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Full Length Research Paper

Carbon sequestration potential of East African Highland Banana cultivars (*Musa* spp. AAA-EAHB) cv. *Kibuzi, Nakitembe, Enyeru* and *Nakinyika* in Uganda

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Despite the global interest to increase the world's carbon stocks, most carbon sequestration strategies have largely depended on woody ecosystems whose production is threatened by the continuous shortage of land, hence the need to explore viable alternatives. The potential of bananas to sequester carbon has been reported but there is limited knowledge on the performance of various cultivars as specific carbon stocks are often lost in global assessments. Therefore, this study aimed at exploring the potential of and variability in carbon stocks of selected East African Highland Banana (EAHB) cultivars. Plant and soil data were collected using destructive and non-destructive techniques in 30×30m^2 sampling plots for 4 cultivars *Kibuzi*, *Nakitembe*, *Enyeru* and *Nakinyika* growing in two agro-ecological zones of Uganda being the L.Victoria Crescent and the South-western region. Total carbon and Soil Organic Carbon (SOC) stocks did not differ considerably across cultivars (P>0.05). However, there was significant variation (P<0.05) in plant carbon stock being lowest in two cultivars: *Nakinyika* at 0.37±0.19 Mgha^{-1} and *Nakitembe* at 0.40±0.19Mgha^{-1}; and highest in *Enyeru* at 1.64±0.18 Mgha^{-1}. The SOC stock variation difference across depth was 2.9-8.5 Mgha^{-1} being higher in top soil than sub-soil. Despite the small plant carbon stock amounts, the system enables much more carbon to be stored in the soil considering the proportion of what is contained in the plant to that in the soil across all cultivars (0.4-2%). The study therefore recommends revision of existing carbon frameworks to incorporate the contribution of non-woody perennials like bananas in the carbon cycle so that the poor small scale farmers who cannot afford large acreages to establish tree plantations can also benefit from such initiatives.

Key words: Agro-ecological zone, growth stage, carbon stock, cultivars, SOC

INTRODUCTION

Developing adaptation and mitigation strategies for addressing global climate change has become an increasingly important issue influencing management of ecosystems around the world. Among other management approaches being proposed to mitigate climate change, the need to enhance carbon stores in the biosphere (Nair et al., 2009; Anthony et al*.,* 2011) through carbon sequestration has gained momentum in recent years especially in agro-ecosystems (Lal, 2011).

Despite the global interest to increase the world's carbon stocks, most carbon sequestration strategies have largely depended on woody ecosystems given their quickest means of increasing above ground carbon stocks (Henry et al*.,* 2009; Nair et al., 2009). However, studies have shown that land available for production of such systems is continuously becoming limited (Henry et al., 2009); perhaps due to the increasing demand for agricultural production to meet food requirements of the ever increasing population. Hence, the increasing limitation of land calls for a need to explore viable alternatives such as the use of appropriate crops as well as good land management strategies that lead to increased carbon retention (FAO, 2002). Given the perennial and morphological nature of a crop like banana, it is worthwhile exploring its contribution to the carbon cycle. Moreover, its production ensures proper environmental management in addition to contributing to poverty eradication and food security (AATF, 2009; Rodel et al., 2000).

Other globally recognized mitigation options include: improved agricultural land management and agronomic practices, restoration of organic soils and rehabilitation of degraded land (Aertsens et al., 2013). In order to meet the ultimate objective of United Nations Framework Convention on Climate Chang - UNFCCC (Hairiah et al*.,* 2010), it calls for trade-offs between increasing carbon stocks and livelihood needs so as to create a win-win situation; like a high net benefit obtained from crop production and sequestration (Palmer and Silber, 2012). This is in line with the World Bank report (2012) that calls for the need to ensure that new climate change adaptation and or mitigation strategies proposed are compatible with emerging economic challenges. This, therefore, puts agricultural research and development efforts geared towards identifying and evolving strategies against climate change at the fore front.

Uganda is one of the largest national producers and consumers of bananas in the world ranking second and first respectively after India. It is also recognized as a secondary center of diversity with different observed cultivars on individual farms with over 75% being East African Highland Bananas (Suzanne and Emile, 1999; Edmeades et al*.,* 2005; FAO, 2009, Karamura, 1998; Nantale et al., 2008). Banana farming system dominates Uganda's cropping system (Bagamba et al*.,* 1999; Kamanyire, 2000). The perennial banana crop is an important food security crop cultivated in a wide range of agro-ecological zones and readily fruits throughout the year (NARO, 2001; Eledu et al*.,* 2004; Wairegi, 2010). The crop has viable economic benefit as a source of income for smallholder farmers in many parts of the country (AATF, 2009). The banana crop occupies the greatest acreage of land utilized for agricultural production covering about 38 % of the total arable land with most of the production on small subsistence farms of less than 0.5% ha (Gold et al*.,* 1998; Svetlana et al., 2006). The crop is mostly grown as a mono-crop and or commonly intercropped with perennial or annual crops (Svetlana et al., 2007).

The potential of banana to sequester carbon has been reported with a carbon storage capacity of 114.72 $mgha^{-1}$ (Rodel et al*.,* 2000; Christina, 2004; Oliver, 2009). However, there is limited knowledge on how much carbon the different cultivars sequester considering the high morphological and physiological differences among cultivars within the *Musacea* family.

Despite their importance in climate change mitigation, the potential of non-woody plants to sequester carbon in agro-ecosystems has generally received little attention (Mesele et al*.,* 2013). This could perhaps be attributed to the fact that agricultural ecosystems have been known for the depletion of important terrestrial carbon pools such as Soil Organic Carbon (SOC), thereby creating a large carbon debt (Lal, 2011). On the contrary, the banana crop has a high potential to restore such lost carbon pools because its agronomic management practices do not involve disastrous processes like burning biomass and removal of plant residues (Joris et al., 2013). This study, therefore, sought to explore the variability in plant and soil carbon stocks of selected EAHB cultivars grown in Uganda.

MATERIALS AND METHODS

Study area

Plant and soil carbon data were obtained in 2013 from two distinct agro-ecological zones, that is, the Lake Victoria Crescent and South-western Grass Farmlands in Lwengo and Mbarara districts, respectively. The zones were selected because they were classified as potential banana production areas by Eledu et al*.,* (2004). Data was specifically obtained from Kisekka and Nyakayojo sub-counties for Lwengo and Mbarara districts, respectively (Figure 1). The districts were based on consultation with local agricultural authorities who identified them as important banana growing areas, while the sub-counties were based on a reconnaissance study conducted in these districts in December 2012 that identified them

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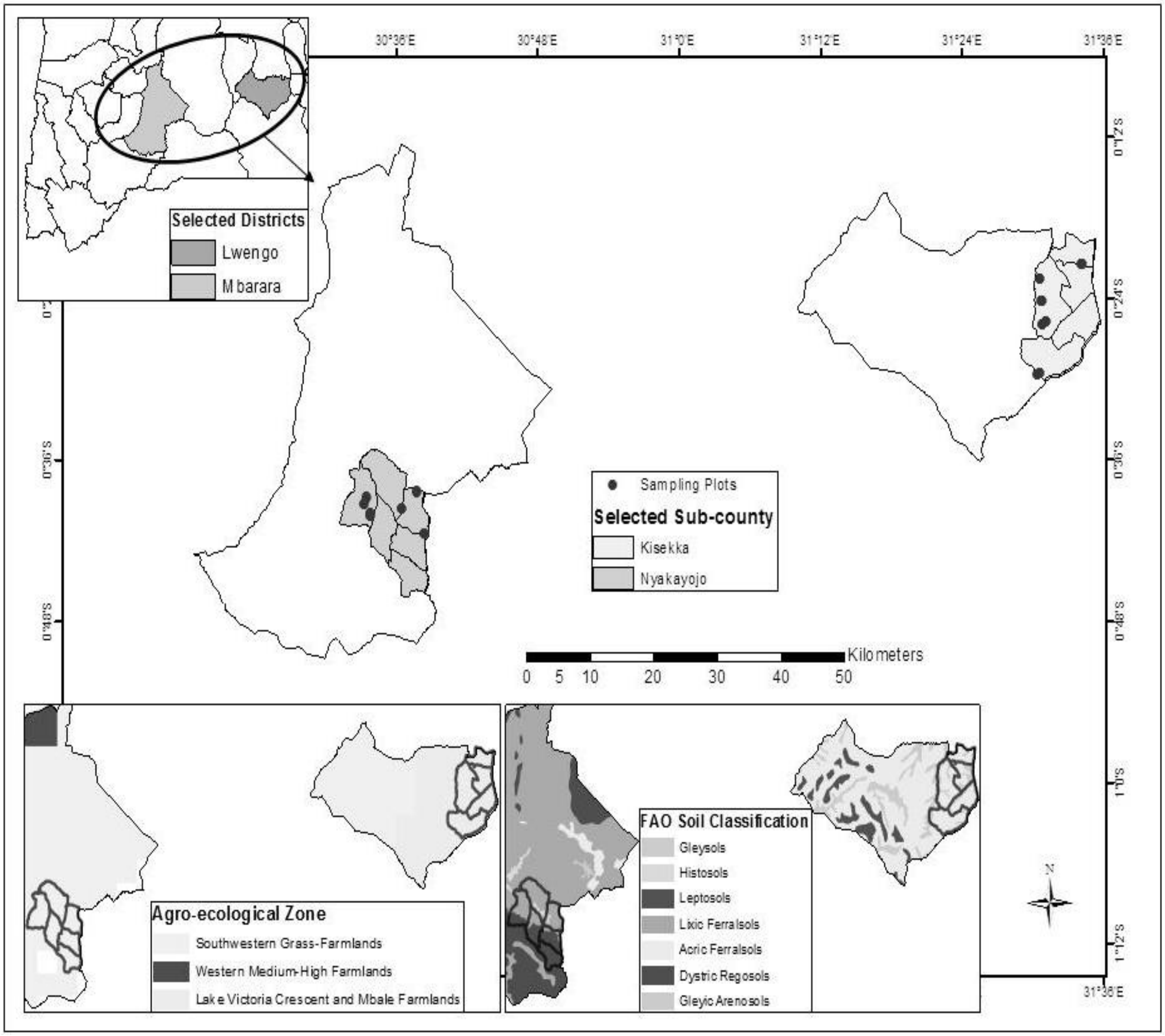

Figure 1. Detailed map of the study area showing sampling plots.

as the highest banana producing areas in the respective districts. Mbarara district lies at a high altitude of about 1400 m above sea level (0°20.5'S 30°31'E) and Lwengo at a low altitude range of 1080-1330 m above sea level (00°24'S 31°25'E) (NEMA, 1997; Nantale et al., 2008; Kemigabo and Adamek, 2010). Both areas experience a bimodal mean annual rainfall range of about 1000-1500 mm (Lwengo) and 1000-1200 mm (Mbarara). Their mean annual temperature range lies between 20-25ºC. According to the 1998 FAO soil classification (FAO, 1998), the soil types are acric ferralsols, and dystric regosols; and lixic ferralsols for Kisekka and Nyakayojo, respectively (Figure 1). However, to minimize variability across regions, all farms selected were comprised of the ferralsol soils given that they are deep in nature and cover about 60% of the potential banana production area for Uganda (Eledu et al., 2004).

Farm site selection

Prior to data collection, a reconnaissance survey was carried out in the proposed study areas in December 2012 to obtain a clear understanding of what cultivars are grown by the farmers as well as some physical and historical characteristics of the plantations; such as soils, altitude and plantation age. Based on the preliminary findings of the survey and with the aim of minimizing the effect of potential confounding factors, participating farmers were purposively selected following a set of criteria: a) The farm had all the cultivars of interest; b) The plantation was mature (20 to over 50 years); c) All farms in a given region existed in a similar soil type classification and relatively same altitude range; and d) The farmer was willing to participate fully in the study. (b) and (d) were also considered for the same reason in other studies (e.g. Nantale et al., 2008; Wairegi et al., 2009). Therefore, out of 58 visited farms, a total of 14 farmer plantations (7 in each area) were considered since they were the only ones meeting the above criteria.

Sampling plots

Considering the differences in plantation sizes ranging from 0.4 ha to about 3 ha, 2 squared sampling plots of 30×30 m were established randomly on each farm using a measuring tape and plot demarcation stakes. This was also done because banana plantations have low variability in terms of species composition in a single stand (Timothy et al., 2005; Hairiah et al., 2010). Sample plot center coordinates were also geo-referenced and mapped in the field using a GarminGpx60 GPS instrument (±3 Accuracy). A total of 28 sampling plots were established, 14 per site.

Biomass estimation

In reference to the findings of the reconnaissance survey, only 4 cultivars were chosen for the study; that is, *Kibuzi* and *Nakitembe* existing in both sites, and *Enyeru* and *Nakinyika* being unique to Mbarara and Lwengo sites, respectively. These were selected because they had a higher population density than others cultivars identified, similar to observations of Wairegi et al. (2009). In each sampling plot, all individuals belonging to the cultivars of interest were inventoried *in-situ* (ICRAF, 2011). Using a diameter tape, Diameter at Breast Height (DBH) measurements were recorded for the estimation of total plant biomass using cultivar specific allometric equations developed by Kamusingize (2014).

Soil organic carbon sampling

Banana plants invest carbon in the soil through nodal roots that arise from the corm (Turner, 2003). Therefore, composite soil samples were collected from underneath cultivars of interest for SOC determination. Composite samples were obtained from 4 points around one mat per cultivar, randomly selected in each sampling plot, drawn using a soil auger at 2 depth levels of 0-15 cm and 15-30 cm following sampling procedures by Hairiah et al. (2010) in the plant's rhizosphere, 30 cm from the mat. Using a fabricated core of 15 cm height and 4.3 cm diameter, two samples were also systematically drawn at 2 points from each selected mat at the same depth levels for average bulk density analysis. In total, 296 bulk density samples were obtained (148 per site) and 148 composite samples (74 per site). Samples were analyzed at the National Agricultural Research Laboratories Soil Science Department using procedures laid out in Okalebo et al. (2002); that is, SOC concentration by the wet acid oxidation method and bulk density by the core method. Prior to analysis, all samples were oven dried at 40°C. Samples for SOC analysis were ground to powder and passed through a 1 mm sieve after removing all identifiable roots, stones and any crop materials.

Estimation of carbon stocks

Total carbon stock per cultivar was obtained from both plant and soil carbon stocks. Plant carbon stock was estimated using the equation described by Christina (2004) with modification whereby;

$$Plant\ Carbon\ Stock\ \left(Mgha^{-1}\right) = Total\ Plant\ Biomass\ \left(Mgha^{-1}\right) \times C_B\%......\text{Eqn 1}$$

Where C_B was equal to 47.6% (before flowering – H1) and or 48.8% (at maturity – H2), mean carbon content value of EAHB cultivars at different growth stages as determined in a study by Kamusingize (2014). SOC was estimated using the equation obtained from Anderson and Ingram (1993) and Hairah et al. (2010) as:

$$C\ Storage\ in\ Soil = \%C\ Concentration \times Bulk\ Density \times Soil\ Depth.....\text{Eqn 2}$$

$$C\ Storage\ in\ Soil\ per\ hectare\left(Mgha^{-1}\right) = \frac{Result\ Eqn2}{Area\ of\ Subplot} \times 10000\ ......\text{Eqn 3}$$

Therefore, total carbon stock per cultivar was then estimated based on an equation adopted from Woomer and Palm (1998) as:

$$Total\ Carbon\ Stock\ (Mgha^{-1}) = \sum Eqn1 + Eqn3......\text{Eqn 4}$$

Data analysis

All data were statistically analyzed using GenStat software (v.13.3.5165) to ascertain the variability of carbon stocks across cultivars. One Way ANOVA was performed to test for any significant differences, if any, in plant carbon stock, SOC stock and total carbon stock across cultivars at a 95% confidence interval. Mean values of the various carbon stocks per cultivar per site were also determined. The proportion of plant to SOC stock was also determined for all cultivars to establish how much carbon stock iscontained in the banana plant compared to that in the soil.

RESULTS

The observed variation in cultivar specific carbon stocks from the 2 sites under study are presented in Tables 1, 2 and 3. There were significant differences (P<0.05) in plant carbon stocks across cultivars (Tables 1 and 3). However, SOC stock and total carbon stocks were not significantly different (P>0.05) across cultivars (Tables 2 and 3). The highest total carbon and SOC stocks were observed in site specific cultivars *Enyeru* and *Nakinyika* (Table 3). On the contrary, cultivar *Nakinyika* (at 0.37 ± 0.19 $Mgha^{-1}$) and *Nakitembe* (at 0.40 ± 0.19 $Mgha^{-1}$) had the lowest total plant carbon stock in Lwengo and Mbarara, respectively. Results for the 2 cultivars common to both sites -*Kibuzi* and *Nakitembe* showed higher total plant carbon stock in Lwengo than that obtained in Mbarara (Table 3). Furthermore, the mean variation observed in plant carbon stock before flowering and at maturity stages was very small and in some cultivars zero (Table 1).

The total SOC stocks underneath all cultivars studied was high with over 81 $Mgha^{-1}$ (Table 3). However, there were SOC stock differences across soil depth with more carbon stored in the top soil (0-15 cm) than in the sub-soil (15-30 cm). In terms of studied cultivars, the least SOC stocks were obtained in site common cultivars compared to site specific cultivars (Table 2). In addition, the % contribution of plant carbon stock to total carbon stock in all cultivars was very small (0.4-2.0%) compared to that obtained from the soil (Table 3).

Table 1. Variation of plant carbon stock at two growth stages across cultivars.

Site	Cultivar	Mean Carbon Stock before flowering±95%CI(Mgha^{-1})	Mean Carbon Stock at maturity±95%CI (Mgha^{-1})	Mean Plant Stock Difference±95%CI (Mgha^{-1})
	Kibuzi	0.06±0.01	0.04±0.01	0.02
Lwengo	*Nakitembe*	0.03±0.01	0.02±0.01	0.01
	Nakinyika	0.03±0.01	0.01±0.00	0.02
	Kibuzi	0.04±0.01	0.04±0.01	-
Mbarara	*Nakitembe*	0.02±0.01	0.02±0.00	-
	Enyeru	0.09±0.01	0.06±0.01	0.04

Table 2. Variation of SOC stock with soil depth across cultivars.

Site	Cultivar	Mean SOC Stock±95%CI 0-15 cm (Mgha^{-1})	Mean SOC Stock±95%CI 15-30 cm (Mgha^{-1})	Mean SOC Stock Difference±95%CI (Mgha^{-1})
	Kibuzi	43.95±4.23	37.48±3.19	6.5
Lwengo	*Nakitembe*	46.34±2.59	42.34±4.07	4
	Nakinyika	50.20±3.25	42.27±3.26	7.9
	Kibuzi	42.72±2.94	39.32±3.26	3.4
Mbarara	*Nakitembe*	44.11±3.66	41.22±4.45	2.9
	Enyeru	49.51±3.17	41.01±2.68	8.5

Table 3. Means of total carbon stocks across cultivars.

Site	Cultivar	Total Plant Carbon Stock±95%CI (Mgha^{-1})	Total SOC Stock±95%CI 0-30 cm (Mgha^{-1})	Total Carbon Stock±95%CI (Mgha^{-1})	Proportion of Banana/Soil (%)
	Kibuzi	1.03±0.19	81.4±5.06	82.5±5.05	1.3
Lwengo	*Nakitembe*	0.54±0.21	88.7±5.77	89.2±5.76	0.6
	Nakinyika	0.37±0.19	92.5±5.27	92.8±5.26	0.4
	Kibuzi	0.85±0.21	82.0±5.77	82.9±5.76	1.1
Mbarara	*Nakitembe*	0.40±0.19	85.3±5.06	85.7±5.05	0.5
	Enyeru	1.64±0.18	90.5±4.88	92.2±4.87	2

DISCUSSION

Although there are no significant differences in total carbon stock across the studied banana cultivars (Table 3), the values were considerably higher (82.5 ± 5.05 - 92.8 ± 5.26 Mgha^{-1}) than those reported for Eucalyptus dominated woodlots (63.8 Mgha^{-1}) and perennial crops of *Allophylus africanus* (49.6 Mgha^{-1}) in Eastern Uganda, Sirike (2012). However, the total plant carbon stock across cultivars was small (0.37-1.64 Mgha^{-1}) compared to that reported in some perennial crops such as cocoa at 9 Mgha^{-1} in Above Ground Biomass stock (Eduardo et al., 2013) and banana (*Musa sp.*) at 3.0-3.1 Mgha^{-1} which dominate home gardens in Western Kenya (Henry et al., 2009). This could perhaps be attributed to the high cultivar diversity on a given banana plantation (Karamura, 1998) affecting the overall number of individuals assessed per cultivar per farm which in turn result in relatively small biomass amounts as shown in Figure 2; e.g. *Nakitembe* and *Nakinyika* in Mbarara and Lwengo, respectively. This also explains the small variation difference in plant carbon stocks across growth stages given that the number of mature plants (H2) assessed in the field were on average lower than that of plants at pre-

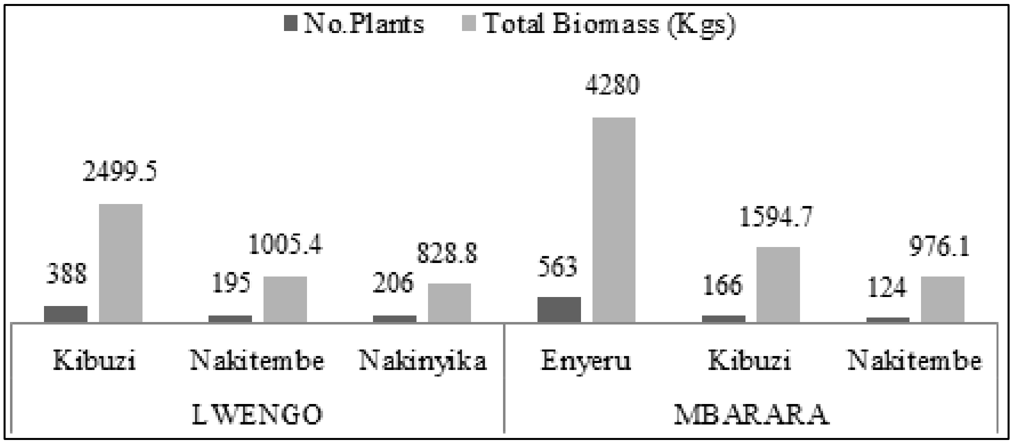

Figure 2. Number of plants and biomass assessed per cultivar.

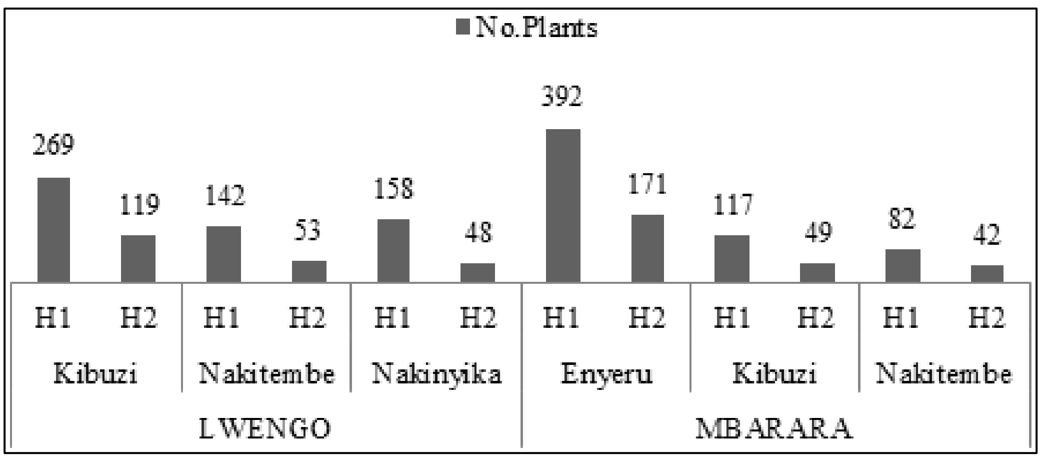

Figure 3. Number of plants assessed per cultivar across growth stage.

flowering stage (H1) (Figure 3). This could also perhaps explain the significantly different result of plant carbon stock ($P<0.05$) across all cultivars. But also, more importantly to the fact that banana as a crop contains a high moisture content (Jing et al., 2010) resulting in small amounts of plant dry biomass which in turn give small plant carbon stocks.

Though not significantly different ($P>0.05$), the total SOC stock beneath all cultivars was considerably high ranging from 81-92 Mgha^{-1}. This is in agreement with previous reports showing that banana plants not only invest carbon into the soil through nodal roots that arise from the corm but also over time during photosynthesis as carbon moves from the vegetative canopy into the soil (Turner, 2003; Hairiah et al., 2010). Results from this study show that EAHB are capable of sequestering higher carbon stocks in the soil compared to the stocks estimated in Eucalyptus dominated woodlots in Eastern Uganda at 55.4 Mgha^{-1} (Sirike, 2012), tea plantations at 69 ± 10.0Mgha^{-1} and the natural forest at 68.6 ± 14 Mgha^{-1} in South Western Uganda (Twongyirwe, 2010; Twongyirwe et al., 2013). However, soil carbon stocks estimated from EAHB plantations were similar to that obtained in *Patula* pine plantations of Columbia at 87.2 Mgha^{-1} (Juan et al., 2010). Results obtained from this study therefore place banana cultivars close to woody species in the SOC stock spectrum.

The banana cropping system enables much more carbon to be stored in the soil despite the fact that banana cultivars contain small average amounts of plant carbon stocks. In this study, the proportion of carbon contained in the plant to that in the soil across all cultivars was in the range of 0.4-2%. Large soil carbon stocks in banana cropping systems under study could perhaps be attributed to the sustainable agricultural land management practices employed by farmers such as mulching, the use of trenches to minimize erosion, minimal or no tillage and the return of crop residues - leaves, stem cuttings and banana peelings (Lal, 2011; Paswel et al., 2012; Joris et al., 2013).

Investing in proper management of banana plantations is invaluable towards contributing to SOC as a major carbon pool in agro-ecosystems. Considering that EAHB cultivars cover 75% of the total area under banana production in Uganda (Gold et al*.,* 1998; Nantale et al., 2008), banana cropping systems therefore need to be revised to incorporate species as EAHB whose significant contribution towards a major carbon pool has for years gone unnoticed. In addition, climate change mitigation and adaptation efforts like the Clean Development Mechanism (CDM) framework should be considered to improve investments in smart agricultural practices like proper management of banana plantations. This is because the CDM framework tends to be economically benefitial to activities under afforestation/re-afforestation through say carbon trade (UNFCCC, 2004), while under estimating the sequestration potential of non-woody but important perennials like banana cultivars.

Existing reports from a study conducted in Sub Saharan Africa show that it is cheaper and better for small scale farmers to adopt environmentally beneficial agricultural practices that also enhance productivity under a carbon payment system rather than subsidies on agricultural inputs (Paswel et al., 2012). Therefore, given that bananas contribute substantially to food security and poverty reduction in Uganda (Eledu et al., 2004), large scale production of banana cultivars that lock more carbon into the soil could be proposed and promoted as an accommodative adaptation and mitigation strategy to climate change as well as rural development.

CONCLUSIONS

Key findings from this study showed a significant difference in total plant carbon stock (P<0.05) across different cultivars and sites. Plant carbon stock was also found to be very small ranging between 0.37-1.64 $Mgha^{-1}$, yet SOC was considerably high 81.4-92.5 $Mgha^{-1}$. In all banana cultivars evaluated, the proportion of carbon contained in the plant to that in the soil was only 0.4-2%. Nevertheless, despite the small amounts of plant carbon, the banana cropping system was found to enable much more carbon to be sequestered into the soil to amounts comparable to tree plantations.

RECOMMENDATIONS

Emphasis should be put on proper management of existing and or establishment of more banana plantations constituting more EAHB cultivars to enhance SOC stocks. Due to high sequestration into the soil, banana cropping systems have potential to benefit small scale farmers in terms of carbon initiatives that have presently gained momentum for woody species. In addition, enhancing carbon stocks will have a significant contribution towards global efforts to mitigate climate change without compromising food production and economic development. Finally, future studies on carbon sequestration in banana cropping systems could consider exploring factors like slope, management practice, landscape positioning and cropping systems to ascertain their effect on SOC variability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of applying different ratios of compost made of municipal solid waste on the growth of *Zea mays* L. (Corn)

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Since composts are soil like amendments made from plant and animal remains, they are more important than inorganic fertilizer because they consist of relatively stable decomposed materials resulting from accelerated biological degradation of organic matter. However, little attention has been paid on the use of compost as bio-fertilizers to improve soil structure, fertility and consequently growth and productivity of plants among farmers in Sri Lanka mainly due to lack of awareness on the beneficial effects. Therefore, the present study focuses on obtaining baseline data set on the efficacy in terms of plant growth characteristics by using different soil compost ratios of different types of composts. Four different types of composts and three different soil compost ratios (1:0.5, 1:1 and 1:1.5) were used in this study. Results of the present study clearly indicated that different composts act differently on the growth parameters tested and showed a reasonable variation with different soil compost ratios indicating both positive and negative effects on plant growth and yield. The results showed that the best soil compost ratio that could be used to significantly improve the growth parameters of *Zea mays* is 1:1 followed by 1:0.5. From among the different MSW composts used in this study, the best performance was shown by Dikovita followed by Mihisaru Segregated. This study further highlighted that higher ratio (1:1.5 soil compost) of certain MSW composts was not desirable and showed a negative effect on plant height.

Key words: Aggregate stability, compost, nutrients, phytotoxicity, soil amendment, solid waste.

INTRODUCTION

Approximately, 76% of solid waste can be turned into compost. Municipal Solid Waste (MSW) is a permanent and inexpensive source of organic matter, when there is low organic matter in soil (Zakaria et al., 2014). A survey of MSW compost has reported that on average, 20% of the total C in MSW compost was organic C, 8% carbonate C, and 71% residual C which may have included organic C components (He et al., 1995). It can be also used as a suitable alternative to chemical fertilizers (Singh et al., 2007). Municipal solid waste is largely made-up of kitchen and yard waste, and its composting has been adopted by many municipalities

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(Otten, 2001). Compost is normally produced through the activity of aerobic (oxygen requiring) microorganisms. These microbes require oxygen, moisture, and nutrients in order to grow and multiply. MSW compost increases the aggregate stability of soil through the formation of cationic bridges thereby, improving the soil structure (Hernando et al., 1989). Various experiments have indicated that applications of compost improve plant health, yield and nutritional quality. Research conducted by Lima et al. (2004), demonstrated the beneficial action of compost on the physical and chemical properties of soil and on plant development. Ramadass and Palaniyandi concluded that the amount of nitrate nitrogen and ammonium nitrogen content were found significantly high in enriched compost applied soil (Ramadass and Palaniyandi, 2007). Pant et al. (2012) demonstrated that compost quality impacted on nutrient extraction efficiency, microbial activity, phytohormones and, total nutrient content of the extracts. They also reported that these differences in extract quality in turn influenced growth and tissue mineral nutrient content of pak choi.

Since composts are soil like amendment made from plant and animal remains, they are more important than inorganic fertilizer because they consist of relatively stable decomposed materials resulting from accelerated biological degradation of organic matter under controlled aerobic conditions (Storey et al., 1996). The advantages of compost fertilizer in crop production includes ready availability of nutrient materials, gradual release of nutrients without being wasted through leaching, increased soil drainage, aeration, water holding capacity, nutrient holding capacity. Further, compost application is very popular among farmers as an environmentally friendly fertilizer.

Compost has two main effects on soils, particularly on nutrient-poor soils. It replenishes soil organic matter and supplies plant nutrients (Sanchez-Monderoo et al., 2004). Organic matter plays a crucial role in improving physical, chemical and biological properties of soils. Soil structure can be improved by the binding between soil organic matter and clay particles via cation bridges and through stimulation of microbial activity and root growth (Farrell and Jones, 2009).

From a biological point of view, compost application to soil directly affects both diversity and size of microbial communities as well as enzyme activities, since most of the processes in soil are mediated by enzymes from microbial origin (Böhme et al., 2005). On the other hand, the improvement of soil micro-biota in turn influences plant growth by means of the presence of plant growth promoting substances and the increase of nutrient availability (Ros et al., 2006). Further, some organic materials like compost can increase crop yields due to improved soil through nutrient release during decomposition and mineralization (Otten, 2001). They may also improve soil physical properties such as moisture retention, bulk density and aeration. The positive effect on physico-chemical and biological properties of compost amendments promotes ideal conditions for plant growth and, in turn, improve yield. There are many studies that support this influence (Warman and Termeer, 2005). A wide diversity of raw materials have been used in these studies, although a combination of different wastes is recommended to prevent some detrimental properties of specific materials, which might hamper the composting process (Sánchez-Arias et al., 2008). However, compost quality is not the only factor to be considered for the success of the amendment. Soil properties also play an important role by making necessary adaptation of compost characteristics to the specific soil demands. Sometimes, these demands are better met not by means of improved physico-chemical or nutritional compost properties but through the action of microbial inoculants (Grandlic et al., 2009).

The assessment of compost influence on plant growth can be achieved through different parameters, among them yield, productivity, dry weight of plant, weight and number of fruits, length and weight of stem, shoot and root Carbon, N or P uptake capacity, etc (Warman and Termeer, 2005). Application of compost and bio-fertilizers to improve soil structure, fertility and consequently development and productivity of plants has received little attention either due to the non-availability of compost or non-awareness about the benefits of compost among farmers in Sri Lanka. Further, the production of compost especially at domestic level is significantly low due to the non-availability of suitable user friendly solid waste management methods and research data to prove the efficacy of this valuable resource.

In addition, very few studies have been conducted on the best soil compost ratio to be practised and to recommend under field conditions. As a result, there is a huge void about the awareness of practical application in terms of soil compost ratio and on the recommended doses of organic fertiliser. Therefore, the main aim of the present study is to give some base line data on the effectiveness of applying MSW compost on the vegetative growth of plants using *Zea mays* while making different mixes of locally available MSW compost. Presently, *Zea mays* is one of the fast growing and spreading cash crops in Sri Lanka.

Study area

The study was carried out in pot bags at Phorowatta, Mihisaru compositing facility of the western province waste management authority. The site was located about 35 km to the south of Colombo, the capital of Sri Lanka and is managed by the Western Province Waste Management Authority of Sri Lanka.

Table 1. Some physical and chemical properties of the composts used for this study *(Source: Western Province Waste Management Authority).*

Compost name	pH	EC(dS/m)	Moisture (%)	Org. C %	Total N %	P_2O_5 %	K_2O%	C:N
Agalawaththa	8.6	6.91	15	37.79	0.36	1.3	1.7	28.6
Mathugama	7.8	2.1	36	35.90	0.08	1.3	1.8	38.1
Mihisaru - Seg	8.3	5.25	21	52.26	1.77	1.4	1.7	29.5
Dikovita	7.3	2.6	36	28.17	1.22	1.4	0.6	23.1

Table 2. Effect of compost mixes on vegetative development of *Zea mays.*

Treatment		Plant height (cm)			Stem girth (cm)			Number of leaves			Wet biomass (g)
WAP		4	6	8	4	6	8	4	6	8	8
	1: 0.5	16.33^{a}	59.67^{a}	104.00^{a}	3.67^{a}	6.33^{a}	7.00^{a}	7.00^{a}c	13.33^{a}	16.00^{a}	458.33^{a}
AGL	1:1	17.00^{a}	65.33^{a}	109.33^{a}	3.76^{a}	7.33^{a}	7.33^{a}	6.33^{a}	12.33^{a}	15.33^{a}	516.00^{a}
	1:1.5	22.00^{b}	83.69^{a}	131.33^{a}	5.00^{b}	8.33^{a}	7.33^{a}	8.67c	15.33^{a}	15.33^{a}	449.33^{a}
	1: 0.5	27.33^{a}	91.33^{a}	$153.00.^{a}$	7.67^{a}	10.0^{a}	8.00^{a}	9.67^{a}	14.33^{a}	17.67^{a}	550.00^{a}
DWT	1:1	27.00^{a}	87.0^{ab}	155.67^{a}	6.50^{a}	9.0^{ab}	8.16^{a}	10.33^{a}	15.00^{a}	17.33^{a}	534.33^{a}
	1:1.5	26.33^{a}	75.00^{b}	126.33^{b}	6.33^{a}	8.33^{b}	7.83^{a}	9.67^{a}	14.33^{a}	16.33^{a}	458.33^{a}
	1: 0.5	21.67^{a}	67.00^{a}	116.00^{a}	5.33^{a}	8.67^{a}	8.33^{a}	8.67^{a}	14.00^{a}	16.33^{a}	463.33^{a}
MI-S	1:1	17.67^{a}	50.0^{ab}	114.33^{a}	5.00^{a}	8.00^{a}	7.67^{a}	8.33^{a}	14.33^{a}	15.67^{a}	516.67^{a}
	1:1.5	13.33^{a}	41.67^{b}	97.30^{b}	4.67^{a}	7.67^{a}	7.67^{a}	7.33^{a}	12.00^{a}	15.33^{a}	521.67^{a}
	1: 0.5	16.33^{a}	77.67^{a}	136.00^{a}	5.00^{a}	9.33^{a}	7.33^{a}	8.67^{a}	14.33^{a}	16.67^{a}	535.00^{a}
MTG	1:1	16.67^{a}	66.67^{a}	124.67^{a}	4.73^{a}	9.00^{a}	7.67^{a}	7.67^{a}	13.00^{a}	16.67^{a}	605.00^{a}
	1:1.5	16.33^{a}	69.00^{a}	124.67^{a}	4.67^{a}	8.67^{a}	8.16^{a}	8.76^{a}	14.00^{a}	17.00^{a}	561.67^{a}

Means represented by the same letter along column are not significantly different.

METHODOLOGY

Four locally available MSW compost varieties (Dikovita, Mathugama, Mihisaru Segregated and Agalawatta) which had been prepared by aerobic oxidation using windrow composting technique were used for this study. The plant pots were filled using three soil compost mixes (1:0.5, 1:1 and 1:1.5). Four seeds of *Zea mays* were planted per pot but thinned down to have one seedling per pot two weeks after planting to give ten (10) plant pots per trial. Data on growth parameters (Plant height, stem girth, number of leaves and wet biomass) were recorded at 4, 6 and 8 weeks after planting (WAP).

Data collected were averaged over the two trials before being subjected to statistical analysis of variance and significant means were compared using Duncans Multiple Range Test (DnMRT) at $p<0.05$ confident level.

RESULTS AND DISCUSSION

From the results of the physical and chemical analysis of the soil used for the trial (Table 1), it is obvious that the fertility status of the soil is inherently low, according to the nutrient rating for soil fertility classes in Nigeria (Obigbesan, 2001) and this implies that cropping the soil without the use of soil amendments will not be economical. Variation in nutrient composition of different composts used in this study was similar to those reported by Adebayo et al. (2011) working with organic amendment and its effect on early growth of *Moringa oleifera*. They observed higher nutrient concentrations in compost prepared with the same type of animal droppings but different plant residues, the nutrient composition was in the order *Tithonia diversifolia* compost > *Chromonela odorata* compost > *Celosia cristata* compost.

Effects of different soil compost ratios on the vegetative growth of *Z. mays*

When Agalawaththa (AGL) compost is considered, significant increase in plant height had been recorded for 1: 1.5 ratio of soil and compost only at the 4WAP and no significant difference has been recorded for any other ratios at 6 and 8 WAP (Table 2). However for Dikovita (DWT) and Mihisaru Seg (Mi-S) composts, significant increase in plant height has been observed for 1:1.5 ratio both at 4 and 8 WAP. No significant increase in plant height was recorded for any soil compost ratio at any WAP for any MSW compost except AGL used in this study (Figure 1).

According to the results of the present study (Figures 1 to 4), compost as a soil amendment can have

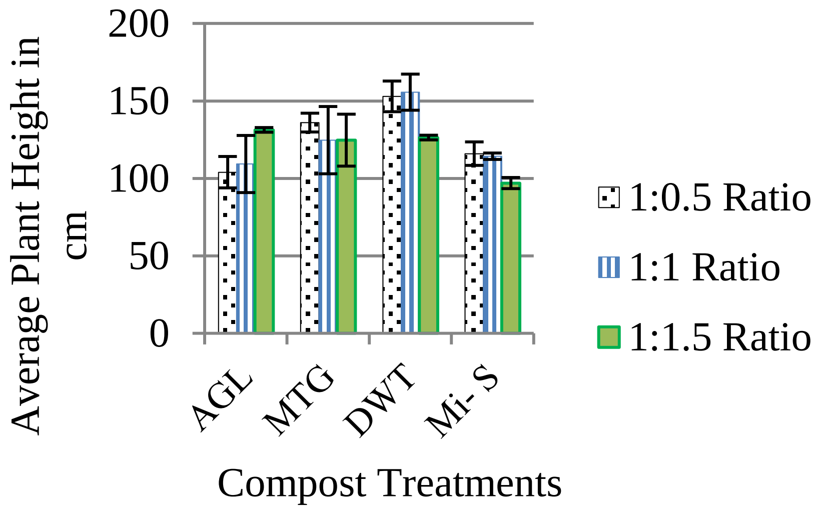

Figure 1. Effect of different MSW compost on plant height at different soil compost ratios at 8 WAP.

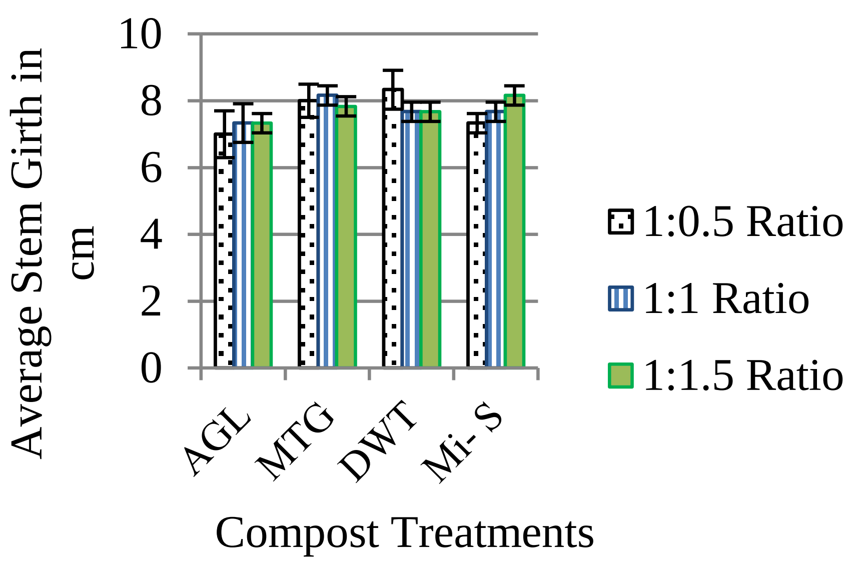

Figure 2. Effect of different MSW compost on stem girth at different soil compost ratios at 8 WAP.

considerable effects on plant growth and yield. However, results were not always positive and can vary depending on rates, compost maturity and available N (Cisar and Snyder, 1992). The results of this study confirm that the significantly beneficial treatment to improve the plant height is 1:1.5 soil AGL compost ratios for the growth of *Z. Mays* at 4 WAP and for Mihisaru Seg and Dikovita at 6 and 8 WAP (Table 3).

These results are consistent with the result of Lima et al. (2004) who concluded that the urban waste application contributes to increase the growth of Corn (*Z. mays*) plants. These results obviously endorse the fact that the compost quality varies with the raw material used, maturity and the method by which those composts were made as reported by Pant et al. (2012). However no significant increase of growth parameters was recorded at 6 or 8 WAP for any compost. This could be due to the non-availability of easily available nutrients by 6 and 8 weeks confirming the use of all available nutrients by the 4^{th} week. When physico-chemical parameters of the composts used in this study are considered, Mihisaru seg had the optimum C:N ratio to have the maximum performance. Since the pH and moisture recorded are not favourable for good microbial growth, no significant

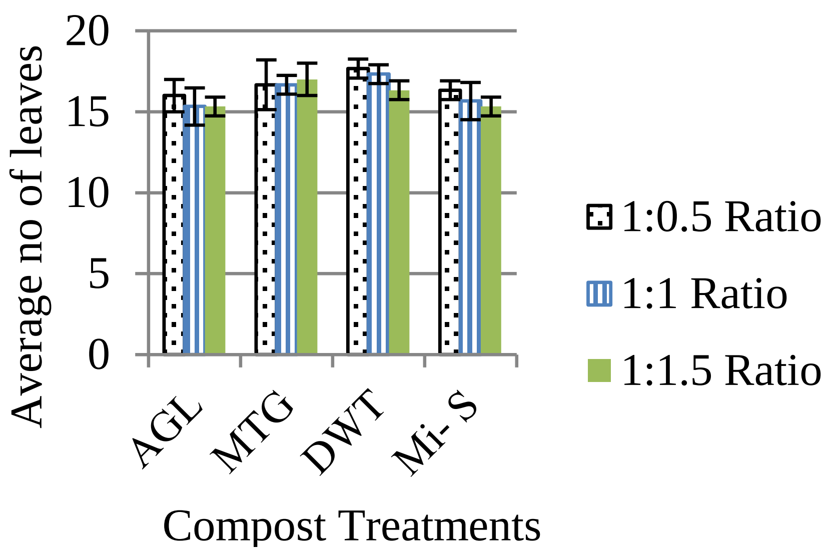

Figure 3. Effect of different MSW compost on no. of leaves at different soil compost ratios at 8 WAP.

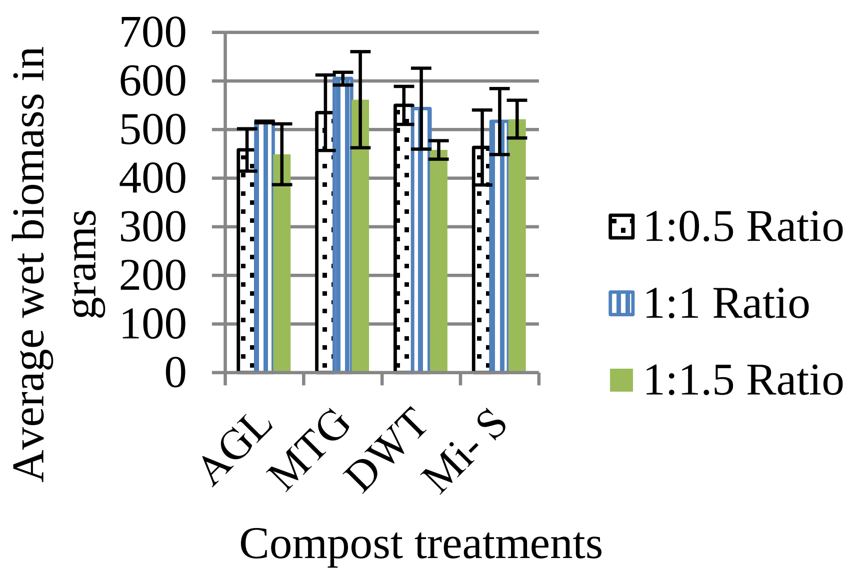

Figure 4. Effect of different MSW compost on wet biomass at different soil compost ratios at 8 WAP.

difference for any of the growth parameters at any soil compost ratio was recorded for Mihisaru seg compost.

When all the growth parameters are considered, results of this study confirmed that DWT performed well in all soil compost ratios suggesting the ability to provide suitable conditions for optimum growth at 8 WAP. Composts with a C/N ratio of less than 20 are ideal for plant production and ratios above 30 may be toxic, causing plant death because it generates phytotoxicity in some plants as reported by Zucconi et al. (1981). These findings further endorse the best performance of Dikovita MSW with all favourable physico chemical properties and C:N ratio of 23.1. Ribeiro et al. (2007) found that the addition of 10 to 20% MSW compost, increased growth and yield of *Geranium.* Furthermore, application rates of 30 and 60 Mg $ha^{-1}$of MSW compost increased the aggregate stability of soil through the formation of cationic bridges thereby, improving the soil structure (Perucci, 1990). Improved plant height after compost addition is related to increases of biomass N, C, and S (Pant et al., 2012). Application of 2.5, 10, 20, and 40 Mg ha^{-1} MSW compost increased soil microbial

Table 3. Effect of different compost types on vegetative development of *Zea mays* at 1:0.5, 1:1 and 1:1.5 soil compost ratios.

Treatment WAP		Plant height (cm)			Stem girth (cm)			Number of leaves			Wet biomass (g)
		4	6	8	4	6	8	4	6	8	8
1: 0.5	AGL	16.33^{a}	59.67^{a}	104.00^{a}	3.67^{a}	6.33^{a}	7.00^{a}	7.00^{a}	13.33^{a}	16.00^{a}	458.33^{a}
	MTG	16.33^{a}	77.67^{a}	136.00^{b}	5.00^{a}	9.33^{a}	7.33^{a}	8.67^{a}	14.33^{a}	16.67^{a}	535.00^{a}
	DKV	27.33^{b}	91.33^{b}	153.00^{b}	7.67^{b}	10.0^{b}	8.00^{b}	9.67^{b}	14.33^{a}	17.67^{a}	550.00^{a}
	MI-S	21.67^{a}	67.00^{a}	116.00^{a}	5.33^{a}	8.67^{a}	8.33^{a}	8.67^{a}	14.00^{a}	16.33^{a}	463.33^{a}
1:1	AGL	17.00^{a}	65.33^{a}	109.33^{a}	3.76^{a}	7.33^{a}	7.33^{a}	6.33^{a}	12.33^{a}	15.33^{a}	516.00^{a}
	MTG	16.67^{a}	66.67^{a}	124.67^{a}	4.73^{a}	9.00^{a}	7.67^{a}	7.67^{a}	13.00^{a}	16.67^{a}	605.00^{a}
	DKV	27.00^{a}	87.00^{a}	155.67^{b}	6.50^{a}	9.00^{a}	8.16^{a}	10.33^{a}	15.00^{a}	17.30^{a}	534.33^{a}
	MI-S	17.67^{a}	50.00^{a}	114.33^{a}	5.00^{a}	8.00^{a}	7.67^{a}	8.33^{a}	14.33^{a}	15.67^{a}	516.67^{a}
1:1.5	AGL	22.00^{a}	83.69^{a}	131.33^{a}	5.00^{a}	8.33^{a}	7.33^{a}	8.67^{a}	15.33^{a}	15.33^{a}	449.33^{a}
	MTG	16.33^{a}	69.00^{a}	124.67^{a}	4.67^{a}	8.67^{a}	8.16^{a}	8.76^{a}	14.00^{a}	17.00^{a}	561.67^{a}
	DKV	26.33^{a}	75.00^{a}	126.33^{a}	6.33^{a}	8.33^{a}	7.83^{b}	9.67^{a}	14.33^{a}	16.33^{a}	458.33^{a}
	MI-S	13.33^{a}	41.67^{b}	97.30^{b}	4.67^{a}	7.67^{a}	7.67^{b}	7.33^{a}	12.00^{a}	15.33^{a}	521.67^{a}

Means represented by same letter along column are not significantly different.

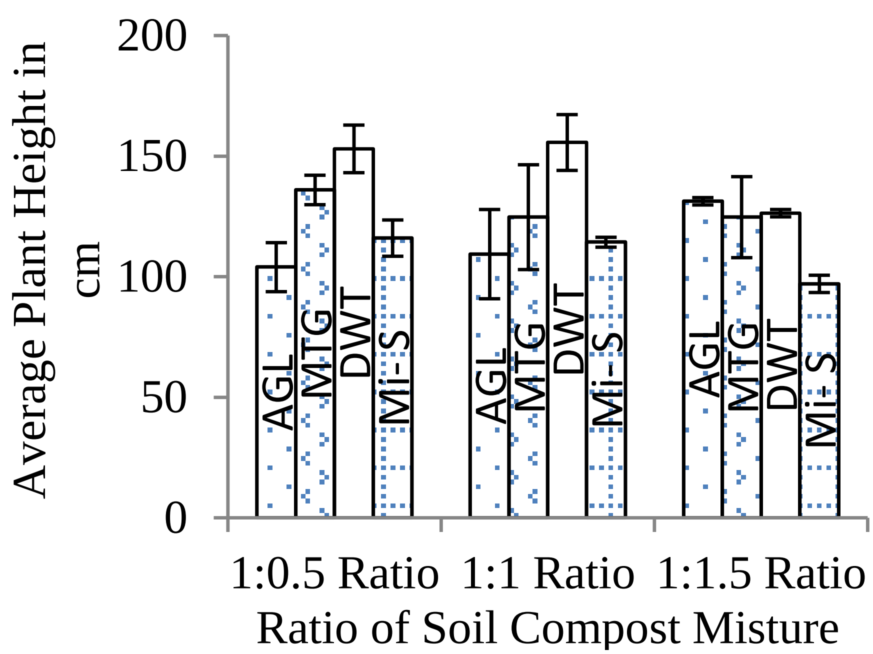

Figure 5. Effect of different MSW compost on plant height at different soil compost ratios at 8 WAP.

biomass C and soil respiration when compared to a control (Bhattacharyya et al., 2003).

When wet biomass at 8 WAP is considered, Mathugama (MTG) showed remarkably higher values than the other composts at all ratios. This could be attributed to the highest C:N ratio of MTG compared to all other MSW composts used. This clearly establishes the fact that C:N ratio could be the most important factor for enhanced vegetative growth as reported by Zheng (2009).

Effect of different compost types on the vegetative development of *Z. mays* at a constant ratio of soil compost mix

The results of the study carried out to identify the effect of different composts on the growth of *Z. mays* are given in Table 3. As per the results, it is clear that all vegetative growth (plant height, stem girth, number of leaves) results for Dikovita (DKV) compost at 1:0.5 ratio performed significantly better at all weeks after planting than the

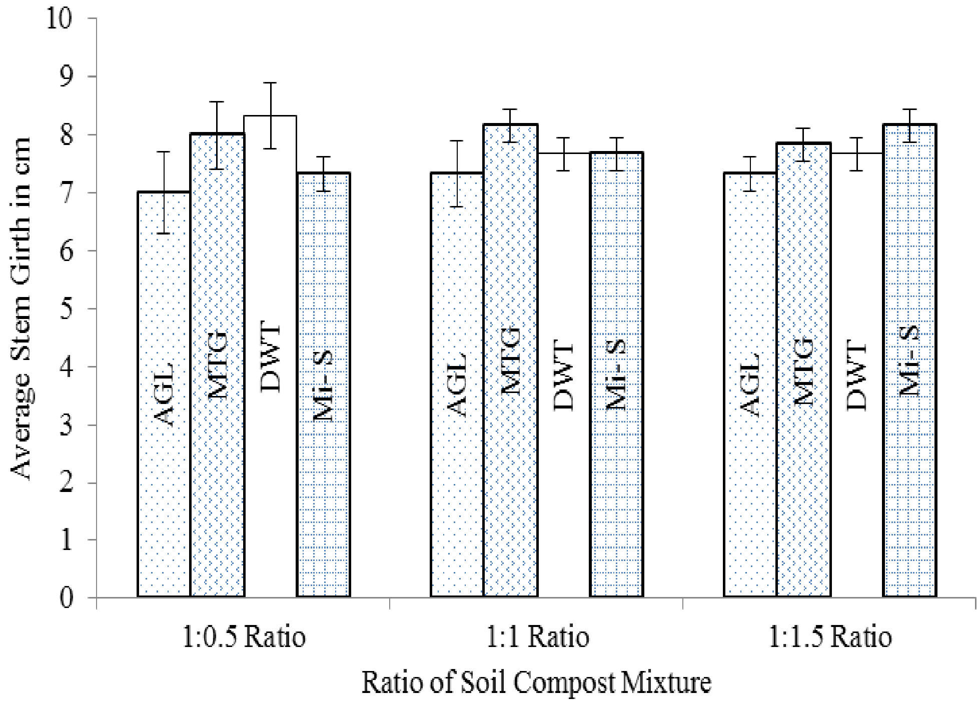

Figure 6. Effect of different MSW compost on stem girth at different soil compost ratios at 8 WAP.

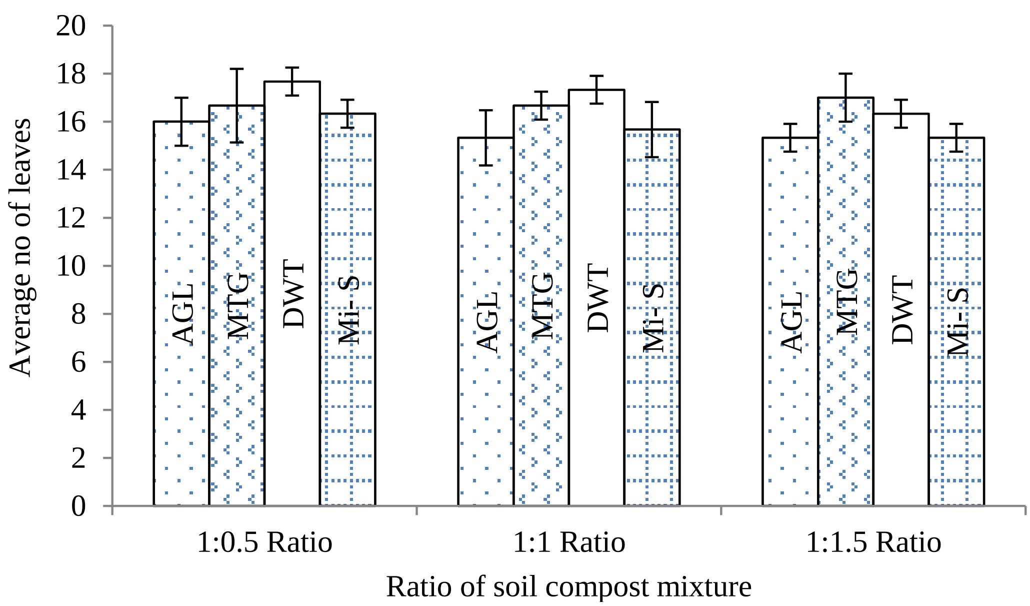

Figure 7. Effect of different MSW compost on the number of leaves at different soil compost ratios at 8 W AP.

other composts (Figures 5, 6, 7). No significant difference was observed for any other soil compost ratio for any type of compost for any growth parameter except for DKW at 1:1 and 1:1.5 ratio at 6 and 8 WAP. However, no significant differences among four compost types were observed for wet biomass at any soil compost ratio (Figure 8).

Even though Zheljazkov and Warman (2004), reported that the addition of municipal solid waste compost to agricultural soils has beneficial effects on crop

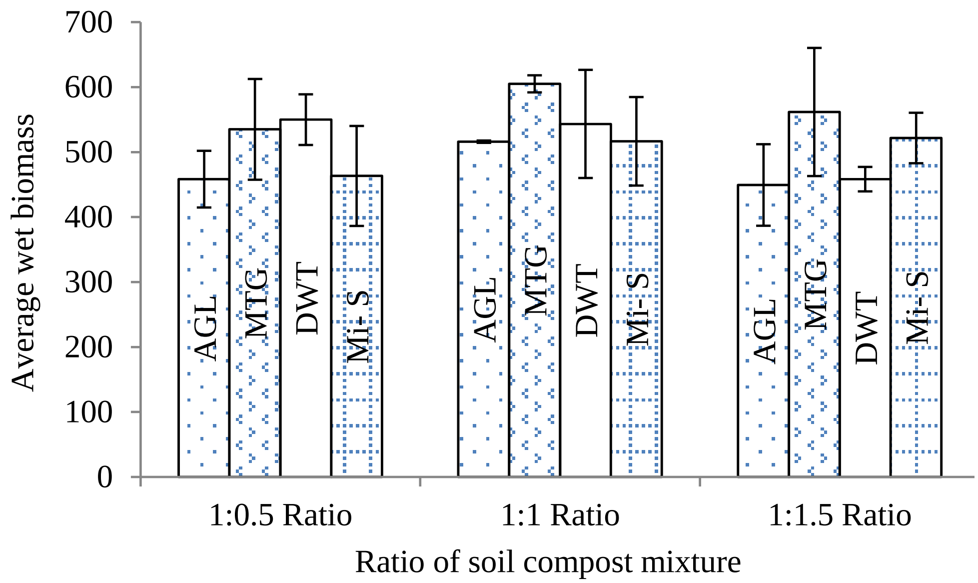

Figure 8. Effect of different MSW compost on wet biomass at different soil compost ratios at 8 WAP.

development and yields by improving soil physical and biological properties, failure to obtain significant difference for increased compost addition by way of higher ratios in this study could be attributed to the non-availability of nutrients and not having suitable properties in the compost used as reported by Alvarenga et al. (2007). It is further reported that compost generally have greater residual effect on subsequent crops than inorganic nutrient sources due to slow release of their nutrients over time. This could also be one reason why significant growth increase was not detected at 8 WAP during this study. Further, at 1:1.5 soil compost ratio, Mihisaru seg showed significantly low plant height at 6 and 8 WAP and also stem girth at 8 WAP. These strange results could be due to the excessive salt content in municipal solid waste as reported by Alvarenga et al. (2007). This observation could be further proved by the recorded high EC in the Mihisaru seg compost.

Results indicated that average plant height of *Z. mays* (Corn) were significantly ($P< 0.05$) influenced by the compost treatments (Table 3). Corn plants treated with Dikovita (DWT) compost had the significantly highest plant height and stem girth at 1:0.5 compost ratio at all WAP. However, significantly low plant height was reported when plants are treated with 1:1.5 soil:compost ratio. This could again be due to the salt toxicity or phytotoxicity as reported earlier. From among all composts tested, Dikovita performed significantly well compared to the rest of the composts in all mixes (Figure 1).

Brinton (2000) reported that composts having C:N ratio less than 20 would prevent nutrient immobilization or N starvation in the soil (Brinton, 2000). On the other hand, C:N ratio higher than 30:1 will cause microorganisms to be immobilized (that is, consume and make unavailable for plant uptake) in soil. Having a C:N ratio of 23.1 for DWT could be the main reason for significantly better action of both plant height and stem girth as evidenced by Brinton (2000). However, number of leaves and wet biomass did not show any significant difference among the different MSW composts used in this study at any given soil compost ratio. Even though this observation issomewhat extraordinary and unexplainable, some sort of growth disturbance with respect to the number of leaves is indicated. This may be attributed to either to phytotoxicity or salt intolerance as reported by many researchers previously.

Conclusions

Overall this study revealed how differently the organic fertilizers from different sources influence *Z. mays* plant growth. From among the different MSW compost used in this study, Dikovita compost was more beneficial than all other composts at 1:1 soil compost ratio at 4 WAP when vegetative variables analysis of number of leaves, stem girth and plant height are considered. Therefore, it can be concluded that the best soil compost ratio that could be used to improve the growth parameters of *Z. mays* significantly is 1:1 followed by 1:0.5. This study further highlighted that higher ratio (1:1.5 soil compost ratio) of certain MSW composts is not desirable and showed a negative effect on plant height. No significant increase or decrease in wet biomass over the different soil compost ratios was observed in this study signalling the need of further investigations on the quality and the production process of compost.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Description, characterization and classification of the major soils in Jinka Agricultural Research Center, South Western Ethiopia

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The soils of Jinka in Southern Ethiopia were studied based on the detail works on soil pit description, characterizing and classification following the FAO and USDA guidelines. For this, along with the topo-sequence and landscape, six soil profiles were opened on an area of 100 ha of research field to make them suit for sustainable soil management practices. The soils were generally described as dark reddish brown to very dark brown and deep. These soils were characterized as slightly (4.87) to moderately acidic (6.18). The OC and available phosphorus were found to range from low to medium. All micronutrients were found to be highly associated with lower soil reaction. These soils group can be classified as Cambisols. Therefore, amending the soil with lime based on exchangeable acidity, essential and deficient nutrients will be vital for supplying food and feed crops in the region. However, continuous assessment of the nutrient status at every five to seven years is necessary to make sure that the soil quality is maintained.

Key words: Blocky, consistency, friable, granular, sub-angular, structure.

INTRODUCTION

In most developing countries where population grows very swift like Ethiopia, focusing only on the potential areas for agricultural use would not help to feed these mounting human and livestock populations. Therefore, exploiting the potential of marginal areas could be the best option to address agricultural product needs for local consumptions as well as export market through boosting agricultural production and productivity and hence economic development, too. In line with this fact that the Jinka Agricultural Research Center (JARC) was established in 2011 in order to address agricultural production constraints in marginal areas so as to fight poverty and exploit the potential of these areas thereby increasing the economic development of Ethiopia. Accordingly, it was intended to represents the humid lowlands of Ethiopia and to address the agricultural production related problems in the eight weredas. Six of them (Male, Salamago, Bena-Tsemay, Hamer, Gnangatom and Dasenech) are highly dominated by people who make their mainstay in agro-pastoral way of

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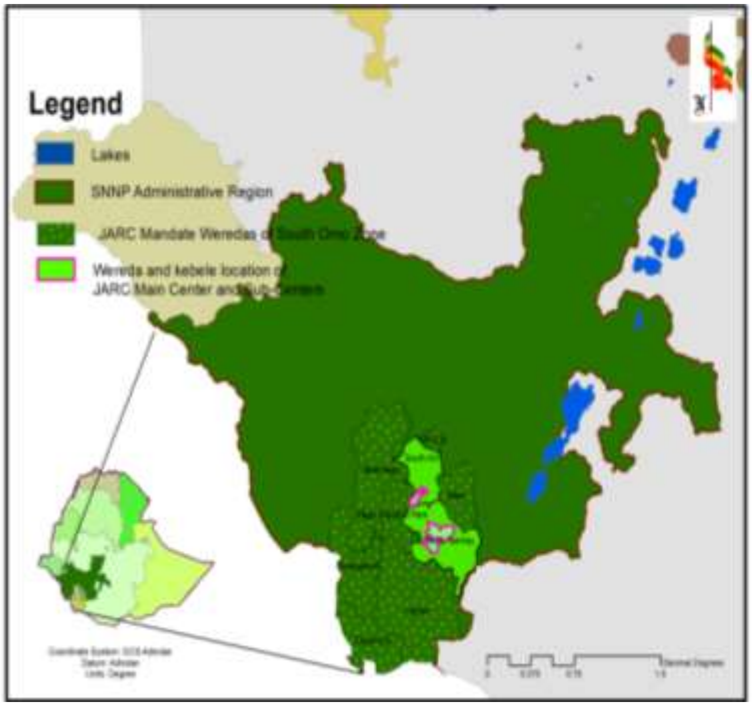

Figure 1. Location of JARC.

living while the rest two (Debub Ari and Semen Ari-Gelila) are known for crop production in the South Omo Zones of the South Nations, Nationalities and Peoples Regional state (SNNPR).

Generally, crop production involves a complex interaction among the environment, soil and nutrient dynamics. Because of this fact, the soil must be studied in terms of its dynamics and environment in order to make it more productive via proper management. Accordingly, failure to understand these complexities along with lack of proper management has resulted in poor crop production potential and hence agricultural production used to be very low (Bashour and Sayegh, 2007).

Management and exploitation of soil potential is strictly dependent on the critical and detail study on description, characterization and classification of the major soil types in the given area. However, there is no baseline information on the nutrient status and the overall characteristics of soils of the experimental site at JARC. The objective of this study is, therefore, to describe the major landforms, characterize and finally to classify the soils of Jinka.

MATERIALS AND METHODS

Description of the experimental site

JARC, is one of the research center of SARI, located 729 kms South West of the capital Addis Ababa at E 36° 33' 02.7" Longitude and N 05° 46' 52.0" Latitude and at an altitude of 1383 masl (Figure 1). Long term weather data revealed that the maximum and minimum monthly average temperature is 27.55 and 16.55°C, respectively while the mean annual rainfall of the area is 1274.67 mm. It is characterized by gentle to flat land features. The slope of the research field ranges from 0 to 5%.

Soil description and sampling

Based on unevenness of vegetation and land use system, six representative soil profile pits (Figure 2) were opened and described in situ according to the guidelines of FAO (2006). Besides, twenty four horizon samples (Table 1) from six profiles were collected from 72 auger points, recorded with GPS and analyzed for physico-chemical properties. Soil color notation was described according to Munsell Color Chart (KIC, 2000).

Laboratory analysis

Texture was determined by hydrometer method (Bouyoucos, 1962). The soil pH was potentio-metrically measured in the supernatant suspension of a 1:2.5 while the electrical conductivity was measured in 1:5 soil to water ratio (Rayment and Higginson, 1992). Organic carbon was determined using Walkley-Black oxidation method (Allison, 1965). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method, and available P was determined using the standard Olsen extraction method (Olsen et al., 1954). Total exchangeable bases were determined after leaching the soils with ammonium acetate (Reeuwijk, 2002). Amounts of K^+, Na^+, Ca^{2+} and Mg^{2+} in the leachate were analyzed by AAS. Cation exchange capacity was determined at soil pH level of 7 after displacement by using 1N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of

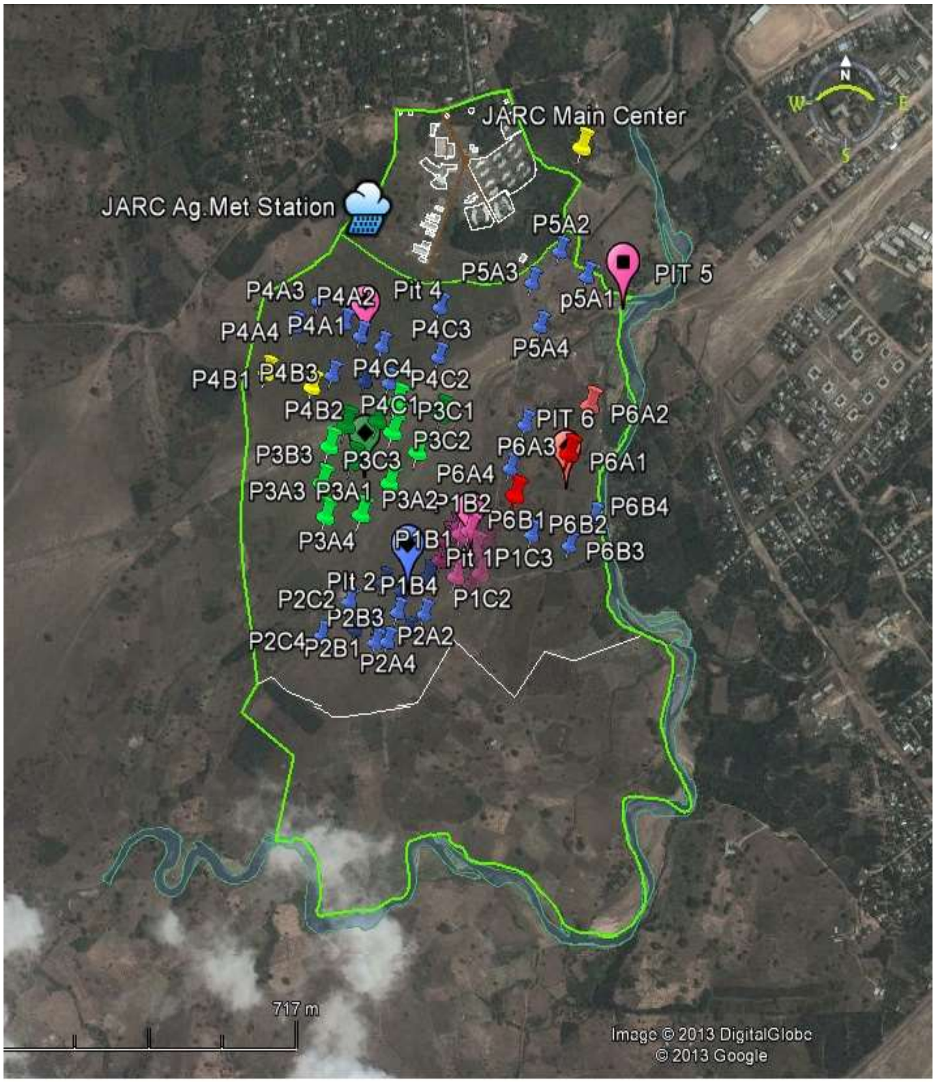

Figure 2. Soil profile distribution at JARC.

Table 1. Surface and profile samples at Jinka Research Center.

Labels	Coordinates	Altitude	Total number of horizon samples	Remark
JK1	05°46'30.4"N036°33'10.9"E	1366	4	12 Auger points
JK2	05°46'30.4"N036°33'10.9"E	1366	4	12
JK3	05°46'35.6"N036°33'02.7"E	1375	5	15
JK4	05°46'44.9"N036°33'02.7"E	1369	4	12
JK5	05°46'47.8"N036°33'20.4"E	1370	4	12
JK6	05°46'34.8"N036°33'18.3"E	1376	3	9
Total			24	72 Auger points

*Three sub-samples were taken to make composite horizon samples.

ammonium that was displaced by sodium (Chapman, 1965). Available micronutrient contents of the soil were extracted by diethylenetriaminepentaacetic acid (DTPA) method (Tan, 1996) and concentrations were determined by AAS.

Table 2. Selected physical characteristics of Jinka Research Center.

Horizon	Depth (cm)	Texture (%)			Textural class
		Sand	Clay	Silt	
1A	0-20	34	41	25	Clay
1AB	20-60	30	51	19	Clay
1BA	60-105	24	49	27	Clay
1B	105+	28	45	27	Clay
2A	0-25	20	47	33	Clay
2AB	25-50	18	39	43	Silty Clay Loam
2BA	50-85	28	42	30	Clay
2B	85+	38	40	22	Clay
3A	0-12	36	52	12	Clay
3AB	12-50	28	68	4	Heavy clay
3BA	50-80	22	70	8	Heavy clay
3BA	80-100	20	74	6	Heavy clay
3B	100+	22	68	10	Heavy clay
4O	0-22	22	66	12	Heavy clay
4A	22-80	26	48	26	Clay
4AB	80-130	14	70	16	Heavy clay
4B	130+	22	50	28	Clay
5A	0-40	26	58	16	Clay
5AB	40-90	24	68	8	Heavy clay
5BA	90-160	28	38	34	Clay Loam
5C	160-205	24	48	28	Clay
6A	0-20	32	64	4	Heavy clay
6E	20-60	32	60	8	Clay
6AB	60+	28	64	8	Heavy clay

RESULT AND DISCUSSION

Physical characteristics of the site

The main experimental site is quite flat and targeted to representing crop research. However, some wetlands have been formed at the heart of the experimental fields and at the peripheries, there is a river called Neri. It is used to be a common grazing land and has been partly cropped with maize (Zea maize) and Sorghum (Sorghum bicolor) by the surrounding farmers and those residing at the outskirt of Jinka town.

Morphological properties of the soils

The soil depth has been identified as very deep (> 150 cm). Pedons in JK1, JK2, JK3, JK4, JK5 and JK6 were characterized by Ap-AB-BA-Bt, Ap-AB-BA-Bt, Ap-AB-BA-BA-Bt, O-A-BA-Bt, O-A-Bt-C and Ap-E-A/AB, respectively. The thickness of the A horizon, which is a ploughed layer, varied from 12 to 58 cm while E was observed in only a pedon by having 20 cm. It does also contain a well established AB, BA, B and C horizons. Significant amount of clay translocation was observed in the middle and lower horizons, as evidenced considerable increase in the clay content of the B horizon (Table 2). Generally, the distinctness of the boundaries between horizons was clear with abrupt and diffuse changes.

A Munsell color chart reveals that the soil color varies from very Dark Grey (7.5 YR 3/1) to Dark Brown (7.5 YR 3/2) and Dark Grey (7.5 YR 4/1) to Black (7.5 YR 2.5/1) for dry and moist conditions, respectively (Table 2). With increasing soil depth, Value keeps increasing with the same Hue and sometime chroma implying that the organic matter distribution in the soil profile declines as the soil textural class mainly dominated by clay. According to Foth (1990), reddish color is due to the presence of iron compounds in various states of oxidation. Abayneh (2005) found that wet soil profiles have darker hues in the B horizons compared to those with relatively dry horizons.

All surface horizons of the studied soils had moderate fine granular structure while the sub-surface horizons had moderately strong to strong fine to very fine granular to

Table 3. Some morphological properties of soils at Jinka Research Center.

Horizon[a]	Depth (cm)	Color		Texture	Structure (Grade, Size, Shape)	Consistency (Moist)	Horizon boundary
		Dry	Moist				
				JK 1			
A	0 - 20	7.5YR4/2	7.5YR3/2	C	MO, FI, GR	VFR	Abrupt
AB	20 - 60	7.5YR4/2	7.5YR3/2	C	MO, FI, GR	VFR	Diffuse
BA	60 - 105	7.5YR4/1	7.5YR3/1	C	MS, FI, GR	VFR	Diffuse
B	105+	7.5YR6/1	7.5YR5/1	C	ST, VF, WE	FR	Diffuse
				JK 2			
A	0 - 25	7.5YR4/1	7.5YR3/1	SCL	MO, FI, GR	SO	difuse
AB	25 - 50	5YR4/1	5YR3/1	C	MO, FI, GR	SO	Diffuse
BA	50 - 85	7.5YR5/1	7.5YR4/1	C	MO, FI, GR	SHA	Abrupt
B	85+	7.5YR6/1	7.5YR5/1	C	MS, VF, WE	HA	Abrupt
				JK 3			
A	0 - 12	7.5YR4/1	7.5YR3/2	HC	MO, VF, GR	SO	Diffuse
AB	12 - 50	7.5YR5/3	7.5YR4/3	HC	MO, FI, GR	SO	Diffuse
BA	50 - 80	7.5YR5/1	7.5YR4/1	HC	MS, FI, GR	SO	Diffuse
BA	80 - 100	7.5YR6/1	7.5YR5/1	HC	ST, VF, BL	SHA	Abrupt
B	100+	7.5YR6/1	7.5YR5/1	HC	ST,FI, BL	HA	
				JK 4			
O	0 - 22	7.5YR3/1	7.5YR2.5/1	C	MO, VF, GR	SO	Diffuse
A	22 - 80	7.5YR5/2	7.5YR4/2	HC	MS, FI, GR	SO	Diffuse
BA	80 - 130	7.5YR5/1	7.5YR4/1	HC	ST, VF, GR	SHA	Abrupt
B	130+	7.5YR6/1	7.5YR5/1	HC	ST, FI, BL	HA	
				JK 5			
A	0-40	7.5YR4/4	7.5YR3/4	C	MS, FI, GR	SO	Diffuse
BA	40-90	7.5YR4/4	7.5YR4/4	C	MS, VF, GR	SHA	Diffuse
B	90-160	7.5YR4/4	7.5YR4/4	C	ST, FI, SAB	HA	Diffuse
C	160-205	7.5YR4/4	7.5YR4/4	C			
				JK 6			
A	0 - 20	7.5YR4/2	7.5YR3/2	C	MO, VF, GR	SO	Diffuse
E	20-60	7.5YR3/3	7.5YR2.5/3	C	MS, FI, GR	SHA	Diffuse
AB	60+	7.5YR4/3	2.5YR3/3	C	MS, FI, G	HA	Diffuse

*****[a] represent the number of soil profiles opened at Jinka while C, HC and SCL meant to clay, heavy clay and silt clay loam, respectively.

wedge structure (Table 3). Well developed structure of the subsurface soils could be due to the relatively higher clay content of the subsurface horizons than that of the surface horizons (Ahn, 1993). The moist consistencies of the surface layers ranges from soft to very friable while the sub-surfaces from friable to hard due to overburden effect of the overlay soils (Table 2)

Physico-chemical properties

The results of the particle size analysis indicate that the soils within the Jinka are fine to very fine textured soils. Generally, the soil textural classes of each of the six pedons were clayey to heavy clay. The proportion of clays in these textural classes ranges from 38 to 74 while sand and silt varies 14 to 42 and 4 to 43%, respectively (Table 2). The soil pH-H2O in all the study profiles ranges from 4.87 to 6.18 and had shown a general tendency of increasing with soil depth (Table 4). According to Murphy (1968) and Tekalign (1991) classification, it has been rated as very strongly acidic to slightly acidic, which is preferred range for most crops with some management.

The organic matter contents were classified to ranges from low to very medium by having a range of values between 2.07 to 3.37% (Murphy, 1968; Berhanu, 1980; Tekalign, 1991). All the three authors, generally, agreed that these soils have low OM contents (Table 4). The total

Table 4. Soil pH, EC, % OM, available P (ppm) and % TN of Jinka Research Center.

Horizon	Depth (cm)	pH	EC (ds m^{-1})	% OM	% TN	Av. P (ppm)
1A	0-20	5.09	0.04	3.059	0.2392	5.10
1AB	20-60	5.10	0.05	3.026	0.4855	6.08
1BA	60-105	5.24	0.04	3.021	0.1856	6.14
1B	105+	6.10	0.04	2.980	0.2856	5.12
2A	0-25	5.16	0.03	3.372	0.2892	5.09
2AB	25-50	5.52	0.04	3.103	0.3392	4.08
2BA	50-85	5.76	0.04	3.016	0.2356	5.11
2B	85+	5.89	0.03	3.044	0.3534	7.02
3A	0-12	5.36	0.06	4.955	0.1714	4.14
3AB	12-50	5.67	0.05	2.431	0.0500	3.30
3BA	50-80	5.70	0.04	3.076	0.1464	7.10
3BA	80-100	5.93	0.02	2.861	0.6747	5.08
3B	100+	6.11	0.02	2.491	0.0393	5.14
4O	0-22	5.80	0.02	5.957	0.0928	3.12
4A	22-80	5.83	0.04	2.420	0.2249	3.09
4AB	80-130	5.83	0.04	3.641	0.1607	2.10
4B	130+	6.18	0.02	2.703	0.1000	2.08
5A	0-40	5.52	0.01	2.592	0.0536	5.14
5AB	40-90	5.54	0.01	2.444	0.0464	2.12
5BA	90-160	6.17	0.04	6.650	0.2820	7.09
5C	160-205	6.18	0.04	6.192	0.2927	6.08
6A	0-20	5.49	0.02	4.770	0.1214	5.10
6E	20-60	4.90	0.06	2.212	0.0678	4.08
6AB	60+	5.20	0.01	2.461	0.1000	5.14

nitrogen contents of the soils of the sites ranges from 0.00.393 to 0.4855% and ranged from low to high according to the same authors. The high level of TN in the soil profile has probability been attributed to the effect of current cultivation and fertilization of the field with research experiments. These soils contains low to medium levels of available P, which was found to be little deficient to maintain annual crops (Olsen et al., 1954; Cottenie, 1980).

The cation exchange capacity (CEC) ranged from 18.16 to 25 Cmol (+) kg-1 (Table 5) and classified as a moderate which ranges from 12 to 25 Cmol (+) kg-1 soils for all profiles (Hazelton and Murphy, 2007; Landon, 1991). In general, there was an increase in CEC with depth which could be due to the strong association between clay contents and CEC. The exchange complex of the soils is dominated by Ca followed by Mg, K and Na (Table 5). According to Havlin et al. (1999), the prevalence of Ca followed by the rest in the exchange site of soils is favorable for crop production. Generally, the exchangeable cations increase with increasing soil depth. The increment was attributed to the leaching of exchangeable cations (Wakene and Heluf, 2003).

The range of critical values for optimum crop production for K, Ca and Mg are from 0.28 - 0.51, 1.25 - 2.5, and 0.25 - 0.5 cmol (+) kg-1 soil, respectively (Sims, 2000). Accordingly, the exchangeable K, Ca and Mg content of the soils are mostly within and sometimes little above the critical values. However, this does not prove a balanced proportion of the exchangeable bases. The ratio of exchangeable Ca/Mg should not exceed 10/1 to 15/1 to prevent Mg deficiency and also the recommended K/Mg are < 5/1 for field crops, 3/1 for vegetables and sugar beets and 2/1 for fruit and greenhouse crops. The Ca/Mg ratio of the studied soils was in the range of 2 - 7 indicating that the response of crops to Mg is not likely. The K/Mg ratio of the studied soils varied from 0.2 to 0.9 and hence it is within the acceptable range for crop production (Havlin et al., 1999). The base saturation (BS), calculated as the sum of exchangeable bases divided by the CEC and multiplied by 100, for all profiles ranges from very low-to-low (20.61 to 35.07%). Low BS is usually associated with low soil pH and the results of this project confirm this fact.

Generally, the concentration of available micronutrients were found to be Fe>Mn>Zn>Cu order. The micro nutrient content of soils is influenced by several factors among which soil organic matter content, soil reaction

Table 5. Soil exchangeable cations, CEC, BS and ESP of Jinka Research Center.

Horizon	Depth (cm)	Exchangeable Cations (Cmol$^+$ kg^{-1} soil)				CEC	BS (%)	ESP	Ca:Mg	K:Mg
		Na	K	Ca	Mg					
1A	0-20	0.3	1.61	2.39	0.74	18.67	27.00	1.61	3.23	1.88
1AB	20-60	0.33	1.39	3.44	0.73	23.66	24.89	1.39	4.71	2.38
1BA	60-105	0.41	1.74	3.3	0.79	23.56	26.49	1.74	4.18	2.44
1B	105+	0.39	1.93	2.52	0.57	20.2	26.78	1.93	4.42	1.81
2A	0-25	0.22	1.03	3.02	0.97	21.32	24.58	1.03	3.11	1.25
2AB	25-50	0.27	1.21	3.37	0.99	22.24	26.26	1.21	3.40	2.14
2BA	50-85	0.43	2.12	3.82	1.32	20.26	37.96	2.12	2.89	1.51
2B	85+	0.46	1.99	4.3	1.57	23.17	35.91	1.99	2.74	0.87
3A	0-12	0.32	1.37	2.53	0.68	23.31	21.02	1.37	3.72	4.24
3AB	12-50	0.65	2.88	3.26	0.75	22.58	33.39	2.88	4.35	3.33
3BA	50-80	0.6	2.5	3.06	0.85	23.97	29.24	2.50	3.60	3.04
3BA	80-100	0.65	2.58	3.63	1.67	25.23	33.81	2.58	2.17	1.78
3B	100+	0.68	2.98	3.28	1.48	22.85	36.85	2.98	2.22	0.85
4O	0-22	0.26	1.26	2.56	0.34	20.66	21.39	1.26	7.53	3.56
4A	22-80	0.28	1.21	2.82	0.39	23.19	20.27	1.21	7.23	3.31
4AB	80-130	0.3	1.29	2.87	0.82	23.26	22.70	1.29	3.50	1.56
4B	130+	0.32	1.28	3.03	1.49	24.94	24.54	1.28	2.03	1.07
5A	0-40	0.32	1.6	2.32	0.62	19.99	24.31	1.60	3.74	2.39
5AB	40-90	0.38	1.48	2.91	0.67	25.7	21.17	1.48	4.34	2.28
5BA	90-160	0.38	1.53	3.29	0.72	24.79	23.88	1.53	4.57	2.29
5C	160-205	0.4	1.65	3.65	0.79	24.28	26.73	1.65	4.62	1.77
6A	0-20	0.31	1.4	2.07	0.3	22.12	18.44	1.40	6.90	7.60
6E	20-60	0.53	2.28	3.19	0.69	23.23	28.80	2.28	4.62	3.39
6AB	60+	0.58	2.34	3.96	1.28	24.82	32.88	2.34	3.09	2.23

and clay content are the major ones (Fisseha, 1992). The soils at Jinka are classified as medium (2.21-5.47) for Cu, (75.78-138.73) for Fe, (14.49-48.76) for Mn and (0.58-2.37) for Zn (Table 6). Although they fell into medium classes, most of the figures are found close to the lower margins of the medium class. Therefore, care has to be made and monitoring their status at every five to seven years is vital to keep these soils productive.

CONCLUSION AND RECOMMENDATION

The majority of the fields of the main research field have a very deep (> 150 cm) soil depth. Very dark grey (7.5 YR 3/1) to Dark Brown (7.5 YR 3/2) and dark grey (7.5 YR 4/1) to Black (7.5 YR 2.5/1) for dry and moist conditions represent the color of Jinka soils for both in dry and moist conditions.

Generally, the soil reaction varies from strongly acidic to slightly acidic and further increases with soil depth as the root and all biological activities ceases as the soil depth increases. The soil OM and the associated total nitrogen contents found to be low for all but it varies upto medium. Available P follows similar trends with TN and OM and found to be generally low for all. Exchangeable bases ranges from low to medium. However, the exchangeable Calcium were found to be Medium as the soil reaction rose but for the rest two even goes upto very low. Consequently, the base Saturation found to vary from very low to low as the soil reaction is low that can be accompanied by low levels of exchangeable bases. At Jinka, the micronutrients found to fall in medium.

The dominant soils of JARC are classified based on the criteria of World Reference Base (2006) of FAO/UNESCO and Soil Taxonomy (2010) of USDA. Accordingly, these soils were found to have a clayey B horizon, brown in color, increasing clay content and low base saturation. Besides, they are having low soil pH (mostly less than 6), leached soils from humid areas of the tropics and having a base saturation of less than 50% in most soil profiles. Therefore, these types of soils can be classified as CAMBISOLS according to Soil Taxonomy (2010) and FAO/UNESCO (WRB, 2006). Cambisols generally make good agricultural land and are used intensively. More acid Cambisols, although less fertile, are used for mixed arable farming and as grazing and

Table 6. Soil micronutrients of Jinka Research Center.

Horizon	Depth (cm)	Micronutrients (ppm)			
		Cu	Fe	Mn	Zn
1A	0-20	2.75	75.78	14.49	1.25
1AB	20-60	3.80	76.90	15.80	1.47
1BA	60-105	4.91	78.31	22.24	1.65
1B	105+	5.09	103.55	32.64	1.80
2A	0-25	2.74	75.26	22.88	0.89
2AB	25-50	3.74	78.48	33.54	1.39
2BA	50-85	4.34	93.83	42.58	1.83
2B	85+	4.88	109.94	48.76	2.37
3A	0-12	2.21	76.86	16.48	0.87
3AB	12-50	2.32	77.39	16.71	0.97
3BA	50-80	2.43	79.52	17.87	1.03
3BA	80-100	3.35	83.73	18.11	1.06
3B	100+	3.91	101.53	19.05	1.19
4O	0-22	2.49	82.38	17.84	0.85
4A	22-80	2.51	87.81	18.62	0.91
4AB	80-130	5.26	98.17	18.66	1.29
4B	130+	5.42	100.39	26.35	2.02
5A	0-40	2.62	78.90	18.39	0.95
5AB	40-90	2.70	86.29	19.85	1.68
5BA	90-160	3.36	99.26	32.69	1.98
5C	160-205	5.26	108.01	48.70	2.01
6A	0-20	2.05	83.38	18.35	0.85
6E	20-60	3.48	94.08	20.70	0.58
6AB	60-160	4.40	112.04	25.67	0.69

forest land. In the humid tropics are typically poor in nutrients but are still richer than associated Acrisols or Ferralsols and they have a greater CEC. Therefore, amending the soil with lime, essential and deficient nutrients will be vital for supplying food and feed crops in the region. However, continuous assessment of the nutrient status at every five to seven years is necessary to make sure that the soil quality is maintained.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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Evaluation of the effectiveness of soil and water conservation practices on improving selected soil properties in Wonago district, Southern Ethiopia

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Accelerated soil erosion remains the major challenge that is adversely affecting the agricultural performance in Ethiopia. Efforts towards soil and water conservation (SWC) goal were started since the mid-1970s and 80s to alleviate soil erosion and low crop productivity. However, the effectiveness of SWC practices on improving soil properties remains less studied. Soil physical analysis (%sand, silt and clay) and chemical analysis (pH, exchangeable potassium (K^+), available phosphorous (P), total nitrogen (TN), soil organic carbon (SOC) and cation exchange capacity (CEC)) were analyzed. A total of 36 soil samples from two sub watersheds (SWs) with SWC and without SWC practices (Elmo without, Elmo with, Hobene without and Hobene with) from three landscapes with three landscape positions (upper slope, middle slope, and bottom) were studied. The results showed that soil pH, K^+, P, TN, SOC, %clay and CEC were significant ($p \leq 0.05$) for SWC practices. The sand and silt fractions were not significant ($p < 0.05$) for SWC practices. P, SOC, %silt and CEC were significantly different for landscape position. The study indicated the effectiveness of SWC practices in improving the soil properties. There should be a continuous awareness creation for technically efficient implementation and proper maintenance of SWC practices for optimum improvement of soil properties.

Key words: Soil erosion, soil and water conservation (SWC) practices, landscape position, sub watershed.

INTRODUCTION

Land degradation by accelerated soil erosion remains one of the biggest environmental problems worldwide, threatening both developed and developing countries (Lal, 2014). It is considered one of the main problems constraining the development of the agricultural sector in Ethiopia (Amsalu and Graaff, 2007; Kirubel and Gebreyesus, 2011; Kebede and Mesele, 2014). As agriculture is the backbone of the Ethiopian economy, it is given special attention by the government to spearhead the economic transformation of the country (Woldeamlak, 2003). However, land degradation in general and soil erosion in particular still remain the major challenges that are adversely affecting the agricultural performance of the country. The majority of the farmers in rural areas of Ethiopia are subsistence-oriented, cultivating impoverished soils on sloppy and marginal lands that are generally highly susceptible to soil erosion and other degrading forces (Shimelis, 2012).

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The severity of this land degradation process makes large areas unsuitable for agricultural production, because the topsoil and even part of the sub-soil in some areas has been removed, and stones or bare rock are left at the surface (Esser et al., 2002). The land degradation problem has had serious consequences in Ethiopia such as occurrence of persistent food insecurity, economic losses and various environmental hazards such as recurrent drought (Bekele and Holden, 1999). As noted by Pimentel et al. (1995), erosion adversely affects crop productivity by reducing water availability, water-holding capacity of the soil, nutrient levels, soil organic matter and soil depth. Research results confirmed that soil nutrient depletion caused by erosion is the major cause for decline of agricultural production (Bekele and Holden, 1998; Abay et al., 2016). Deforestation and conversion of marginal land to agriculture has been followed by severe soil erosion that has caused crop production losses, which in turn result in economic losses (Bojö and Cassels, 1995). For example, due to soil and nutrient loss through erosion, Ethiopia has been annually losing about US$ 106 million (Bojö and Cassels, 1995).

In Ethiopia, coping with these problems, efforts towards soil and water conservation goal were started since the mid-1970s and 80s to alleviate both problems of erosion and low crop productivity (Shimelis, 2012). As a result, government implemented soil and water conservation (SWC) practices to reduce erosion-induced land degradation (Hurni, 1993; Bekele and Holden, 1999). Since then, various mechanical (bunds, terraces, check dams, cutoff drains and waterways) and biological (homestead and communal tree plantations and enclosures) SWC measures have been implemented in drought-prone areas (Amsalu and de Graaff, 2007). The implementation of sustainable land management practices may help to increase agricultural productivity, improve ecosystem functions and enhance resilience to adverse environmental impacts. SWC practices undoubtedly have affected positively the productivity of agriculture where agriculture is hampered by drought, erosion; low soil fertility and moisture stress (Mulugeta and Stahr, 2010; Kirubel and Gebreyesus, 2011).

Recognizing land degradation by accelerated soil erosion as major environmental and socio-economic problems and the importance of SWC, the Wenago district agricultural office has made considerable efforts to improve food security by rehabilitating degraded land and preventing further degradation. As a result, different degraded watershed areas have been, covered by physical and biological soil and water conservation measures. Some of the implemented soil and water conservation practices in the SWs include soil bunds, check dams, cut-off drains, waterways, area closure, trenches and plantation of tree seedlings.

However, the effectiveness of SWC practices on improving soil properties remains under studied. Although, many resources in terms of money and labor, have been invested in the construction of SWC structures in sub-watersheds, their impact on improving soil properties is not well studied. Comparing changes with soil properties between two SWs (both SWs have areas with and without SWC adjacently) could contribute to further improvement of design, implementation and sustainable maintenance of SWC practices. Therefore, the main objective of the study was to evaluate the effectiveness of SWC on improving the selected soil properties.

MATERIALS AND METHODS

Description of the study area

The research was conducted in Wenago district (Figure 1), Gedeo Zone, Southern Ethiopia, located at 375 km South of Addis Ababa, the capital of Ethiopia. The Wenago district lies in geographical coordinates between 6°20'30" and 6°15'0″North - 38°15' 30" and 38°21'0" East. Total area coverage is estimated to be about 13.7 km^2, and the district is sub divided into 17 administrative rural kebeles (villages) (GZFES, 2005). Topographic feature of the district generally shows that there is a decreasing altitude from east to west and north to south. The physical features of land are dissected and undulating and each hillside or mountain is followed by plateau and then by short or long slopping to flat land. Erratic and irregular rainfall of the study area is bi-modal including the spring (short rainy season) from March to May (60 - 90 days), while the main rainy season is from July to September (90 - 120 days). According to CSA (2007), the climate of Wenago district is characterized by annual rainfall and temperature of 1001 - 1800 mm and 12 to 25°C, respectively. The soil types that dominantly occur in the study area include chromic luvisol, eutric fluvisol and dystric nitisol in decreasing order.

Data collection

Delineation of watershed

The study was conducted April 2015 to March 2016 in Elmo SW (Figure 2) with an area of 233.74 ha area in Karasodity village and Hobine SW (Figure 3) with an area of 167.43 ha in Dako village (Figure 1). The SWs have both SWC practices and degraded areas without SWC practices. Lakew et al. (2005) noted sub-watershed units prioritized for key interventions. The SWs were delineated by using digital elevation model (DEM). The topographic transect walk method was employed for the assessment of existing SWC measures in the sub watersheds. Transect walk was made to identify the major SWC practices implemented in the study area. The slope of the SWs is indicated in Figures 2 and 3.

Soil data collection and analysis

Soil physical and chemical analysis (%sand, silt, clay, and organic carbon, total nitrogen (TN), available phosphorus (P), exchangeable potassium (K) and cation exchange capacity (CEC) were analyzed to evaluate the effectiveness of SWC measures on improving soil properties at the two sub watershed. The two SWs were characterized by having both conserved and non-conserved areas adjacently. A total of 36 soil samples from two SWs with SWC practices and without SWC practices (Elmo without SWC, Elmo with SWC, Hobene without SWC, and Hobene with SWC) from three landscapes (replications) with three landscape positions

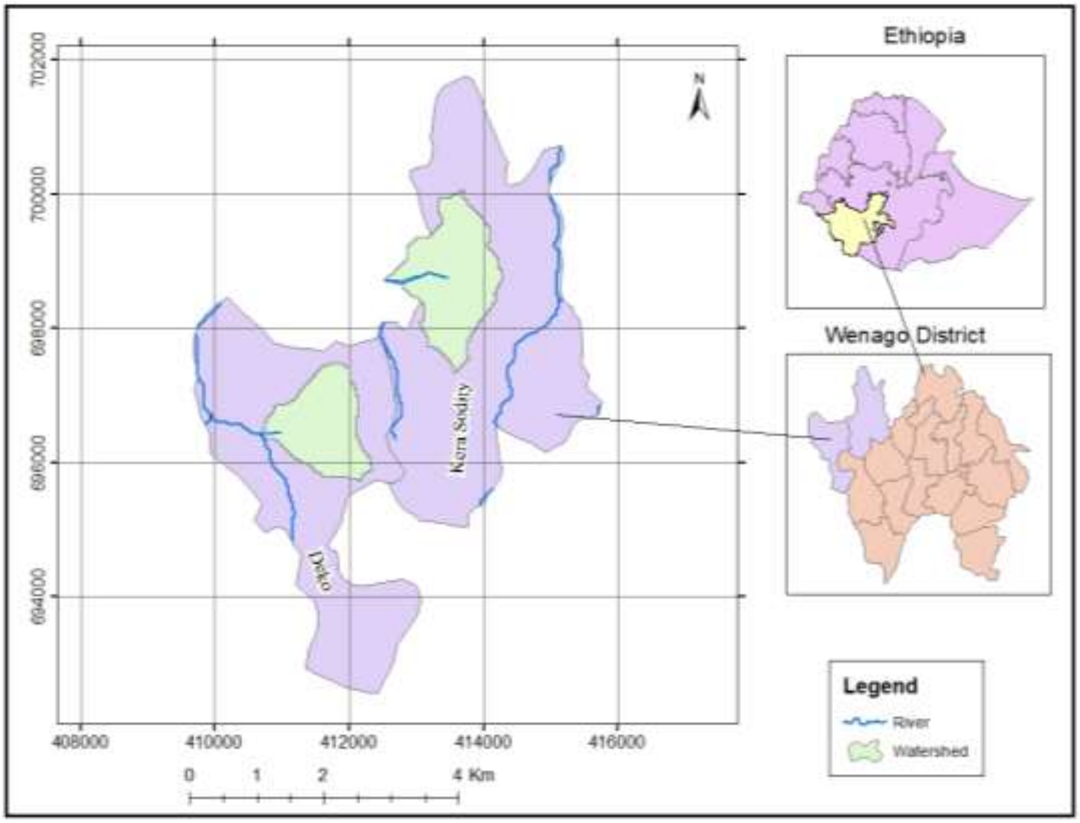

Figure 1. Location of the study area.

(upper, middle and bottom slopes) were taken at one depth (0-30 cm). There were two treatments (SWC practices and land positions) and three landscapes (replications). The study followed factorial randomized complete block design (RCBD). The soil physical and chemical properties were analyzed based on their standard methods. The particle size distribution of the soil was done using the Bouyoucos hydrometric method (Bouyoucus, 1962). For this, disturbed soil samples from representative locations (transect) were collected from a depth of 0-30 cm with the help of soil auger.

Soil organic carbon (%) was determined by potassium dichromate wet combustion procedure (Walkly and Black, 1934). The pH of the soil was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combined electrode (Van Reeuwijk, 2002). TN content was determined by wet oxidation procedure of the Kjeldahl method (Mostara and Roy, 2008). The available P content was determined by 0.5 M sodium bicarbonate extraction procedures (Olsen et al., 1954). Flame photometer (Toth and Prince, 1949) was used for determination of K^+. CEC was determined by extraction with ammonium acetate method (Chapman, 1965)

Statistical analysis

The impact of independent variables (SWC practices and landscape positions) on the dependent variables (soil properties) was statistically tested. For each measured response, analysis of variance (ANOVA) was performed. Data was analyzed for variability using General Linear Model of SAS version 9.1 statistical software (SAS institute, 2008). The mean separation was made using least significant difference ($LSD_{0.05}$) method.

RESULTS AND DISCUSSION

Characterization of the SWC practices in the study

Based on detailed inquiry on two SWs (sub watersheds) along the transect line, different SWC practices were implemented since 2009. The SWC measures in the SWs were installed for the purpose of land rehabilitation and to control further soil erosion in agricultural areas. Majority of the physical SWC practices constructed were soil bunds (Figure 4), fanyajuu, half-moons, trenches (Figure 5) and micro basins (Figure 6), and cut off drain in area closures on grazing and fallow land. Similarly, the commonly practiced biological SWC include maintaining natural vegetation and tree plantation in area closures, plantation of valley bottoms, and stabilization of physical structures using natural vegetations, vetiver grass and elephant grass. Implementation of conservation practices may keep the soil in place and reduce both the on-site and off-site effects of soil erosion (Blanco and Lal, 2008). The field observations revealed that most of the SWC measures have been widely implemented are stabilized with some irregularities in dimensions and lack of maintenance. Stability of SWC structures depend on various factors such as slope of the land, construction quality, construction material, support of physical structures by biological measures, and appropriateness

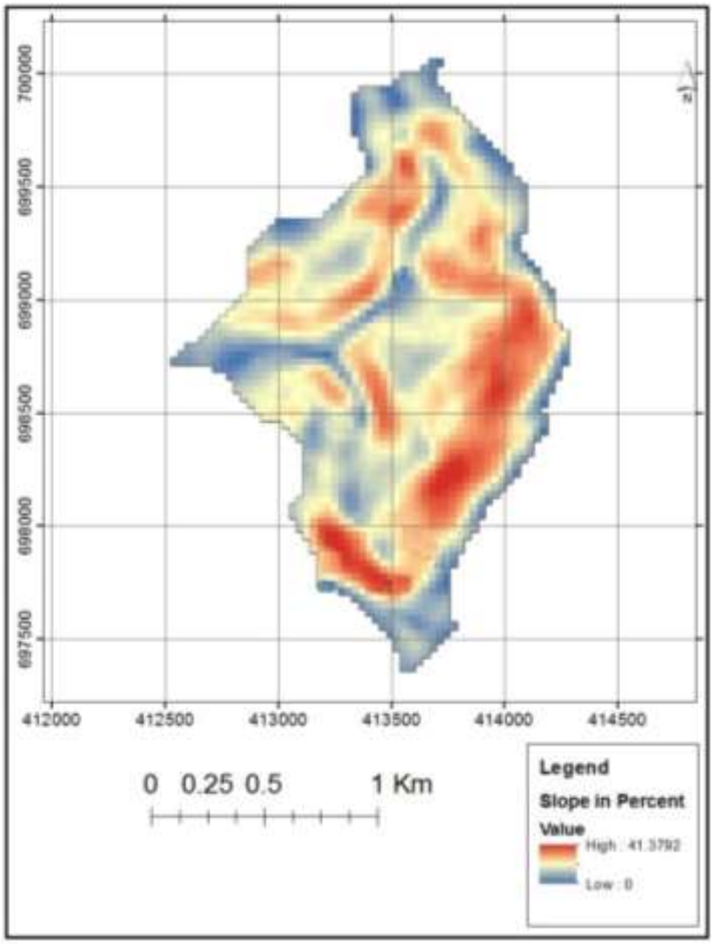

Figure 2. Elmo sub watershed with slope (%).

of structure to the site conditions (Olarieta et al., 2008).

The SWC practices improve the biophysical change by reducing soil and water loss, discharge of springs (Figure 7), improved micro climate, greening the area (Figure 5), supplying grass for cut and carry (Figure 5), modifying terrain, improving soil depth, stabilizing active gullies. Even though the above benefits, there are limitations in the design and installation of the practices. The study of Kirubel and Gebreyesus (2011) indicated that there has been success in maintaining and improving land resources, viz. soil, water, vegetation and humidity due to the implementation of SWC practices. Most the SWC practices did not follow the site specific design criteria of vertical interval and dimension of the structures based on the soil depth, slope and rainfall. Simeneh (2016) reported that most of the existing physical SWC structures were not constructed according to the standards in Wyebla Watershed. The SWC technologies introduced by both government extension system and nongovernmental organizations (NGOs) working at grassroots level is predominantly biased to standard structural SWC technologies (Mitiku et al., 2006).

Effectiveness of soil and water conservation practices on improving soil properties

Sand, clay and silt fractions

According to ANOVA sand and silt fractions were not significantly different ($p < 0.05$) for SWC practices and %sand and %clay were not significant landscape position and their interaction (Table 1). This result confirms findings by Lemma et al. (2015). The maximum sand of 22.45% at Elmo without SWC and minimum of 19.56% at Elmo with SWC were observed (Table 1). The variation may be due to the steep landscapes; transportation and translocation of fine particles are expected. The analysis also showed significant variation of clay for SWC practices with maximum clay of 48.49% at Hobene with SWC and lower 39.53 at Elmo without SWC with variation on effect of SWC practices. The maximum value of silt observed was 38.61% at Elmo without SWC and the lower content was 29.50% at Hobene with SWC. The non-significant difference in texture may be due to the young age of SWC practices that cannot make

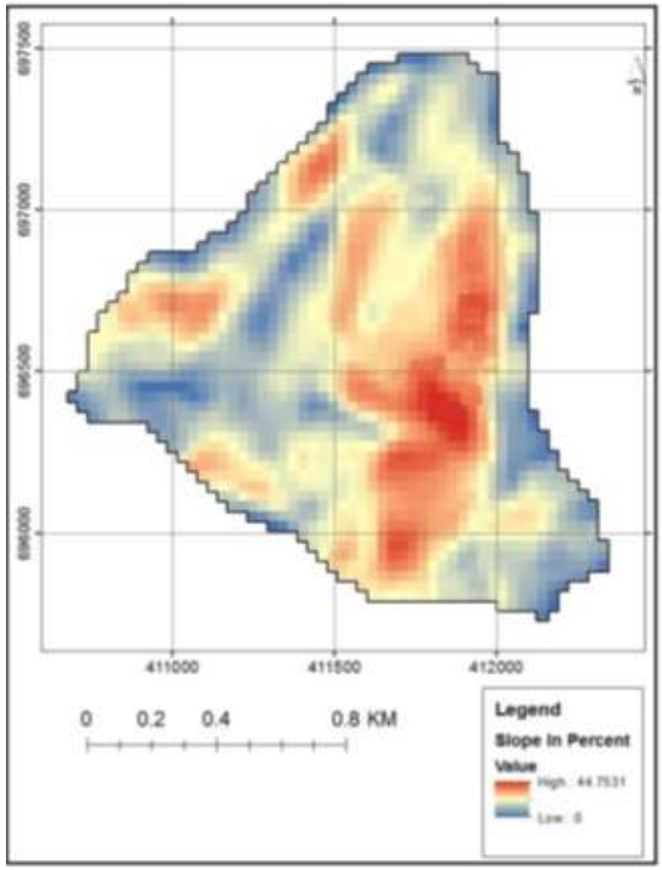

Figure 3. Hobene sub watershed with slope (%).

Figure 4. Stabilized soil bund.

significant change on soil weathering (Lemma et al., 2015). For landscape position, maximum sand content of 22.78% was indicated at middle and lower position, value of 20.13% at bottom, maximum clay content of 47.43% was indicated at upper and lower position, value of 41.07% was indicated at middle position, maximum silt content of 38.67% was indicated at bottom position and lower value of 30.95% was indicated at upper position

Figure 5. Water harvested in area closure with trench .

Figure 6. Micro water harvesting structure.

with variation due to position. The highest silt content measured at bottom may result to erosion and sedimentation processes, as there could be a balance between soil particle detachment, runoff velocity and deposition. This may be due to soil particles resistance to detachment, and susceptibility to transportation. Gebremichael et al. (2005) reported that selective removal of soil particles to steeper slopes leave behind coarser materials (sand, gravel and stones), while the transported material is deposited as the slope steepness decreases. Sandy soils are less cohesive than clayey soils and thus aggregates with high sand content are more easily detached; silty soils derived from loess parent material are the most erodible type of soil (Blanco and Lal, 2008).

Soil pH

The soil pH in the experimental area varied from 5.0 to 7.3 with an average value of 6.06 which is moderately acidic (Tekalign and Haque, 1991). The pH was not significantly different at $p<0.05$ level of significance for landscape position and for interaction, and highly

Figure 7. Discharge of water below area closure.

Table 1. SWC practices and landscape position effects on soil properties.

Treatment		pH (H_2O)	K^+ (ppm)	P (ppm)	TN (%)	SOC (%)	Particles size distribution (%) Sand	Clay	Silt	CEC (meq/100 g
SWC practices	Elmo without SWC	6.23^b	3.70^b	4.196^b	0.139^b	1.9^c	22.45^a	39.53^b	38.01^a	25.81^c
	Elmo with SWC	6.75^a	5.19^b	5.73^a	0.320^a	3.42^{ab}	19.56^a	41.82^{ab}	38.61^a	43.18^a
	Hobene without SWC	5.48^c	5.09^b	4.21^b	0.163^b	2.69^b	22.02^a	44.44^{ab}	33.54^a	25.88^c
	Hobene with SWC	5.78^{bc}	7.00^a	5.55^a	0.272^a	3.61^a	22.01^a	48.49^a	29.50^a	38.22^b
	$LSD_{0.05}$	0.49	1.72	0.56	0.096	0.74	4.77	8.09	8.4	4.12
Landscape position	Upper	5.90^a	4.53^a	4.41^b	0.237^a	2.85^b	21.62^a	47.43^a	30.95^b	29.51^b
	Middle	6.14^a	5.50^a	4.83^b	0.223^a	2.37^b	22.78^a	41.07^a	35.14^{ab}	36.70^a
	Bottom	6.13^a	5.70^a	5.53^a	0.211^a	3.49^a	20.13^a	41.21^a	38.67^a	33.61^a
	$LSD_{0.05}$	0.43	1.49	0.48	0.08	0.64	4.13	7.00	7.27	3.64
CV (%)		8.38	13.55	11.63	23.94	26.07	22.36	18.98	24.61	12.91

K^+ = Exchangeable potassium; P = available phosphorous; TN = total nitrogen; SOC = soil organic matter; CEC = cation exchange capacity.

significant for SWC practices. Maximum pH value of 6.75 was obtained from areas with SWC practices at Elmo and relatively lower pH value of 5.48 at Hobene without SWC practice. This indicates that SWC practices increase the pH of the soil and then reduces soil acidity. Similarly, pH value did not vary for landscape positions. Maximum pH value of 6.27 was found on bottom landscape with SWC and pH value of 5.65 found on upper. This study agreed with Tadele et al. (2013) who found relatively lower pH mean value for the loss zone (without SWC) which may be attributed due to the relatively lower base saturation percentage and lower soil organic matter content while the highest pH value in the accumulation zone (with SWC). This could be attributed to the presence of higher exchangeable cations due to reduced erosion. Similarly, Shimelis (2012) reported that pH values on the farmland terraces decreased with increase in slope of the terrain.

Exchangeable (K^+)

The soil K^+ value in the experimental area varied from 0.6 to 8.7 ppm with an average value of 5.24 (Table 1) which is lower based on standard values of nutrients by Marx et al. (1999). Results of Mulugeta and Stahr (2010) also indicated that tropical soils are deficient in K^+. The exchangeable K^+ is significantly different for SWC practices (p=0.0065) and for interaction (p=0.0489), but not significant for landscape position at 5% level. Even though it is not significantly different, a maximum K^+ value of 5.7 ppm was obtained from bottom position. Area with SWC practices at Hobene showed higher K^+ value of 7.00 ppm and relatively lower K^+ value of 3.7 ppm at Elmo without SWC. Similarity, average K^+ value of 5.7, 5.50 and 4.53 ppm were found from bottom, middle and upper position of the field, respectively (Table 1). The interaction effect also showed significance with maximum K^+ value of 8.03 ppm found on lower position with SWC at Hobene and lower K^+ value of 3.53 ppm found on Elmo without SWC at the middle position. This may be due to the fact that erosion and leaching remove soluble salts from upper-slope and accumulate these at the down-slope erosion (*Pimentel* et al., 1995). Olarieta et al. (2008) reported that at the lower slope positions, water has a relatively longer residence time and as a result, soluble materials precipitate down.

Available P

Available phosphorus (P) was significantly different between the areas with SWC and without SWC (p<0.0001), among the landscape positions (p =0.0004) and their interaction (p<0.0001). Maximum available P value of 7.78 ppm found on lower position with SWC at Hobene and lower available P value of 4.05 ppm was measured on Hobene without SWC at middle terrain. Similar finding was obtained by Mulugeta and Stahr (2010). This may be due to the fact that organic sources of P are important for amending the agricultural land for a better land productivity. Higher available P of 5.73 ppm was found at Elmo with SWC and lower available P of 4.196 ppm was determined at Elmo without SWC. The lower P from areas without SWC was possibly due to the difference in the past land degradation resulting from continuous cultivation, extractive plant harvest and soil erosion. Bottom position showed higher available P of 5.73 ppm and a lower value of 4.41 ppm was observed at upper position (Table 1). P contents increased from upper to bottom position. Even though comparatively higher P found from areas with SWC, it was found at the lower range of medium based on London (1991) which is ≤ 5ppm as lower, 5-15 ppm as medium and >15 ppm as higher content of P. The lower plant available P could be attributed to inherent soil properties such as P fixation by iron and aluminum, while the differences between the terraces across slope of the terrain could be related to organic matter (OM) input differences (Shimelis, 2012).

Total nitrogen (TN)

The plots treated with SWC practices within the sub watersheds was found to exhibit higher total nitrogen (TN) than the non-conserved parts of the sub watersheds. TN was significant (p = 0.0018) for SWC practices and the highest content was found from the conserved parts with SWC practices than adjacent part without SWC practices. Mulugeta and Stahr (2010) also reported that the lands with SWC measures have high TN as compared to the non-conserved land. Abay et al. (2016) found TN (%) differed significantly between conserved and non-conserved, slope positions and also with their interactions (p≤0.05). This indicates the positive impacts of SWC practices in improving the nutrient status of farms treated by structures (Hailu et al., 2012). Lemma et al. (2015) also reported the overall total nitrogen (TN) was higher under closed area with SWC than in soil under closed area without SWC. Similar to exchangeable K and soil pH, no significant differences were found for TN in the landscape positions. Following the rating of TN greater than 1% as very high, 0.5 to 1% as high, 0.2 to 0.5% as medium, 0.1 to 0.2% as low and less than 0.1% as very low nitrogen status as indicated by (London, 1991), TN of conserved and non-conserved farm plots of the study area were found between low and medium. These may be attributed to less physical protection against water erosion, intensive tillage, due to leaching and limited nutrient amendments.

Soil organic carbon (SOC)

Based on ANOVA result, soil organic carbon differences between the conserved and non-conserved SWs were statistically significant (p = 0.0003 and p = 0.0052) with respect to landscape position, with higher values at Hobene and at bottom. This reveals the physical structures stabilized with vegetative practices have a better effect in soil OM accumulation. This finding agrees with Mulugata and Stahr (2010) who assessed the effect of integrated SWC measures on key soil properties with higher soil organic matter (SOC) (3.69%) in conserved catchment as compared to non-conserved (2.24%). As compared to sites without SWC practices, the implementation of SWC practices in this erosion-prone landscape resulted in the recovery of SOC. Moreover, SWC measures may hold great potential for increasing SOM levels since the areas where these are implemented are often heavily degraded.

This variation in SOC could be attributed due to the erosion reduction effects of SWC measures implemented and biomass accumulation (Tadele et al., 2013; Abay et al., 2016; Lemma et al., 2016). This implies SWC practices can bring current land use systems to a higher above and below ground biomass (and hence SOC) level by enhancing better ground cover. Kebede et al. (2011) on crop field also reported that the non-conserved fields had lower SOC as compared to the conserved fields with different conservation measures. Lal and Bruce (1999) also generally indicated technologies for restoration of degraded soils by establishing ecological-based vegetation cover, using appropriate soil and water conservation measures, adopting water harvesting measures, enhancing nutrient recycling mechanisms, and controlling stocking rate. Because soil organic matter is highly concentrated at the top layers of soils, it is highly affected by erosion. At the bottom slope position, higher organic carbon content was due to lower erosion rate and higher biomass production at bottom position (Tadele et al., 2013.)

Cation exchange capacity (CEC)

Statistical analysis revealed that the soils had statistically significantly different CEC ($p < 0.001$), SWC practices ($p= 0.0019$), and landscape position ($p=0.0003$) for their interaction, CEC was higher in parts of SWs treated with SWC as compared to without SWC adjacent parts. The conserved area at Elmo was found to have higher mean CEC value of 48.18 meq/100 g and lowest value of 25.81 meq/100 g at Elmo without SWC (Table 1). This is in line with research conducted by Abay et al. (2016) who revealed significant difference in CEC (meq/100 g) between the treatments and with respect to slope gradients ($p \le 0.05$). The mean CEC (meq/100 g) did not vary (p=5%) between middle and bottom positions with 36.5 and 33.6, respectively and the lower different value of 29.51 at upper position. This result is similar to Abay et al. (2016) who found that the highest CEC (36.08 meq/100 g) was observed in the bottom, although there was no significant difference with that of middle slope whose value was 34.6 meq/100 g. The lowest value was observed in the upper slope positions with 31.8 meq/100 g. Similarly, according to a study conducted by Mulugata and Stahr (2010), areas with SWC showed higher CEC than areas without SWC. Lal et al. (1999) discussed that CEC of a soil can be reduced by soil erosion through the loss of soil OM. By the rating of London (1991), CEC greater than 40 meq/100 g is very high, 25 to 40 meq/100 g is high, 15 to 25 meq/100 g is medium, 5 to 15 meq/100 g is low and less than 5 meq/100 g is very low; soils of the study area could be regarded as high CEC.

CONCLUSION AND RECOMMENDATION

This study showed that the effectiveness of soil and water conservation at both SWs improved significantly the soil qualities (soil pH, K^+, available P, SOC, TN, clay and CEC) than in the adjacent without SWC treatment, in the same SW. This indicates the positive impacts of SWC practices in improving the nutrient status. Further the results of the soil analysis showed that most of the soil chemical properties had significant variations with respect to landscape positions. It would be possible to conserve more soil if the technical characteristics of the SWC practices and the maintenance systems were improved. Variability in soil types, slope gradient and landscapes (upper, middle and bottom slopes) affect the efficiency of different SWC measures and should be considered when designing and placing such measures for maximizing the benefit from that conserved. Bearing in mind, the effectiveness of SWC practices towards improving the soil quality and thereby sustainable agricultural productivity, there should be a continuous awareness creation mechanism for technically efficient implementation and a follow up process on the proper maintenance for optimum soil properties improvement.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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