Table 5).

Table 5. Paired sample statistics values of nutrient, soil moisture content and crop yield treated versus untreated farm.

parameters		Mean	Std. Deviation	Std. Error Mean
PH	treated	6.98^{ns}	0.04	0.02
	untreated	6.71	0.21	0.12
Available P	treated	11.96^{ns}	1.99	1.15
	untreated	11.04	1.14	0.66
OM (%)	treated	2.76*	0.16	0.09
	untreated	2.07	0.07	0.04
CEC (cmol/kg)	treated	49.66**	0.83	0.48
	untreated	39.96	0.99	0.57
K+(cmol/kg)	treated	1.31^{ns}	0.07	0.04
	untreated	1.42	0.50	0.29
Moisture content	treated	24.4**	1.10	0.37
	untreated	22.88	0.51	0.17
Sorghum	treated	2059.15*	355.241	118.414
	untreated	1881.19	403.530	134.510
Chickpea	treated	1441.43**	242.237	80.746
	untreated	963.85	89.899	29.966

*Where ** indicates highly significant differences, * indicates significantly differences at ($p<0.05$) and ns indicates non-significant between treated and untreated farm plot within each parameter.*

Soil OM was positively and significantly correlated with MC and CEC. Because of this close link, soil organic matter has an influence on soil properties. Hence, declines in soil OM contributes to the loss of grain production and results in food insecurity. According to the soil classification of soil OM ranges suggested by Barber (1984), the mean values of organic matter of both terraced and non-terraced farm plots were found to be medium. This may be attributed to erosion before the structures built and linked to poor soil fertility management practices conducted by the land users after the structures. In the study area, soil OM depletion needs special attention in the future.

Soil PH

Soil pH has shown significant variation at ($p<0.05$) significant level on main-plot (bunds) treatments in both sites. In site-1, higher soil pH (7.07±0.03) was observed at lower bund as compared to middle (6.99±0.04) and upper (6.88±0.03) bunds (Table 9). In site-2 also, higher soil pH (6.75±0.03) was observed at lower bund as compared to the middle (6.63±0.04) and upper (6.56±0.03) bunds (Table 10). The variations for soil pH, which affects nutrient availability and toxicity, microbial activity and root growth were generally small in sub-plot treatments and the interactions. But the accumulation zone (A) had absolutely higher pH value in both sites as compared to middle (B) and loss (C) zone (see Table 8 and 11). The laboratory result of sampled soils is in agreement with the reports of other similar studies. For instance Alemayehu (2003), also found that stone bund had no significant effect on soil PH. Vancampenhout *et al.* (2006), also reported pH values did not vary with position in the plots between consecutive stone terraces. So, the result showed that the upper and middle positions of stone bunds were more acidic than approximately 2m above stone bunds. This might be the fact that available cat ions (Ca^{2+}, Mg^{2+}, and K^{+} etc.) were eroded and deposited near to stone bunds and acidic elements were left in the upper positions. Soil pH also didn't show any significant difference at ($p<0.05$) between conserved and non-conserved treatments. Numerically higher (6.98) pH value was observed on treated land than untreated (6.71) one (Table 5).

Cation Exchange Capacity (CEC)

The value of CEC in the soil samples collected and analyzed showed highly significant variation at ($p<0.01$) only at the main-plot treatments solely in site two. The results obtained were higher in the lower bunds (46.50±1.47) as compared to the middle (39.95±1.11) and upper (36.94±0.78) bund areas (Table 10). But it didn't show any significant variation with respect to intra-bund positions and the interaction in both sites. Similar to soil pH, soil CEC showed an increment when we move from upper to lower positions of stone bunds (Table 8, 9, 10 and 11). This finding implies, that improving soil OM and pH can significantly increase soil CEC. The high clay fraction along with soil OM may also attribute to the high rate of soil CEC in the study site. Hence, processes that affect soil organic matter due to soil erosion, intensive cultivation, and land use changes can affect CEC of soil (Bremner and Mulvaney, 1982), which in turn affects soil fertility and can cause severe yield decrements. CEC has shown highly significant ($p<0.01$) variation between treated and untreated farmlands. As shown in table 5, CEC had higher (49.67) values in the farm plot constructed by stone bund and lower (39.96) value without the construction of stone bunds. This might be based on the fact that bunds can protect nutrients from erosion and leaching.

Available Phosphorus (P)

Available p showed highly significant differences ($p<0.01$) only the intra-bund position treatments only in site one and didn't show any significant variation in main-plot and the interaction in both sites (Table 6 and 7). Like other nutrient parameters, phosphorus had also higher (14.22±0.50) value at the accumulation (A) zone as compared to the middle (11.18±0.48) and upper (10.48±0.62) loss zone (Table 8). As we see the main-plot in Table 9 and 10, there were no significant variations between each bund in both sites. But the numerically higher value was observed at the lower (12.46±0.86) bunds as compared to the middle (11.38±0.51) and upper (12.04±0.88) bunds in site one. Unlike OM, CEC and MC, Available p didn't show any significant variation between treated and untreated land (see Table and 5), but numerically higher available P was shown on treated (11.96) land as compared to untreated (11.04) farmland.

Potassium ion (K+)

Potassium only showed a significant difference ($p<0.05$) on the main-plot treatment in site two. But it didn't show any significant variation sub-plot and the interaction. It didn't also show any variation among treated and untreated land. Like other parameters, P also observed higher values at accumulation zone in intra-bund positions, at lower bund in consecutive bunds and in conserved farmland between treated and untreated farm plots.

Table 6. Summary of ANOVA table for nutrient parameters of site-1

		pH (H_2O)		Available P (ppm)		% OM		CEC (cmol/kg)		K+ (cmol/kg)	
Source	DF	MS	P	MS	P	MS	P	MS	P	MS	P
replications	2	0.048		7.21		0.07		13.37		0.02	
bunds	2	0.086	0.03	2.64	0.63	0.40	0.12	20.51	0.26	0.11	0.46
Error (bunds)	4	0.008		5.00		0.10		10.56		0.11	
Intra-bund positions	2	0.014	0.15	35.5	<0.001	0.22	0.04	6.27	0.47	0.05	0.13
bunds*intra-position	4	0.004	0.68	1.66	0.335	0.11	0.15	19.15	0.10	0.04	0.20
Error (Intra-position)	12	0.006		1.31		0.05		7.74		0.02	

Table 7. Summary of ANOVA table for nutrient parameters of site -2

		pH (H_2O)		Available P (ppm)		% OM		CEC (cmol/kg)		K+ (cmol/kg)	
Source	DF	MS	P	MS	P	MS	P	MS	P	MS	P
replications	2	0.035		9.45		0.061		2.34		0.12	
bunds	2	0.084	0.035	43.05	0.180	0.346	0.190	213.23	0.001	0.36	0.037
Error (bunds)	4	0.010		15.86		0.134		3.55		0.04	
Intra-positions	2	0.019	0.081	4.23	0.680	0.004	0.966	29.93	0.214	0.03	0.244
Bunds* intra-positions	4	0.005	0.524	11.32	0.413	0.517	0.017	1.30	0.988	0.04	0.111
Error (Intra positions)	12	0.006		10.57		0.110		17.01		0.02	

Table 8. The mean ± SE values of nutrient parameters in the sub-plot treatments (intra-bund areas) of site-1.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol./kg)	K+ (cmol./kg)
A	7.03±0.05	14.22±0.50[a]	2.97±0.11[a]	50.60±1.26	1.40±0.09
B	6.95±0.03	11.18±0.48[b]	2.44±0.07[b]	49.39±0.77	1.25±0.06
C	6.96±0.05	10.48±0.62[b]	2.86±0.13[a]	49.01±1.31	1.28±0.06
CV (%)	1.14	21.36	14.13	5.6	11.06
LSD (0.05)	0.0819	1.17	0.2329	2.86	0.15

Where A=accumulation zone, B=middle zone, C=loss zone, P=phosphorus, OM=percent organic matter, CEC= cat ion exchange capacity and K+=potassium ion. Values with different letters along the same column have significant differences (p<0.05) between treatment means.

Table 9. The mean ± SE values of nutrient parameters in the main-plot treatments (consecutive bunds) of site-1.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol/kg)	K+ (cmol/kg)
lower bund	7.07±0.03[a]	12.46±0.86	3.12±0.04	50.30±1.29	1.43±0.08
middle bund	6.99±0.04[ab]	11.38±0.51	2.78±0.06	50.76±1.11	1.29±0.07
upper bund	6.88±0.03[b]	12.04±0.88	2.40±0.15	47.94±0.76	1.21±0.05
CV (%)	1.31	49.03	20.13	6.54	25.38
LSD (0.05)	0.1198	2.93	0.4228	4.25	0.44

Values with different letters along the same column have significant differences between treatment means.

Generally higher mean nutrient values observed in the accumulation zone (A) and gradual lower fertility towards the erosion zone (C) for most nutrients. The presence of a slope gradient may be considered important with respect to the formation of slow forming terraces. Since most phosphorus is strongly adhering to soil particles (Brady *et al.*, 2008) and therefore easily transported downslope by tillage and water erosion, terracing thus leads to higher values of available P in the accumulation zone. Organic matter can be transported as roots, litter or in solution or adsorbed on soil particles (Brady *et al.*, 2008), but C values are typically low in the Ethiopian highlands as a consequence of stubble grazing and the absence of fallowing. Previous studies in Ecuador (Dercon *et al.*, 2003) and Ethiopia (Esser *et al.*, 2002) also indicate stronger gradients for available P and total nitrogen compared to organic carbon. Remarkably, relatively low amounts of OM are present under the stone bund whereas the highest amounts of OM are located at approximately 2m above the stone bund.

Table 10. The mean ± SE values of nutrient parameters in the main-plot treatments (consecutive bunds) of site-2.

Treatment	pH	Available p (ppm)	% OM	CEC (cmol. /kg)	K+ (cmol./kg)
lower bund	6.75±0.03[a]	14.82±0.85	3.24±0.14	46.50±1.47[a]	1.09±0.05[a]
middle bund	6.63±0.04[ab]	18.32±1.32	2.65±0.16	39.95±1.11[b]	1.45±0.06[a]
upper bund	6.56±0.03[b]	18.83±1.08	3.24±0.11	36.99±0.78[c]	1.43±0.07[b]
CV (%)	1.48	22.99	20.71	4.58	15.63
LSD(0.05)	0.1286	5.21	0.479	2.4663	0.2711

Values with different letters along the same column have significant differences between treatment means.

This observation is in agreement with the mechanism stated by (Rose *et al.*, 2003); sedimentation behind a stone bund alters the geometry and the gradient of the soil surface over which flow occurs (Figure 1). In the test plots, this change of slope is located near 2m above the bund position where most organic carbon is found, which indicates a strong influence of OM transport as water eroded crop residue. The opposite effect is observed at the top of the terrace: most OM is lost at under stone bund, where the local slope gradient increase and therefore the runoff erosive abruptly high. In bund length ranges from 11 m to 25 m and 18 m spacing, water erosion can be considered an important factor of terrace formation besides tillage translocation (Turkelboom *et al.*, 1999; Dercon, 2001).

Table 11. The mean ± SE values of nutrient parameters in the sub-plot treatments (intra-bund areas) of site-2.

treatment	pH	Available P (ppm)	% OM	CEC (cmol./kg)	K+ (cmol./kg)
A	6.70±0.041	17.83±1.397	3.09±0.18	43.25±1.99	1.39±0.11
B	6.62±0.041	16.54±1.164	3.02±0.12	40.04±1.66	1.28±0.05
C	6.63±0.042	17.60±1.193	3.05±0.14	40.15±1.53	1.30±0.08
CV (%)	1.16	18.76	18.8	10.02	10.18
$LSD_{0.05}$	0.08	3.34	0.3414	4.2366	0.1385

Values with different letters along the same column have significant differences between treatment means.

Effect of stone bund on crop yield

The grain yield of crops showed significant ($p<0.05$) variation in the sub-plot (A, B, C) treatments and didn't show any significant differences with respect to main-plot (lower, middle, and upper bund) treatments. Sorghum and chickpea yields are shown highly significant ($p<0.01$) differences with respect to sub-plot treatment means (Table 12). The higher (2490.6 kgha^{-1}) grain yield of sorghum was occurred at the accumulation (A) zone of bunds as compared to the middle (1615 kgha^{-1}) and upper (1934.9 kgha^{-1}) intra-bund positions (Table 13). The table showed that the yield of Tefff at data point of B (middle zone of the bund) was the highest. This is because this zone is moderately drained, have no water logging problem during the rainy season. Tefff is generally known as a robust crop in harsh growing conditions; hence it is expected to be less responsive to soil fertility gradients (Dercon, 2001). Like sorghum, the higher chick pea yield also observed at data point A (1778.9 kg ha^{-1}) as compared to data point B and C which have the average yield amounts of 1224.6 kg ha^{-1} and 1320.88 kg ha^{-1} respectively. This is because immediately above the bund, nutrients and moisture are eroded and leached from the middle and loss zone then stored in the accumulation zone during the summer season and used up by crops after September. Based on paired sample t-test shown in Table 5, sorghum and chickpea yields also shown significant ($p<0.05$) variation among treatments of conserved and non-conserved farm plots. The appreciable yield (2059.15kg ha^{-1} for sorghum and 1441.43 kg ha^{-1}for chickpea) was observed on the farm plots conserved by stone bunds as compared to non-conserved bare land which has the mean yields of 1881.19 and 963.85 kg ha-1 for sorghum and chickpea respectively. Generally, on crop yield sub-plot treatments have shown significant variation as compared to main plot treatments and the interactions.

Table 12. Summary of ANOVA table for Tefff, Sorghum and chickpea yields.

		Tefff		Sorghum		Chickpea	
Sources	DF	MS	P	MS	P	MS	P
replications	2	39998.3		96377		293331	
bunds	2	18585.4	0.56	743324	0.37	232693	0.04
Error (bunds)	4	27380.5		582109		30487	
Intra-bund areas	2	67983.2	0.03	1766769	<0.001	302064	0.002
bunds*intra-bund areas	4	7975.5	0.72	133583	0.31	82143	0.06
Error (intra-bund areas)	12	15166.4		99917		27678	

Where DF= degree of freedom, MS= means of squares.

Table 13. The mean ± SE values of grain yield: A= the main-plot treatments (consecutive bunds) and B=sub-plot treatments (intra-bund areas).

Main-plot Treatments	Tefff yield $Kgha^{-1}$	Sorghum yield $Kgha^{-1}$	Chickpea yield $Kgha^{-1}$	Sub-plot Treatment	Tefff yield $Kgha^{-1}$	Sorghum yield $Kgha^{-1}$	Chickpea yield $Kgha^{-1}$
lower bund	605.68	1719	1192.8[b]	A	539.42[b]	2490.6[a]	1778.9[a]
middle bund	618.18	2028.3	1497.50[a]	B	686.21[a]	1615[b]	1224.6[b]
upper bund	533.97	2293.2	1437[a]	C	532.19[b]	1934.9[b]	1320.8[b]
CV $_{(\%)}$	28.24	37.89	12.7	CV $_{(\%)}$	21.02	15.7	12.1
LSD $_{(0.05)}$	216.57	998.59	228.53	LSD $_{(0.05)}$	126.49	324.66	170.88
		A				B	

Values with different letters along the same column have significant differences (p<0.05) between treatment means.

It can be concluded that the implementation of stone bunds, in general, has only positive effects on crop response, increasing it with 26.52 % in total. To verify if this positive effect results in higher total yields, the land occupied by stone bunds has to be taken into account. Measurements show that 8% of the land is left unplugged due to stone bund building. The hypothetical yield without the implementation of stone bunds equals 1881.15 for sorghum and 963.85 kg ha^{-1} for chickpea. The yield produced from conserved farm plot was 2059.15 and 1441.43 kg ha^{-1} for sorghum and chickpea respectively. This indicating stone bunds increased grain yield by 49.54% for chickpea and 9.50 % for sorghum and an average yield increment of the two crops was about 29.52% as compared to the original bare land situation.

Contrary to what is often found in other regions (Turkelboom *et al.*, 1999; Dercon *et al.*, 2003), and in Tigray based on model application (Hengsdijk *et al.*, 2005), field measurements in this study show that yield did certainly not decrease due to land occupation or the formation of soil fertility gradients, already benefits from water conservation, reduction of runoff and water erosion by stone bunds (Herweg and Ludi, 1999) and therefore provides a 'flattered' reference yield, especially in a dry year. Grass strips near the structures (included in the 8% land occupation) furthermore provide cattle fodder as an additional benefit. Moreover, the land loss estimation of 8% due to stone bund implementation is highly conservative: (I) 3% of this surface was already occupied by boundaries and grass strips forming traditional terraces, (Nyssen *et al.*, 2000a), before a stone bund was placed on top of these structures and (II) cropland increased by 2% due to the removal of stones for stone-bund building from very stony areas. Taking these factors into account, the yield increase is as high as 26.52% in total.

Conclusions and Recommendations

Soil erosion seriously restricts land productivity in Gumara-Makegnit watershed which is part of the Ethiopian highlands. In the study area, stone bunds have shown significant improvement in soil physical properties such as soil MC and chemical properties such as soil OM, pH, CEC available P, and K+. Moreover, the high moisture content in treated land affects more positively the soil productivity as compared to the non-conserved farmlands. The variation was also significant between treatments of treated land on soil physical properties and chemicals properties. Higher OM and CEC were found in at the accumulation zone (immediately above the stone bund (treatment A) as compared to the upper (C) and middle (B) part of consecutive stone bunds.

This implies that SWC measures such as stone bunds have affected positively the productivity of agriculture in conserved lands. The result showed that the upper and middle positions of stone bunds were more acidic than the lower positions of stone bunds. The result also showed that there was no significant variation crop yield among main-plot treatments and the interactions. Generally, the effects of stone bunds on crop yield, soil moisture content and some selected soil chemical properties at Gumara-Maksegnit watershed were found to have pronounced positive effects. Soil properties are relatively better on the lower part than on the upper and middle part of the stone bund. Conservation measures such as terrace were found to be important not only to reduce soil erosion but also to maintain the soil fertility such as soil OM, available P, and CEC.

This implies that SWC measures positively affected the productivity of agricultural lands. However, there is a need for awareness creation and follow up on proper management and regular maintenance of structures. Integration of biological conservation measures is vital for better effectiveness and sustainability of SWC efforts. If SWC practice is not intensively continued, more land will become unsuitable for crop production in the future. Further study on economic benefits (cost-benefit analysis) of stone bunds should be done to hopefully recommend the construction of stone bunds on farmlands.

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The Effect of Ridging and Tie-Ridging time on the Yield Performance of Sorghum (*Sorghum bicholar* L) at North Gondar, Ethiopia

Ertiban Wondifraw[1], Sisay Ambachew[2], Muuz Gebretsadik[3], Melkie Desalegn[1], Edmealem Getu[1] and Baye Ayalew[1]

[1]Gondar Agricultural Research Center, P.O.Box, 37, Gondar, Ethiopia

[2]University of Gondar, Gondar, Ethiopia

[3]Adigrat University, Tigray, Ethiopia

Abstract

The effect of timing of tie-ridging on the yield and yield components of sorghum was studied at Gumara-Maksegnit watershed, Gondar Zuria woreda, Amhara Region, Ethiopia during 2014, 2015 and 2016 production seasons on farmer's field where Vertisols are dominant. In the study area, the amount of annual rainfall ranges from 995 to 1175 mm; more than 70% of the rain occurs within three months (from June to August). During these months, waterlogging occurs in the Vertisols. However, after August during a peak flowering time for many crops the amount of rain dramatically decreased and plants face water shortage and resulted in high yield penalty. There was a concern about the occurrence of unbalanced soil moisture, which demands urgent attention. Therefore, the experiment was done to evaluate the ridging and tie-ridging time on sorghum yield. The experiment was laid out in a randomized complete block design (RCBD) in three replications. There were 7 different timing of tie-ridging treatments. All the necessary management practices and inputs (87kg N and 46 kg P2O5 per hectare) were supplied equally to each plot. Data were analyzed for variance and LSD at 5% level of significance. The three years combined result revealed that the timing of tie-ridging had a significant effect on sorghum grain and stover yield. The maximum yield was recorded at planting at flat land, ridged three weeks after planting and tie the ridge nine weeks after planting. Therefore, this technology can be applied to the study area and similar agroecologies.

Key words*:* sorghum, tie-ridging time, Vertisols

Introduction

Sorghum (*sorghum b.)* is the fourth most important world cereal after wheat, rice, and maize. It is a staple food in the drier parts of tropical Africa, India, and China (Mamoudou *et al*., 2006). Sorghum is also a major and one of the leading traditional food crops in Ethiopia with approximately 297,000 ha production area coverage per annum (Wortmann *et al*., 2006), which comprises 15-20% of the total cereal production in the country.

Climate change is a threat to crop productivity including sorghum in the most vulnerable region of the world, particularly the semi-arid regions where higher temperature and increase in rainfall variability could have a substantially negative impact (Abdulai A. *et al*., 2012). The 21-century surface air temperature projection showed that there is a rise of 1.8-4.0 oC with a very likely occurrence of unpredictable extreme events such as drought and flood (IPCC, 2007). In addition to the likely occurrence of climate variability in the study area, the nature of rainfall in the area is the erratic type. Almost 70% of the total annual rainfall occurs only in two to three months (from June to August) and the rest two to three months (September to November) of the growing season faces terminal moisture stress (dry spells). This phenomenon affects the production of many crops including sorghum.

The research revealed that the most important constraint of sorghum production is water stress and nutrient deficiency (Bicolor, Moench, and Valley, 2019). Accordingly, in Ethiopia, soil water deficits during crop establishment and grain fill were recognized as major constraints (Wortman et al, 2009; Tesfahunegn et al, 2009). On the other hand in many parts of Ethiopia including the study site, the nature of rainfall is erratic which results, waterlogging at the crop development stage especially for Vertisols. All these need appropriate water management techniques.

In-situ water harvesting techniques like tie-ridging is one of the practices in sorghum production areas of drylands to improve sorghum production. Ridging can be designed as open or closed (tied) for holding water and facilitating infiltration in areas of low, erratic rainfall. In tied ridging, sometimes called tied-furrows, ridge furrows are blocked with earth ties spaced on fixed intervals to form a series of micro-basins in the field (Nyamudeza and Jones, 1994; Wiyo et al., 1999; Biazin B., et al., 2012). Crops like sorghum and maize may be sown on the ridge or furrows. The furrows can be tied at intervals of 2two or more meters, depending on field conditions, to prevent runoff in the furrows.

Tie-ridging increases sorghum yield up to 46% as compared to the farmers' practice in the dry areas of Ethiopia. Tie-ridging that was done before planting improves soil water availability and increases sorghum yield over flat land planting and the farmers 'shilshalo' practices (Abebe et al, 2009). Gerbu (2015) also reported that yield advantage of 56% to 68% with cultivation of improved sorghum varieties with fertilizer and tie-ridging over local practices (local cultivar without fertilizer sown in flat planting). However, the effect of tie-ridging on soil water content and crop yield differs from season to season and from location to location (Abebe et al, 2009). Therefore, the study was conducted to evaluate the effect of the timeng of ridging and tie-ridging on sorghum yield in Gumara Maksegnit watershed.

Objective

To evaluate the time of ridging and tie-ridging on sorghum yield

Experimental methods

An on-farm experiment was conducted on sorghum on a Vertisols in 2014, 2015 and 2016 main cropping season. The study was carried out in Gumara-maksegnit watershed in North Gondar administrative zone in the Amhara National Regional State, Ethiopia. The watershed is located between 120 23' 53" to 120 30' 49" latitude and 370 33' 39" to 370 37' 14" longitude. The long term average annual rainfall is about 1052 mm this is similar to the first experimental year annual rainfall amount, but the amount of rainfall in the second season was only about 600mm. The mean minimum and maximum temperatures of the area are 13.3 °C and 28.5 °C. The soil of the experimental site is vertisol and the texture is clay. Local sorghum variety was used and sown at the onset of rains (commonly the second week of June). The recommended amount of 46 kg ha-1 P2O5 and 87 kg ha-1 N fertilizers were applied equally for each treatment. DAP and Urea fertilizers were used as fertilizer sources to supply phosphorous (P) and nitrogen fertilizers respectively. The gross plot size was 5 m x 4.5 m (22.5 m2). Sorghum seeds were drilled in rows at spacing of 75 cm between rows and 15 cm between plants and were thinly covered with soil. Plots were kept weed-free by hand weeding and all other agronomic practices were applied to each plot equally. Tie-ridging has developed with 20cm depth and 75 cm apart and tied at intervals of 2 m during and after planting based on the time fix for each treatment. Weeding was done four times throughout the growing season. Composite soil samples were collected before planting and soil chemical and physical analysis were done at Gondar Soil Laboratory.

Treatments: the study had seven treatments with a single factor of time of tie-ridging.

1. Tied-ridging at planting: the plots were tied and ridged at the time of planting.
2. Ridging at planting and tied at the time of full stand, which were almost 7 weeks later
3. Flat at the time of planting, tie-ridging three weeks after planting:
4. Flat at the time of planting, ridging after three weeks and tied after six weeks
5. Flat land at the time of planting, ridging after three weeks and tied after nine weeks
6. Flat land at the time of planting, ridging after three weeks and tied after twelve weeks
7. Flat at the time of planting, tie and ridging eight weeks after planting.

In the watershed farmers usually, plant sorghum at flat land in the broadcast. Fertilizer application and other agronomic practices like weeding, row planting and tie-ridging are not common. Farmers have their common practice for sorghum planting which is called 'shilshalo' which is a practice that farmers plow their sorghum plot after the good establishment of the plant using oxen for tinning and reducing weeds. Sometimes they do also remove large weeds after 3 to 4 months of planting using sickle and they use the removed weeds for animal feed.

Statistical design and sampling

The design was a randomized complete block design (RCBD) with three replications. The response variables measured were plant height in cm, head weight in g, stover yield in tone, head length in cm and yield in tone, each variable was taken from the middle four rows (3mx5m plot size), 2 rows were left to avoid border effects. Ten plant samples were measured randomly to determine plant height, head length, and head weight, while the entire middle four rows were taken to measure grain yield and stover yield. Soil moisture was also monitored in the growing season at different levels of moisture regime (from 0-20, 20-40, 40-60, 60-80 cm depth). The wet soil samples weighed and then oven-dried to 24 hours at 105° C and weighed again after drying. Soil moisture content percent was determined using the equation stated by Michael (1978) as follows:

$$M\% = \frac{(Ww - Wd) \times 100}{Wd}$$

Where:

M = soil moisture (%) on oven dry basis, Ww = weight of wet soil sample (g) and

Wd = weight of oven-dried soil sample (g).

Statistical analysis

Analysis of variance was carried out with 1 factor (time of tie-ridging). Means and standard errors were calculated for the time of tie-ridging. SAS version 9 statistical software was used for analysis.

Soil chemical and physical properties of the area

Soil texture of the study area is clay, which has cracking and swelling nature during dry and wet soil conditions; and the general slope of the field is about 1%, while its soil depth is more than 1meter. According to Saxon (2006), the wilting point is 26% and field capacity 43%.

Table 1: Soil Physical and Chemical Results of the Experimental Site

Soil depth /cm	Soil structure, shape, size, grade	Surface layer (0-25 cm)				
		OM Walkle & Black %	BD g/cm^3	pH H_2O 1/2.5	T.N Kjeldal %	Exch.P Olsen PPm
>100	Bloky, coarse, strong	1.54	1.63	7.05	0.10	31.38

Rainfall and Crop Water requirement

Most of the rainfall in the study area occurs within two months from the end of June to early September, which is challenging for crop production. Because maximum rainfall occurrence at the early stage of the crop growth has, potential to a water logging consequently stunted growth of the crop. However, onwards at the beginning of September the amount of rainfall goes below the crop demand, which causes water stress for the crop. Figure1 below represents average 10 days effective rainfall (Av Ef RF) and the crop water requirement (AvEtc) in the crop growth period from late June to early December of the year 2015 and 2016. The figure clearly showed that from late June to early September the amount of RF in the area is higher than the CWR whereas afterwards it is below the crop water demand. The overall climatic water balance of the area is also indicated in Figure 2, and it shows that based on the evapo-transpiration and the amount of rainfall in the area, at which time in the growing season the amount of rainfall satisfied the evaporation need and at which time water shortage can be a case for crop growth. Therefore based on figure 2, from the beginning of September there is water deficit or the amount of rainfall events are below the evaporation demand of the area, which needs especial attention to fill the gap.

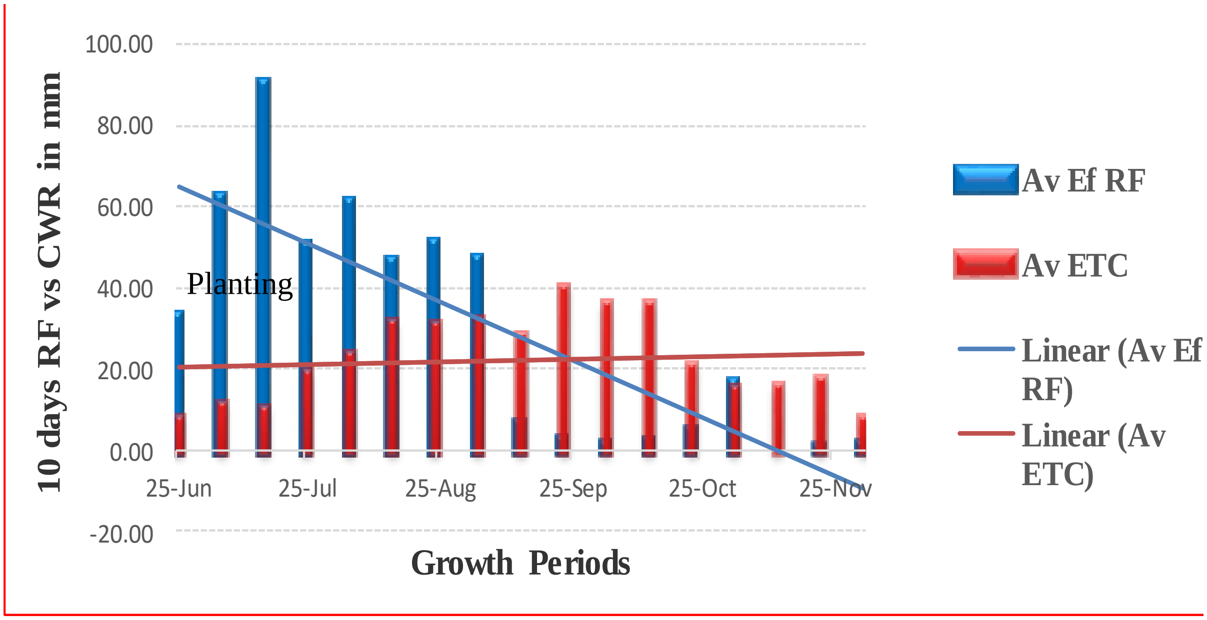

Figure 1. The Amount of Effective RF in the area Vs CWR of Sorghum in 2015 and 2016 growth periods

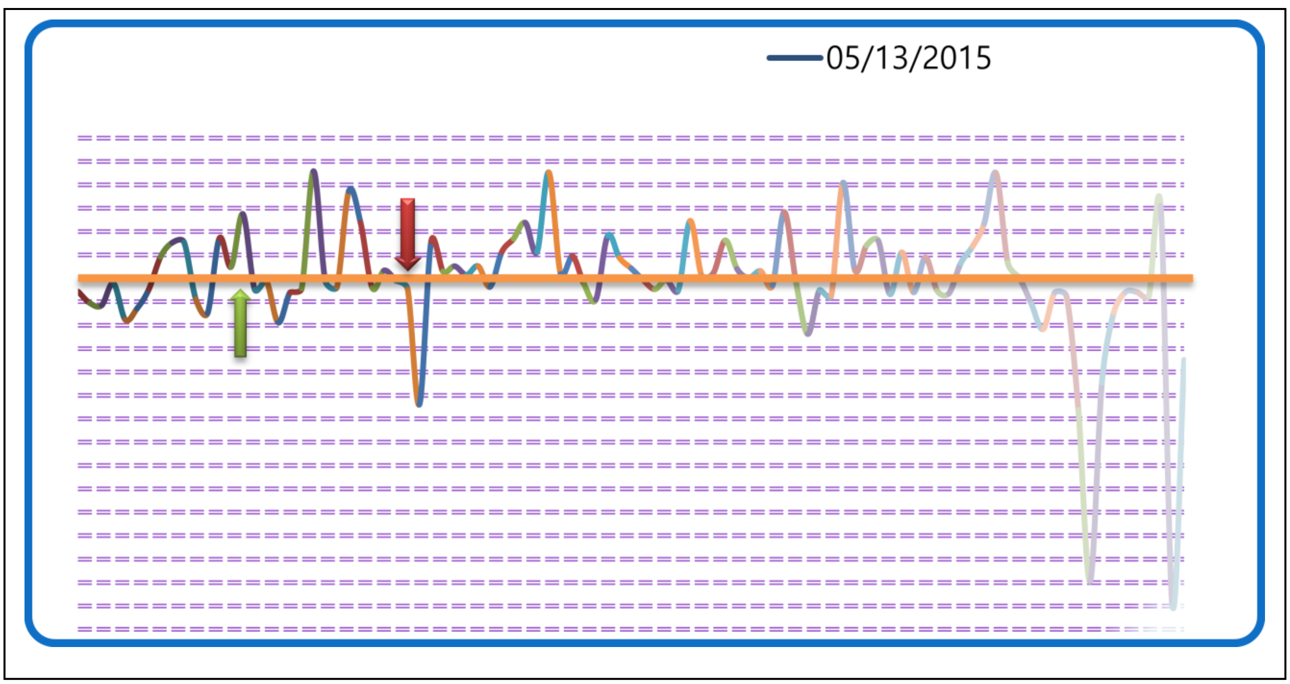

Figure 2. Climatic water balance of G-Maksegnit watershed in 2015

Results and Discussions

Soil moisture variability

As explained in figure 1, variability of rainfall during the growing period results variability in soil water content, therefore, soil water content (SWC) was monitored at different time during the growth time of the crop and presents here. Figure 3 represents minimum and maximum SWC (%) and coefficient of variation (CV %) during the growing season of the crop. It showed that, higher minimum and maximum soil moisture was observed at treatment that tied ridge throughout (t1) in the top 0-20cm soil profile. Similarly, a study in the Northern part of Ethiopia revealed that tied-ridging before or at planting resulted in the best soil water status throughout the season (Brhane, *et al.*, 2006). The higher soil moisture is, may be, due to high opportunity time to infiltrate water into the soil without drained. This treatment has lower coefficient of variation among the observed soil moisture contents in the soil depth 20-40cm. Soil moisture sampling results a range of soil water content (percentage) from above field capacity to wilting point. Commonly in poor drainage soils, soil water status can stay above field capacity for more than 24 hours after effective rain and the soil water content monitoring results (Figure 3) agrees with this argument.

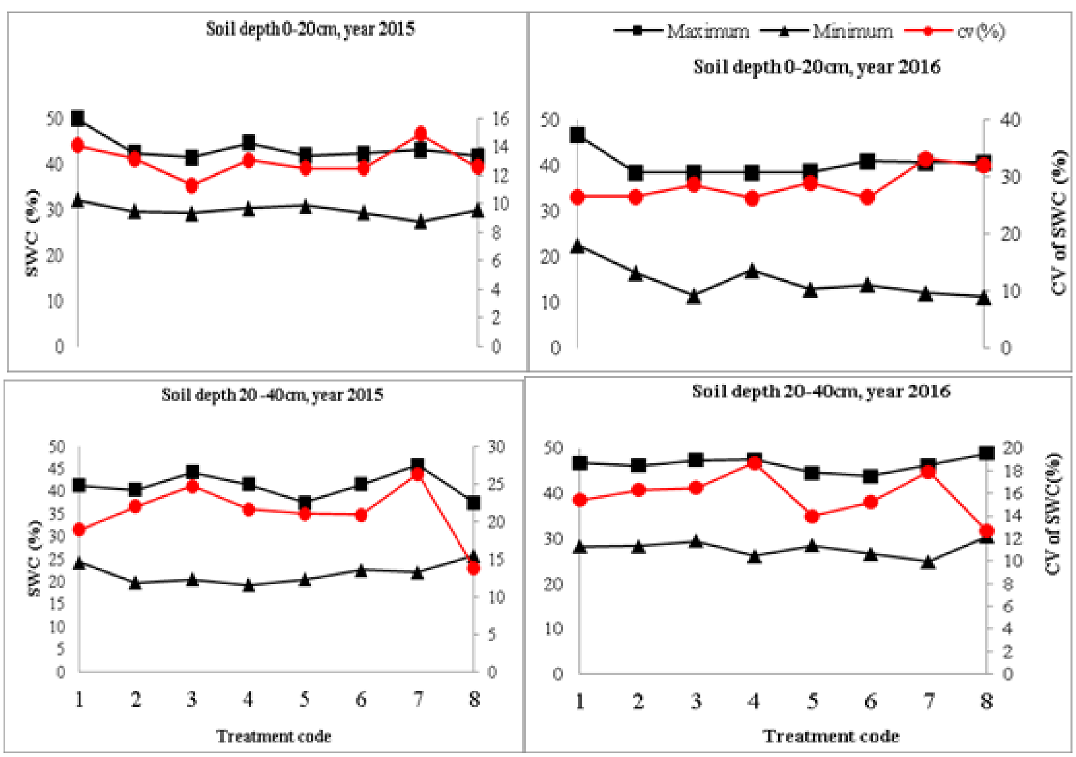

Figure 3. Soil moisture status during the growing period

As presented in Fig.3, the change of soil moisture at the upper soil profile (0-20cm) is dynamic due to its exposure to the atmosphere, where wet and dry conditions simply affect the top soil layers soil moisture level. At 20-40cm soil depth range, the practices of ridging and tied ridging increased soil water status because of the opportunity time variation for water infiltration. If the ridge is tied before the excess rainfall event, water pond in the ridge can increase cumulative infiltration. Then the cumulative infiltration wet the subsoil layer.

Higher coefficient variation of soil moisture was recorded on t7 ‘flat at planting and tied ridge eight weeks after planting'. This variability may arise from the fact that this treatment was flat for two months but after that, tied-ridging was applied and may face to quick wetting during wet day after the later practice employed than the previous flat situation. In addition, variability among treatments may arise, because of the nature of the treatments where some tied ridges or open ridges, at the time of planting whereas others exposed to ridging, or tied ridging later after planting. Biazin , et al., (2012) stated that in heavy rainfall seasons, tied-ridging could cause water logging on maize and sorghum, so this can cause soil moisture variability among treatments. Similarly, Temesgen (2007) found that the interval between tied-ridging and sowing has affected water conservation efficiency.

Grain and Stover Yield of Sorghum

The results (Table 2 and 3) showed that in 2014 growing season a significant highest grain and stover yield were obtained at which sorghum was planted at flat land, ridging after three weeks and tied 6 weeks after planting. While, the least yield was obtained at tie ridging and ridging was done at the time of planting. The 2nd year result 2015 (Table 2) showed that flat planting and tie-ridging three weeks after planting, and tied six week after planting gave a highest significant yield while similar to in the 1st year, riding and tie riding at planting (i.e. treatment 1 and 2) gave the least yield. This result is linked to the crop water requirement and the amount of precipitation during the early stage of the plant growth. In the second year, all the treatments gave a maximum yield, which could be due to the amount of precipitation reduced from 1015mm in the 1st year to 600mm in the 2nd year due to climate variability in this particular year. It was observed that the second season was suitable for sorghum growth and overall yield was maximum during this year than the previous year. The third year result (Table 2) there was no significant difference among treatments of tie ridging however, maximum yield was obtained at treatment planted at flat land, ridged after three weeks and tied nine weeks after planting.

The three years combined result showed that significantly higher grain yields were obtained at which sorghum was planted at flat land, ridged after three weeks and tied 9 weeks after planting. While, the least yield was obtained at tied ridging and ridging was done at the time of planting. This could be related to the rainfall distribution in the area, which is variable (Figure 1). In line with our result, a study in Tanzania showed that the effect of tied ridging was both positive and negative on maize yield, with the positive effect dominating at near-normal rainfall whereas the negative effect dominated at annual rainfalls above 700-900 (Jensen et al., 2003). A similar concept was found by Biazin B., et al., (2012) who stated that in heavy rainfall seasons, tied-ridging could cause water logging on maize and sorghum. Temesgen (2007) investigating that in the semi-arid Rift Valley of Ethiopia, the interval between tied-ridging, sowing has affected water conservation efficiency, and the maize yield negatively influenced under minimum rainfall at the time tie ridging.

Contrary to our results, (Brhane et al., 2006) who argued that tied ridging before or at planting in arid areas of Tigray region, Ethiopia; resulted with optimum soil water status and improved the performance of a crop compared with tied ridging after planting. However, this difference may be come from, the difference in rainfall distribution and topography differences of the two areas. A highest significant yield increment was obtained in closed end tie ridging practices than farmers flat land planting practices by (Gebrekidan, 2003; Demoz, 2016; Brhane, 2017; Bicolor et al., 2019). However, the papers did not discuss on the timing of tie ridging. Our experiment set up was based on the nature of rainfall distribution in the study area and it identified tied ridging can increase yield when it tie at appropriate time.

Table 2: Effect of timing of tie ridging on sorghum grain yields

Treatments	**2014**	**2015**	**2016**	**Combined**
Tied ridging at planting	3.77	4.25	3.00	3.38
Riding at planting and tied ridging at full stand	3.40	4.46	2.90	3.17
Flat at planting, tied ridging after 3 weeks	4.39	4.65	2.77	3.57
Flat at planting, ridging after 3 weeks and tied ridging after 6 weeks	4.49	4.93	2.75	3.62
Flat at planting, ridging after 3 weeks and tied ridging after 9 weeks	4.40	4.43	3.31	3.85
Flat at planting, ridging after 3 weeks and tied ridging after 12 weeks	3.95	4.51	2.98	3.45
Flat at planting, tied ridging after 8 weeks	4.14	5.12	2.98	3.57
CV (%)	9.88	13	11.1	10.24
LSD (0.05)	0.7	1.09	ns	0.43

Table 3: Effect of timing of tie ridging on sorghum Stover yields

Treatments	**2014**	**2015**	**2016**	**Combined**
Tied ridging at planting	12.00	11.14	5.07	9.39
Riding at planting and tied ridging at full stand	10.99	11.77	5.11	9.29
Flat at planting, tied ridging after 3 weeks	14.26	13.50	4.80	10.88
Flat at planting, ridging after 3weeks and tied ridging after 6 weeks	15.67	12.47	4.62	10.91
Flat at planting, ridging after 3 week and tied ridging after 9 weeks	13.33	12.91	5.36	10.53
Flat at planting, ridging after 3 weeks and tied ridging after 12 weeks	13.00	13.91	5.51	10.81
Flat at planting, tied ridging after 8 weeks	12.33	13.48	5.53	10.45
CV (%)	12.85	20	6.9	16.96
LSD (0.05)	2.99	ns	ns	1.67

Conclusions and Recommendations

Timing of ridging and tie-ridging has significant effect on sorghum yield in the 1st and 2nd year of experiment while in the 3rd year there was no significant influence on sorghum grain and stover yields. The three years combined analysis results showed that there were a significant difference among treatments on grain and stover yield of sorghum. Among the treatments flat plating, ridging three weeks after planting and tied 9 weeks after planting gave the maximum grain yield. While, the least grain yield and stover yield were obtained at treatment 1 and 2 at which the tied-ridge and ridged were done at the time of planting respectively. All in all this study magnifies that time of ridging and tie ridging is important to manage sorghum planting on vertisols in areas like Gundar Zuria. Therefore based on the three years experimental result, it is recommended that flat land at planting, ridging 3 weeks after planting and tied 9 weeks after planting can be a useful technology for the woreda and similar areas.

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