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Drain depth effects on selected physico-chemical characteristics of Vertisols in western Ethiopia

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Abstract

To determine the effect of drain depth on selected physico-chemical characteristics of Vertisols, a field experiment was conducted at Ambo Agriculture Research Center experimental site during main rainy season of 2013-2014. Treatments included five drain depths (0, 15, 30, 45 and 60 cm), and arranged in Randomized Complete Block Design (RCBD) with three replications. The analyses of variance showed that there was a significant difference ($P \leq 0.05$) among drain depths on selected physico-chemical characteristics of Vertisols after the formation of drain depth. The result revealed soil moisture contents varied with drain depths and time of sampling. Drains 45 and 60 cm deep resulted in lower soil moisture content than did the 0, 15 and 30 cm drains. The particle size distribution revealed soil of the study site was dominated by clay fraction. The lowest bulk density (BD) value (1.16 g cm-3) was observed in plots with undrained (0 cm) provided in the upper soil layer 0 to 15 cm and the highest BD value (1.30 g cm-3) was recorded in plots with deep drains of 45 and 60 cm in the 45-60 cm soil layer. Total porosity of the soil samples was high (56.23%) for undrained plots and decline as drain depth increased. The pH (H_2O) of the soils increased as drain depth increased, with 45 and 60 cm deep drains resulting in neutral to alkaline soil reaction and moderately acidic for undrained plots. Drains 45 and 60 cm deep resulted in significantly higher OM, total N, available P, exchangeable K and CEC of the soils in the 0 to 45 cm soil layer. Hence, drain depth of 45 cm deep could improve physico-chemical characteristics of waterlogged Vertisols which is vital for crop production in Ambo and similar areas.

Key words: Vertisols, Drain depth, Physico-chemical properties

Introduction

In Ethiopia, Vertisols occupy approximately 12.6 million ha, or about 10% of the land mass of the country and are the fourth most abundant soils after Leptosols (16%), Nitisols (12%) and Cambisols (11.5) (Berhanu, 1985). Of the total area 70% of Vertisols are found in the highlands, and about 25% (2.21 million ha) of the highland Vertisols are cropped and some 6 million ha are left under native pasture because of severe waterlogging problems in the main rainy season (Berhanu, 1985; Jutzi *et al.,* 1987).

Vertisols are characterized by dark coloured and clay-rich soils that shrink and swell with changes in moisture content. During dry seasons, the soil volume shrinks, and deep wide cracks form. The soil volume then expands as it moist up. These soils are of very low basic water infiltration rate and, thus, are susceptible to waterlogging under high intensity rainfall conditions (Coulombe et al., 1996). Drainage is vital for Vertisols occurring in high rainfall areas which are susceptible to waterlogging problem (Sigunga et al., 2002). The magnitude of reduction in soil moisture content during the rainy season was influenced by drain depth of furrow constructed to drain excess moisture (Sigunga et al., 1997).

Drainage is essential for Vertisols occurring in abundant rainfall areas which are susceptible to waterlogging (Sigunga et al., 2002). Rainfall is one of the limiting factors in using Vertisols for agricultural production (Hubble, 1994). The total amount of rainfall and its distribution dictate the need for water removal in early part the season for successful cropping on Vertisols (Pushparajah, 1992). Different land shaping techniques, namely cambered beds, broad beds, and flat beds with furrows have been used to remove excess water to avoid waterlogging of the Vertisols under crop production (Ahmed, 1988). Crop yield improvement has been reported in Ethiopia and other African countries with various soil management practices (Asiedu, 1996; Teklu et al., 2004).

In Ambo, crop production on Vertisols is limited because of impeded drainage, difficulty of land preparation and soil erosion. However, these soils have considerable productive potential, but they are usually underutilized in the traditional production system (Paulos et al., 2001). Hence, achieving sustainable and improved management of Vertisols has been a major challenge for Ethiopian farmers for many years. Realizing the potential of Vertisols in the Ethiopian agriculture, national and international agricultural research institutions have participated in developing sustainable technology to increase the productivity of crops grown on Vertisols. Although a lot of work has been done on Vertisols management there must be more attention given to drainage conditions of Vertisols. Therefore, the objective of this study was to determine the effect of drain depth on physico-chemical properties of Vertisols in Ambo.

Materials and Methods

Study area

A field experiment was conducted at Ambo Agriculture Research Center experimental site during main rainy season of 2013-2014. The study site is located at 126 km west of Addis Ababa and located 80 55' north and 380 07' east at an altitude of 2220 meters above sea level (m.a.s.l) and located in west Shoa zone of Oromia National Regional State, central Ethiopia (Figure 1). The soil type of study area is Pellic Vertisols with pH of 6.1 at soil depth of 0-10/15 cm. The slope of the study site ranges from 0.1-1% and, therefore, in the major rainy season, they are liable to flooding. The area is important for both food and cash crops production under rainfed condition. The dominant crops cultivated in the area are teff, wheat, maize, and faba bean. Chickpea is grown on residual soil moisture at the end of the rainy season. The major land use types are cultivated land and grazing land.

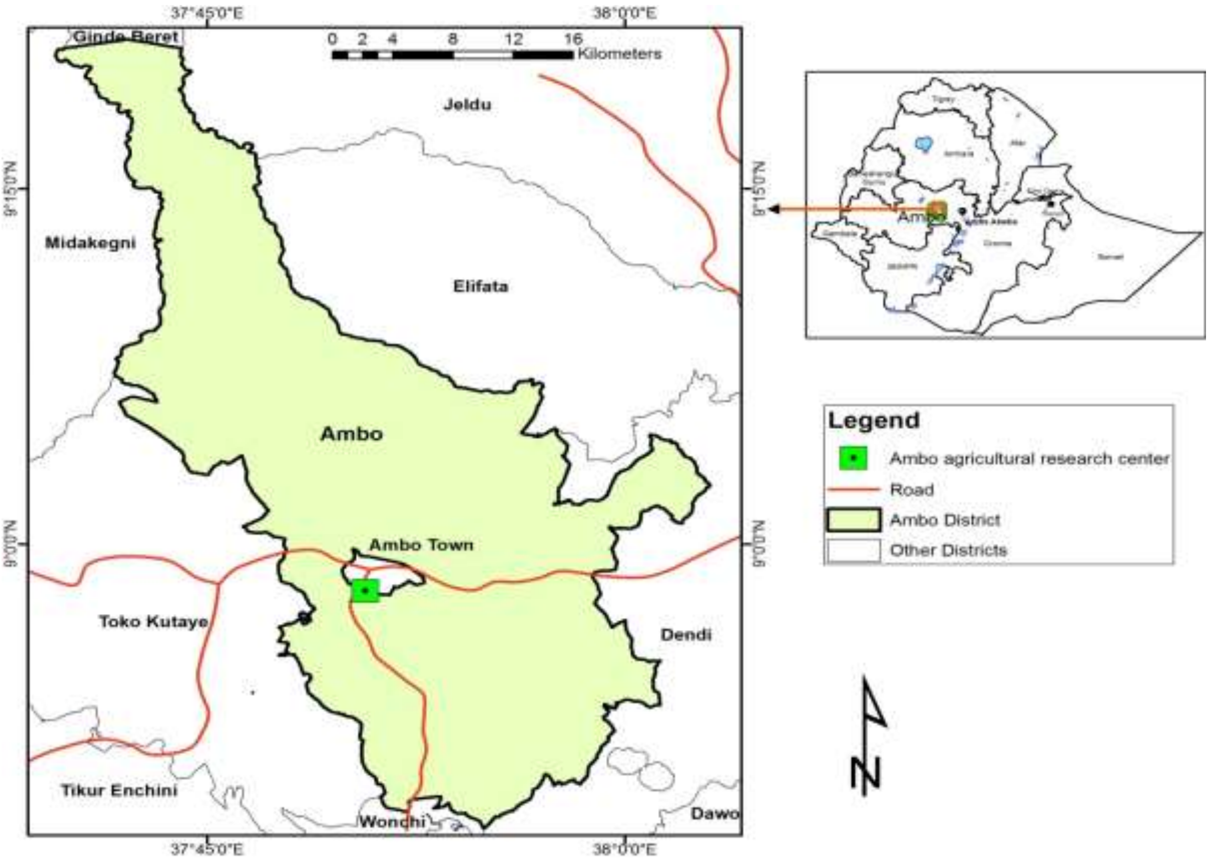

Figure 1: Location map of the study area (Ambo Agriculture Research Center)

Figure 2 presents the monthly rainfall, minimum, maximum and average air temperature recorded at the Ambo Agriculture Research Center Meteorology Station for the 2013 cropping season. The study area has a uni-model rainfall pattern and a total annual rainfall of 1260.90 mm. The rainy season extends from April to October with a peak in the months of June and July during the cropping season (Figure 2).

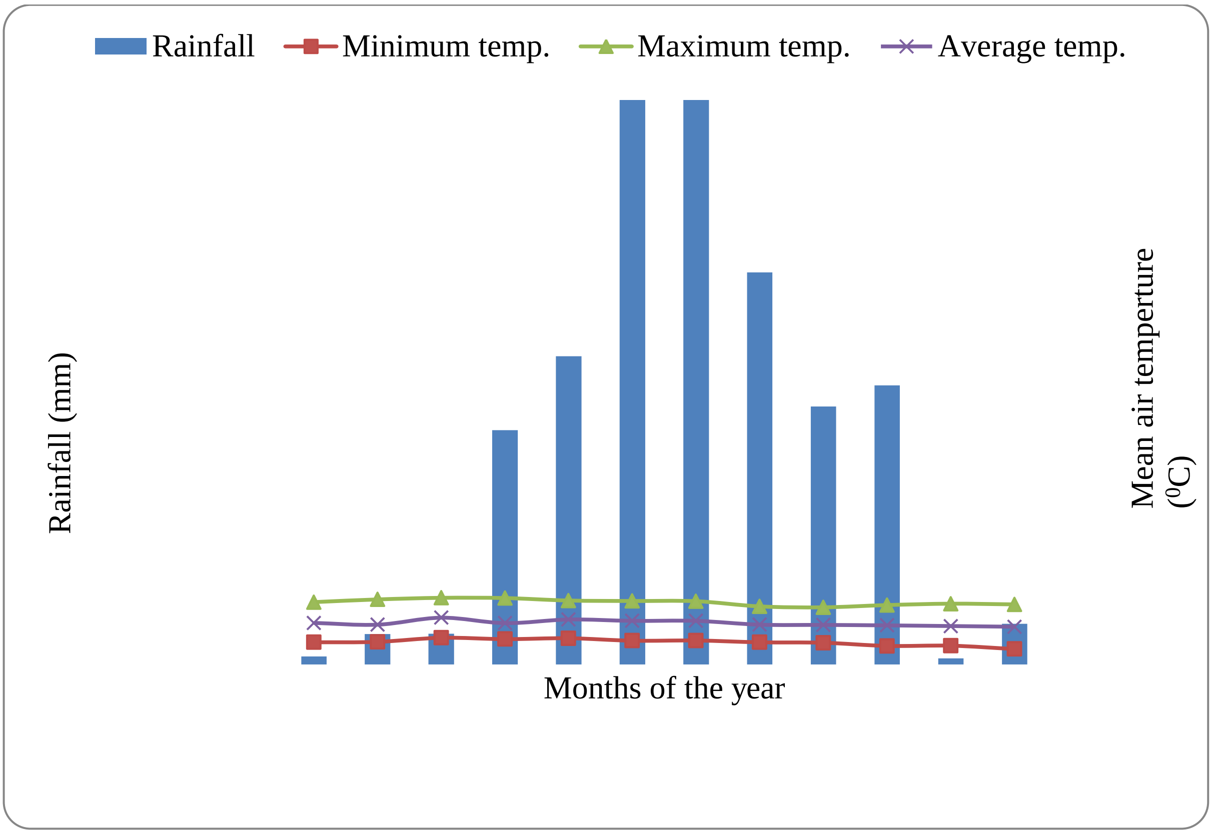

Figure 2: Monthly rainfall (mm), minimum, maximum and average air temperature (0C) at the study area during 2013

Field experiments

A field experiment was designed to test the effect of drain depth on selected physico-chemical properties of Vertisols during the main rainy seasons. A field experiment was laid out in a Randomised Complete Block Design (RCBD) with three replications. The treatments consist of five drain depths (0, 15, 30, 45 and 60 cm). A plot size of 5 m x 3.5 m was used. Plots within a block were separated by 1 m space and blocks separated by a 2 m path. In the study area land cultivation is done using oxen-drawn implements. Cultivation could be starting during the short rainy season when workability of Vertisols is good. Open drains were formed manually using hoes and spade, measured and adjusted to the required drain depths between the recommended row spacing of crops before wet periods to remove excess surface water.

Soil sampling and analysis

A total of five representative composite soil samples were randomly collected from each block from 0-30 cm soil profile before drain depths was made. An auger was used to collect soil samples randomly from each soil depth. The soil of these sub-samples was mixed thoroughly, dried at room temperature, ground and sieved through a 2 mm screen for physico-chemical analysis; whereas for organic carbon (OC) and total N determination soil samples were passed through 0.5 mm sieve.

Laboratory analysis was carried out to characterize the soil physical and chemical properties that are considered important for crop management. Soil particle size was analyzed by using the Bouyoucos hydrometer method following the procedure described by Day (1965). The textural class of the soil samples was obtained from soil textural triangle. After drain depth was made to remove excess surface water from the field, soil samples were collected from all plots from 0-15, 15-30, 30-45 and 45-60 cm depth and analyzed for the aforementioned physical and chemical properties.

The soil moisture content was monitored gravimetrically through oven drying at 105 0C until a constant weight was achieved (Gardner, 1986). Soil moisture contents at 0-15, 15-30, 30-45 and 45-60 cm soil layers were determined at 2 week intervals commencing from major rainy season from mid of May to end of December 2013. Soil samples for soil moisture content determination were taken before rainstorms.

Soil bulk density was determined by sampling the soil under natural condition using 100 cm-3 cylindrical metal samplers (Baruah and Barthakur, 1997). The sample was oven dried at 105 0C for 24 hours and weighed. The mass of the dried sample was divided by the volume of the cylinder. The reported value is for dry bulk density in g cm-3.

The average particle density (PD) value of mineral soils was taken as 2.65 gm cm-3 (Buol et al., 1989). Total porosity was estimated from the BD and PD values using the formula:

Soil pH was measured potentiometriclly using a pH meter with combined glass electrode at soil: water ratio of 1:2.5 as described by Carter (1993). Organic carbon (OC) content of the soil samples was determined using the wet oxidation method (Walkley and Black, 1934) where the carbon is oxidized under standard condition with potassium dichromate in sulfuric acid solution. Finally, the organic matter (OM) content of the soil was calculated by multiplying the per cent OC by 1.724. The total N content of the soil samples were determined by the Kjeldahl method using micro-Kjeldahl distillation unit and Kjeldahl digestion stand (Jackson, 1958). Available P of soil samples were determined by the Olsen method using NaHCO3 as extracting solution (Olsen et al., 1954). Carbon/nitrogen ratio (C: N) which measures the degree of mineralization of total nitrogen in relation to soil organic carbon level was obtained by dividing the value of percent organic carbon by value of percent total nitrogen. Exchangeable K in soil samples was determined from the leachate of ammonium acetate (NH4OAc) solution at (pH 7.0) by flame photometer (Rowell, 1994). Cation exchange capacity (CEC) was determined after saturation of the samples with 1N (pH 8.2) sodium solution. Ammonium acetate (1N) was used to exchange the adsorbed sodium ion from the exchange sites through percolation. Acidified potassium chloride (1N) was used to replace the adsorbed ammonium ions from the exchange sites through percolation. Finally, the amount of ammonium ion in the percolate was determined by distillation using the modified Kjeldahl method as described by Okalebo et al. (2002) and expressed as CEC of the soil in cmol (+) kg-1 of oven dry soil.

Statistical analysis

All soil data collected was processed using the Excel computer software. The collected data was subjected to the analysis of variance using the SAS program version 8.2 (SAS Institute, 2001). Treatment means for each parameter were separated by Duncan's Multiple Range Test (DMRT) and Least Significant Difference (LSD) test at P = 0.05.

Results and Discussion

Soil texture

The results showed that particle size distribution of the soil samples were dominated by clay fraction before drain depth formed in the 0-30 cm soil profile (Table 1). There were however spatial variation within the site in particle size distribution, bulk density and total porosity of the soil. The variation could be possibly being due to different soil management practices used in previous years. Before the formation of drain depth the soil samples had a mean clay content of 66.39%. The sand and silt content were a mean value of 11.39 and 22.2 %, respectively (Table 1).

The analyzed physical properties of the Vertisols at the study site after the formation of drain depth are presented in table 2. The result showed no significant effect of drain depth on sand, silt and clay contents of the Vertisols. The particles size distribution of 0-60 cm soil profile was dominated by clay fraction (above 61%). The variations in three soil separates were not consistent with drain depths within the 0-60 cm profile. The clay and silt content ranging from 61.86 to 66.12% and from 25.20 to 27.96%, respectively in the 0-60 cm soil profile even though statistically not significant (Table 2).

In the 0-15 cm soil layer undrained plots had the highest clay content. The proportion of the clay particles in the soil layers inconsistent with drain depth due to leaching of finer materials with drained water. The clay contents were higher in 0-15 cm soil layer particularly for 0, 15 and 30 cm drains. On the other hand, the sand content increased inconsistently with drain depths from 8.40 to 12.17% in the 0-60 cm profile even though statistically not significant. In the 45-60 cm soil layer, deep drains of 30, 45 and 60 cm resulted in the highest sand content. Relatively low sand content were observed in the 0, 15 and 30 cm drain depths in the 0-15 soil layer. In all soil layers, deep drains of 45 and 60 cm influence the proportion of sand and silt contents to some extent. The silt content showed slight variation with drain depths ranging from 25.20 to 27.96%. The highest silt content was found in deep drains of 30, 45 and 60 cm in the 15-30 cm soil layer (Table 2).

The silt to clay ratio of the soil samples ranging from 0.39 to 0.45 after drain depth and had a mean value of 0.33 before the drain was formed (Table 1 and 2). The highest silt to clay ratio was observed in 15-30 cm soil layer due to high percentage of silt particles at this layer. Hence, the silt to clay ratio of the Vertisols were high (greater than 0.15) both for soil samples before and after drain suggesting low degree of weathering and soil development stages.

Table 1: Selected physical properties of Vertisols of the experimental site before the formation of drain depth in 0-30 cm of the soil profile

Block	Particle size (%)			Textural class	Silt/Clay	BD (g cm^{-3})	TP (%)
	Sand	Silt	Clay				
1	12.18	20.36	67.46	C	0.30	1.20	54.72
2	10.73	21.84	67.43	C	0.32	1.27	52.07
3	11.27	24.45	64.28	C	0.38	1.30	50.94
Mean	11.39	22.2	66.39	C	0.33	1.26	52.58

BD = Bulk density; C = Clay; TP = Total porosity

Table 2: Effect of drain depth on selected physical properties of the Vertisols of the experimental site after formation of drain depth

Sampling depth (cm)	Drain depth (cm)	Particle size (%)			Textural class	Silt/Clay	BD ($g\ cm^{-3}$)	TP (%)
		Sand	Silt	Clay				
0-15	0	8.40	25.48	66.12	C	0.39	1.16b	56.23
	15	8.64	25.50	65.86	C	0.39	1.25a	52.83
	30	8.83	25.98	65.19	C	0.40	1.26a	52.45
	45	9.84	26.09	64.07	C	0.41	1.28a	51.70
	60	9.86	26.10	64.04	C	0.41	1.28a	51.70
LSD (0.05)		NS	NS	NS	-	-	0.07	-
SE (±)		0.20	0.56	1.45	-	-	0.02	-
CV (%)		7.79	7.47	7.70	-	-	6.92	-
15-30	0	9.64	27.71	62.65	C	0.44	1.19b	55.10
	15	9.92	27.52	62.56	C	0.44	1.27a	52.11
	30	10.06	27.96	61.98	C	0.45	1.29a	51.32
	45	10.15	27.94	61.91	C	0.45	1.29a	51.32
	60	10.20	27.94	61.86	C	0.45	1.30a	50.94
LSD (0.05)		NS	NS	NS	-	-	0.08	-
SE (±)		0.24	0.74	1.41	-	-	0.03	-
CV (%)		8.23	9.14	7.83	-	-	7.01	-
30-45	0	9.96	25.92	64.12	C	0.40	1.23	53.58
	15	10.26	26.38	63.36	C	0.42	1.27	52.05
	30	10.43	26.50	63.07	C	0.42	1.28	51.70
	45	10.67	26.88	62.45	C	0.43	1.28	51.70
	60	10.72	26.87	62.41	C	0.43	1.29	51.32
LSD (0.05)		NS	NS	NS	-	-	NS	-
SE (±)		0.27	0.71	1.35	-	-	0.03	-
CV (%)		8.43	8.81	7.39	-	-	6.74	-
45-60	0	11.14	25.55	63.31	C	0.40	1.25	52.83
	15	11.53	25.20	63.27	C	0.40	1.28	51.70
	30	12.01	25.95	62.04	C	0.42	1.29	51.32
	45	12.10	25.90	62.00	C	0.42	1.30	50.94
	60	12.17	25.89	61.94	C	0.42	1.30	50.94
LSD (0.05)		NS	NS	NS	-	-	NS	-
SE (±)		0.34	0.61	1.29	-	-	0.03	-
CV (%)		9.77	8.05	7.11	-	-	7.43	-

Means within a column followed by the same letter(s) are not significantly different at 5% probability. BD = Bulk density; C = Clay; TP = Total porosity; NS = Non-significant at P > 0.05

Bulk density and total porosity

The bulk density values were significantly ($P \leq 0.05$) affected by drain depths in the 0-30 cm soil layer; however, there was no significant difference in bulk density values of Vertisols within 30-60 cm soil depth (Table 2).

The bulk density values of the soil samples varied within 0-60 cm soil profile due to drainage condition. In this profile depth BD value of the Vertisols ranging from 1.16 to 1.30 g cm-3. The bulk density values of the Vertisols before the formation of drain depth had a mean value 1.26 g cm-3 in the 0-30 cm profile. The lowest BD value (1.16 g cm-3) was observed in plots with no drain provided in the upper soil layer (0-15 cm) and the highest BD (1.30 g cm-3) was recorded in plots with deep drains of 45 and 60 cm in the 45-60 cm soil layer. The maximum and minimum BD values correspond to drained and undrained plots, respectively. In general, BD of Vertisols decreases with increase in moisture content and vice versa (Table 1 and Table 2).

Moisture might have strong influence on BD values of these soils as soil BD changed considerably with changes in soil moisture content. The increase in BD of the Vertisols with drain depth attributed to the decrease of soil moisture content with drain depth in the profile. Moreover, the slight increase in BD values with soil profile might be due to the decrease in organic matter content with soil profile depth (Table 2 and 4). Furthermore, relatively low BD at surface layer could be due to high clay content of the Vertisols, i.e. 66.12%, which resulted in high total porosity (56.23%). Soils high in clay contents and low volumes of coarse fragments tend to have low values of bulk density (Table 2). According to Hillel (2004), bulk densities of productive soils usually range from 1.10 to 1.40 g cm-3. In view of this, bulk density values of the soils in the study area were within the normal range as a result of drainage condition that may not affect infiltration, permeability rates and root penetration.

Total porosity of the soil samples was high (56.23%) for plots with no drain provided at surface soil and decline with soil profile depth (Table 2). Similar result was also reported by Abayneh (2001) who reported that the total porosity of the Vertisols of the Raya Valley varied from 46 to 64%. Total porosity of the soil before the formation of drain depth had a mean value of 52.58% in the 0-30 cm profile (Table 1). The total porosity of soil decreased with drain depths in the 0-60 cm soil profile. The decline in total porosity of the soils is associated with increase in the bulk density values. The highest total porosity observed in plots with no drain provided in the 0-

15 soil layer due to the lowest bulk density value, and the highest moisture content, whereas the lowest total porosity corresponds to the highest bulk density value of the drain depth. Plots provided with deep drains of 45 and 60 cm resulted less moisture content resulting in decreasing total porosity of the Vertisols in 45-60 cm soil layer (Table 2).

Effect of drain depth on soil moisture contents

Soil moisture content during crop growth varied with drain depths and time of sampling. Soil moisture content was significantly ($P \leq 0.05$) affected by drain depths in 0-60 cm soil profile in most of the months except November and December (Table 3).

Plots with no drain depth provided had the highest moisture content during the entire crop growth period and though the soil layers to the depth of 60 cm as compared to plots in which drain depth were formed. The drains 15, 30, 45 and 60 cm deep reduced soil moisture to varying extents. Formation of drain depths to 45 and 60 cm had depleted soil moisture in 0-30 cm soil layer. However, formation of drain depth did not show significant variations in soil moisture content in the month of November and December. Plots with 45 and 60 cm deep drains had less soil moisture content than those with 0, 15 and 30 cm deep drains. The 45 and 60 cm deep drains clearly reduced soil moisture content in the 45-60 cm soil layer. The period of high soil moisture content extends from mid of June to August (Table 3).

The present study showed that soil moisture content decreased at deep drain depths of 45 and 60 cm resulting in the lowest moisture content as indicated in table 3. These results coincided well with Sigunga et al. (1997) who reported that drains 40 and 60 cm deep was important in reducing soil moisture content in the 0-60 cm soil profile, thereby preventing waterlogging in Vertisols. Similarly, Meles et al. (2013) in their study reported that ridge and furrow beds were highly drained at 30 cm and 60 cm soil depth for wheat grown on Vertisols.

Table 3: Temporal and spatial variations in moisture content (%) by mass fraction in Vertisols of experimental site

Sampling depth (cm)	Drain depth (cm)	Sampling time							
		May 17	June 18	July 16	Aug 18	Sept 17	Oct 17	Nov 17	Dec 19
0-15	0	35.26a	36.25a	38.46a	38.11a	31.08a	29.71a	28.63	25.98
	15	34.42ab	35.25ab	38.22a	38.10a	30.89ab	29.42ab	27.28	26.38
	30	33.80abc	35.07ab	37.96a	38.08a	30.70ab	29.29ab	27.39	26.30
	45	32.43bc	33.96ab	34.88b	35.09b	28.96ab	27.66b	26.95	25.99
	60	31.84c	32.84b	35.01b	35.04b	28.82b	27.61b	26.60	25.93
LSD (0.05)		2.60	2.59	2.72	2.59	2.17	2.00	NS	NS
SE (±)		0.82	0.82	0.86	0.82	0.69	0.63	0.70	0.65
CV (%)		8.51	8.22	8.10	7.71	7.93	7.64	8.87	8.65
15-30	0	31.16a	34.57a	35.96a	37.34a	30.68a	28.95a	28.82	26.83
	15	30.09ab	33.10a	36.13a	37.22a	29.70ab	28.75a	27.38	25.68
	30	29.40abc	32.70a	36.20a	37.08a	29.51ab	28.99a	27.13	25.60
	45	28.93bc	30.59b	32.38b	33.42b	28.29b	27.36ab	26.66	26.59
	60	27.92c	30.16b	32.15b	33.39b	28.09b	26.95b	26.18	26.01
LSD (0.05)		2.21	2.34	2.61	2.84	2.12	1.83	NS	NS
SE (±)		0.70	0.74	0.83	0.90	0.67	0.58	0.64	0.65
CV (%)		8.23	7.98	8.29	8.76	7.96	7.13	8.12	8.62
30-45	0	29.10a	31.72a	33.64a	33.44a	30.41a	28.25	28.40a	26.79
	15	28.92ab	31.82a	33.33ab	32.56a	29.55ab	27.47	26.75ab	26.66
	30	28.10abc	30.60ab	33.08ab	32.52a	29.37ab	27.40	26.65ab	26.58
	45	27.25bc	29.48b	31.09ab	29.13b	27.70bc	25.95	25.93b	25.48
	60	26.82c	28.99b	31.00b	29.06b	26.90c	25.78	25.62b	25.27
LSD (0.05)		2.08	2.18	2.51	2.58	2.13	NS	2.10	NS
SE (±)		0.66	0.69	0.80	0.82	0.67	0.68	0.66	0.63
CV (%)		8.16	7.87	8.51	9.06	8.12	8.75	8.64	8.30
45-60	0	27.16a	28.76a	32.09a	32.34a	29.60a	26.78a	26.53	26.41
	15	26.89a	27.83a	31.02a	32.37a	28.03ab	25.62ab	25.35	25.38
	30	26.65ab	27.66ab	30.01ab	32.07a	27.76ab	25.61ab	24.55	25.32
	45	25.20ab	27.12ab	28.57b	29.20b	26.21b	24.91b	25.44	24.61
	60	24.90b	25.92b	28.25b	29.12b	26.08b	24.30b	24.03	24.39
LSD (0.05)		2.03	1.92	2.26	2.56	2.08	1.79	NS	NS
SE (±)		0.64	0.61	0.72	0.81	0.66	0.57	0.72	0.66
CV (%)		8.54	7.68	8.28	9.08	8.29	7.74	9.98	9.13

Means within a column for each sampling depth followed by the same letter(s) are not significantly different at 5% probability.

Soil reaction (pH)

The results showed that there was significant variation ($P \leq 0.01$) on soil pH in the 0-60 cm soil layer due to the effect of drain depth of Vertisols (Table 5). The variations in soil pH (H_2O) were not consistent with drain depths. In 0-15 cm soil depth, plots with no drain depth provided were moderately acidic (pH of 5.98), and plots with 15, 30, 45, and 60 cm deep drains were slightly acidic (6.08 - 6.58) based on classification set by Tekalign and Haque (1991). With respect to Vertisols, the present study indicated that soil pH increased as soil depth and drain depths increased. Deep drainage of Vertisols to 45 and 60 cm resulted in neutral to alkaline soil reaction (Table 5). On the other hand soil pH had a mean value of 6.12 before the formation of drain depth (Table 4). In general, soils of the study site were found to have slightly acidic to neutral reactions in the 0-30 cm soil profile and slightly alkaline reactions in the 45-60 cm soil profile. The variability in soil pH in the study site could be due to drainage condition which considerably influences soil moisture content.

Table 4: Selected chemical properties of Vertisols of the experimental site before the formation of drain depth in 0-30 cm of the soil profile

Block	pH (H_2O)	OM (%)	C:N ratio	Total N (%)	AP (mg kg^{-1})	Exch. K (mg kg^{-1})	CEC cmol (+) kg^{-1}
1	6.16	2.64	12.76	0.12	6.02	160.07	46.34
2	6.11	2.66	11.87	0.13	6.01	154.89	45.88
3	6.10	2.69	12.00	0.13	6.03	158.29	48.69
Mean	6.12	2.66	12.21	0.13	6.02	157.75	46.97

OM = Organic matter; AP = Available (Olsen) phosphorus; Exch. K = Exchangeable potassium; CEC = Cation exchange capacity

Table 5: Main effects of drain depth on selected soil chemical properties of the Vertisols of the experimental site after formation of drain depth

Sampling depth (cm)	Drain depth (cm)	pH (H_2O)	OM (%)	C:N ratio	Total N (%)	AP (mg kg^{-1})	Exch. K (mg kg$^{-1)}$	CEC cmol (+) kg^{-1}
0-15	0	5.98c	2.72c	11.78	0.134d	6.02b	170.07b	51.38b
	15	6.08c	2.95c	11.68	0.146c	6.22ab	182.83a	52.32b
	30	6.20bc	3.19b	11.58	0.160b	6.30ab	184.19a	52.71b
	45	6.50ab	3.35ab	11.68	0.167ab	6.55a	193.08a	59.18a
	60	6.58a	3.57a	11.72	0.176a	6.61a	193.95a	59.29a
LSD (0.05)		0.41	0.27	-	0.013	0.47	13.77	4.72
S.E. (±)		0.13	0.08	-	0.004	0.15	4.37	1.51
CV (%)		6.96	9.30	-	9.021	8.12	8.19	9.45
15-30	0	6.11b	2.24b	10.40	0.125c	5.50b	168.87b	48.01b
	15	6.20b	2.32b	10.30	0.131bc	6.01a	181.88a	48.46b
	30	6.23b	2.41ab	10.24	0.137ab	6.27a	183.27a	48.76b
	45	6.56a	2.54a	10.22	0.144a	6.37a	188.56a	55.33a
	60	6.62a	2.55a	10.27	0.144a	6.40a	188.69a	55.45a
LSD (0.05)		0.35	0.19	-	0.010	0.46	13.95	4.56
S.E. (±)		0.11	0.06	-	0.003	0.15	4.43	1.45
CV (%)		6.15	8.48	-	8.219	8.32	8.41	9.79
30-45	0	6.25c	1.74b	9.59	0.105c	5.26b	166.34b	45.11b
	15	6.33c	1.78b	9.32	0.111c	5.45b	176.86ab	44.61b
	30	6.44bc	1.77b	9.11	0.112c	5.48b	179.73a	45.51b
	45	6.72ab	1.94a	9.13	0.123b	6.06a	181.47a	50.81a
	60	6.94a	1.94a	8.56	0.131a	6.25a	183.14a	50.38a
LSD (0.05)		0.40	0.15	-	0.009	0.42	13.24	3.58
S.E. (±)		0.13	0.05	-	0.003	0.13	4.20	1.34
CV (%)		6.74	8.94	-	8.561	8.16	8.20	8.33
45-60	0	6.55b	1.16c	9.29	0.072c	3.37b	161.06b	41.20b
	15	6.76b	1.25bc	9.25	0.078c	3.53ab	171.02ab	43.24b
	30	6.88b	1.31ab	9.32	0.082b	3.63a	172.62ab	43.14b
	45	7.23a	1.36a	8.79	0.090a	3.75a	176.89a	48.27a
	60	7.30a	1.36a	8.56	0.092a	3.70a	177.73a	48.47a
LSD (0.05)		0.38	0.11	-	0.007	0.26	13.01	3.78
S.E. (±)		0.12	0.04	-	0.002	0.08	4.13	1.21
CV (%)		6.03	9.28	-	9.175	8.11	8.32	9.26

Means within a column for each sampling depth followed by the same letter(s) are not significantly different at 5% probability. OM = Organic matter; Total N = Total nitrogen; AP = Available (Olsen) phosphorus; Exch. K = Exchangeable potassium; CEC = Cation exchange capacity

Organic matter, and total nitrogen and carbon-nitrogen ratio

The organic matter content of the soil was significantly ($P \leq 0.01$) affected by drain depths in the 0-60 cm soil layer (Table 5). The organic matter content decreased as soil depth increases while increase in drain depth of Vertisols improved the soil organic matter content to some extent. In Vertisols, soil organic matter content varies from very low to low levels. The lowest organic matter content was observed in the plots with no drain depth provided in the 45-60 cm soil layer. The organic matter content of soils ranged from 1.16 to 3.57% in the 0-60 cm soil profile (Table 5).

On the other hand, OM content of soils before the formation of drain depth had a mean value of 2.66% (Table 4). The highest organic matter was recorded in plots provided with drains 30, 45 and 60 cm deep in the 0-15 cm surface soil layer (Table 5). The level of soil OM content shows an increasing trend with increasing drain depths in the same soil layers and a decreasing trend in the 0-60 cm depth of profile (Table 5).

The results showed that total nitrogen was significantly ($P \leq 0.01$) affected by drain depths of the Vertisols in the 0-60 cm soil profile (Table 5). The total nitrogen contents of the soil after formation of drain depths varied from 0.07-0.18% in the 0-60 cm profile (Table 5). On the other hand, the total N contents of the soils before the formation of drain depth had a mean value of 0.13% (Table 4). These indicate that similar to OM, total N of Vertisols was highly affected by drainage condition of the soils. According to the rating of total N set by (1991), the total N is generally low to very low in the 0-60 cm soil profile. The highest value of total N was recorded at 30, 45 and 60 cm deep drains in the 0-15 cm surface soil layer. This is due to the highest OM content of soils of this layer (Table 5).

On the other hand, plots with no drain depth provided had very low total N content as a result of N losses by denitrification and leaching. The N contents being higher in the upper layers (0-15 and 15-30 cm) than the 30-45 and 45-60 cm layers. In line with soil organic matter contents in the soils profile, the contents of the total N also showed an increasing trend with drain depths and a decreasing trend with soil depth suggesting total N is directly correlated to organic matter contents of the soils. The low total N contents indicate that the soils of the study area are deficient in N to grow crops. Hence, the soils need an external N fertilizer for optimum growth of plants. The drain depths of 30, 45 and 60 cm reduced soil moisture content in the 0-60 cm profile, thereby preventing waterlogging mean while reduced dentrification (Table 3 and 5). This is in line with the findings of (Sigunga et al., 1997) who reported that drain depth reduced N losses in waterlogging Vertisols.

The carbon-nitrogen ratios (C/N) varied irregularly in the 0-60 cm soil profile. It varied from 10.22 to 11.78 in the upper layers (0-15 and 15-30 cm) and 8.56 to 9.59 in the 30-45 and 45-60 cm soil layers (Table 5). On the other hand, C/N ratios of the soil samples before the formation of drain depth had a mean value of 12.21 (Table 4). The C/N ratio is affected by drain depths and C/N ratio is inversely related to soil N. The C/N ratio increases as the level of total N in the soil decreases. This is in agreement with Saikh et al. (1998a) who reported that reduction of soil organic matter and total N due to cultivation of land and management practices resulted in increased C/N ratio of soils. When the C/N ratio is greater than 30:1, N is immobilized by soil microbes while at C/N ratio of less than 20:1, there is N mineralization soil system. The N released into the soil under the narrow condition is available for plant uptake (Jones, 2003). In the present study, the C/N ratio of Vertisols after the formation of drain depth was generally below 11.78; indicating that there could be release of available form of N to the soil system through the mineralization process of soil organic matter.

Available phosphorus

The results showed that available phosphorus (P) was significantly ($P \leq 0.05$) affected by drain depths in the 0-60 cm soil layer. The values of Olsen extractable P of the Vertisols increased as drain depth increased in the 0-60 cm soil profile (Table 5).

The available P varied from 3.37 to 6.61 mg kg-1 soil in the 0–60 cm soil profile and had a mean value of 6.02 mg kg-1 soil before the formation of drain depth in the 0-30 cm soil profile (Table 4). The drains 30, 45 and 60 cm deep increased P content to varying extents in the 0-15 cm soil layer. In this soil layer, deep drains of 30, 45 and 60 cm resulted in high P contents (Table 5). This is due to high percent of organic matter content and removal of excess water by drainage furrows that create conducive environment for soil microorganism to increase the availability of P in the upper soil layer which is in agreement with the suggestion of Clark et al. (1998) who indicated that soil organic matter influence P availability to crops directly by contributing to phosphorus pool.

Moreover, the residual effect of DAP fertilizer applied during the last cropping season might have increased P content of the Vertisols at the upper soil layer. This is in line with the findings of Tekalign et al. (1988) who reported that surface P is usually greater than that in subsoil due to sorption of the added P, greater biological activity and accumulation of organic material on the surface. Birru (1999) reported that availability of P varied considerably with soil reaction, total P reserves and the particle size distributions of the soils.

According to the rating of P set by Landon (1991), the available P contents of the Vertisols were low to very low in the 0-60 cm soil profile. Finck and Vendateswarlu (1982) reported that for cereals, the critical limit below which responses to applied P could be expected on Vertisols is about 8 mg kg-1 soil for Olsen extractable P. Tekalign and Haque (1991) also reported that 8 mg kg-1 P was the critical level for Ethiopian soils when assessed by the Olsen method. Thus, existence of low contents of available P is a common characteristic of soils in Ethiopia. Generally, the available P content of soils in the study area is below the critical values which could significantly limit crop production.

Exchangeable potassium

Exchangeable potassium significantly ($P \leq 0.05$) varied with drain depths in the 0-60 cm soil profile (Table 5). The highest K value (193.95 mg kg-1) was recorded at the upper layer of (0-15 cm) drains formed at 45 and 60 cm deep, whereas the lowest K value (161.06 mg kg-1) was recorded in plots with no drains in the 45-60 cm soil layer (Table 5). Soil samples collected before formation of drain depth had a mean exchangeable K content of 157.75 mg kg-1 soil in the 0-30 cm soil layer (Table 4).

Exchangeable K content increased with drain depths and did not show any consistent trend with soil profile depth. The amount of exchangeable K was higher in the upper soil layer (0-15 cm) due to the higher clay contents that bind exchangeable K at the colloidal sites in this soil layer. Mokwaunye (1978) indicated that exchangeable K content of a soil depends on the drainage condition and degree of soil development, the intensity of cultivation and parent material from which soil is formed. According to the rating of K set by the International Fertilizer Industry Association (IFA) (1992) who categorized exchangeable K contents of the soil in mg kg-1 of < 50 as very low, 50 to 100 low, 100 to 175 medium, 175 to 300 high and > 300 as very high; the exchangeable K contents of the Vertisols of the study were medium to high in all drain depths in the soil profile. Hence, there is no K deficiency in the soil for crop production in the study area.

Cation exchange capacity

The cation exchangeable capacity of the soil was significantly ($P \leq 0.01$) affected by drain depths of the Vertisols (Table 5). The CEC values of the Vertisols at the upper (0-15 and 15-30 cm) soil layer ranged from 48.01 to 59.29 cmol(+) kg-1 soil. It was ranged from, 41.20 to 50.81 cmol(+) kg-1 soil in the lower (30-45 and 45-60 cm) soil layers (Table 5). On the other hand, soil samples before the formation of drain depth had a mean CEC value of 46.97 cmol(+) kg-1 soil (Table 4). The CEC value of the present study is low when compared with values as high as 70 cmol (+) kg-1 reported by Jutzi and Abebe (1987) for Ethiopian Vertisols. The CEC of the Vertisols increased as drain depths increased except in the drain depth of 15 cm in 30-45 cm soil layer. In the 0-15 cm soil layer, drains 45 and 60 cm deep resulted in high CEC of the soils. This variability of CEC with soil depths as a result of drain depths which was substantially influenced soil moisture content (Table 5).

Cation exchange capacity is influenced by drainage condition of the soil. Based on the rating of CEC set by Landon (1991), the CEC of the soils of the study area could be classified as very high in the 0-60 cm soil profile. In Vertisols CEC is positively correlated with organic matter content of the soil. This implies that as organic matter of the soils increased, the CEC also increased as reported by Saikh (1998b).

Conclusion

Drainage plays an important role in improving physico-chemical characteristics of Vertisols for crop production. The effects of drain depth on physico-chemical characteristics of Vertisols were investigated. Deep drain depth of 45 and 60 cm resulted in lower soil moisture within 0-45 cm soil layer. The soil of the study site was dominated by clay fraction. The highest bulk density value was recorded in plots with deep drains of 45 and 60 cm. Similarly, total porosity of the soil was high for undrained plots. The pH (H_2O) of the soils increased as drain depth increased. The effects of drain depths of 45 and 60 cm deep resulted in significantly higher OM, total N, available P, exchangeable K and CEC of the soils in the 0-45 cm soil layer. From this study, it was concluded that drain depth of 45 cm could improve the physico-chemical characteristics of Vertisols for crop production in Ambo and similar areas.

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References

Abayneh E (2001). Some physico-chemical characteristics of the Raya Valley soils, Ethiopia. Ethiopian Journal of Natural Resources. 3(2): 179-193.

Ahmad N (1983). Vertisols in: Pedogenesis and Soil Taxonomy. II. The Soil Orders, by L.P. Wilding, N.E. Smeck and G.F. Hall (eds.). Elsevier Science Publishers B.V., Amsterdam, The Netherlands pp. 91-123.

Ahmed N (1988). Management of Vertisols in humid tropicsIn: L.P. Wilding, and R. Puentes (eds.). Vertisols: Their distribution, properties, classification and management. Techn. Mono. #18, Texas A and M pp. 97-115.

Asiedu E K (1996). Evaluation of four Vertisol management technologies. Using certain soil physical parameters (M Phil Thesis). Dept. of Soil Science, University of Ghana, Legon.

Baruah T C Barthakur H P (1997). A Textbook of soil analysis. Vikas publishing house PVT Ltd., Delhi.

Berhanu D (1985). The Vertisols of Ethiopia their properties, classification and management. 5th Meeting of the Eastern African Soil Correlation and Land Evaluation Sub-Committee, 4-10 December 1983, Wad Medani Sudan. World Soil Resources Report 56. FAO (Food and Agriculture Organization of the United Nations), Rome. And

Birru Y (1999). Phosphorus Status and Sorption Characteristics of the Soils of the North-western Highlands of Ethiopia. MSc. Thesis. Alemaya University.

Buol S W, Hole F D & MCcracken D R (1989). Soil genesis and classification 3rd (ed.). Iowa State University Press, Ames.

Carter M R (1993). Soil sampling and methods of analysis. Canadian Soil Science.

Clark, M.S, Howarth W.R, and Shennan C, Scow M. 1998. Changes in soil chemical properties resulting from organic and low input farming practices. Agronomy Journal. 90: 662-671.

Coulombe C E Wilding L P Dixon J B (1996). Overview of Vertisols: characteristics and impacts on society. Adv. Agron. 57: 289-375.

Day P R (1965). Hydrometer method of particle size analysis. In: C.A. Black (ed.). Methods of Soil Analysis. Agronomy. Part II, No. 9. American Society of Agronomy, Madison, Wisconsin, USA pp. 562-563.

Finck A Venkateswarlu J (1982). Chemical properties and fertility management of Vertisols. In: Vertisols and rice soils of the tropics. Symposium Papers 2. Transaction of the 12th International Congress of Soil Science, New Delhi 3: 61-69.

Gardner W H (1986). Water content. In: A. Klute (Ed.). “Methods of Soil Analysis, Part I. Physical and Mineralogical Methods,” Second Edition, ASA Monograph #9, Madison, WI pp. 493–544.

Hillel D (2004). Soil fertility decline in the tropics: With Case Studies on wheat yield and water use. Soil Sci. Soc. Am. J. 55:1680-1685.

Hubble G D (1994). The cracking clay soils: definition, distribution, nature, genesis and use. In: McGarity J., Hoult, E.H. and H.B. So, (eds.). Properties and Utilization of Cracking Clay Soils, Reviews in Rural Science #5. University of New England, Armidale, New South Wales, Australia pp.3-13.

IFA (International Fertilizer Industry Association) (1992). World Fertilizer Use Manual. Paris, France.

Jackson M L (1958). Soil chemical analysis. Prentice Hall, Inc., Engle Wood Cliffs. New Jersey, USA.

Jones J B (2003. Agronomic handbook: management of crops, soils, and their fertility. CRC Press LLC, N.W. Corporate Blvd., Boca Raton, Florida.

Jutzi S Abebe M (1987). Improved agricultural utilization of Vertisols in Ethiopian Highlands: An Institutional approach. In Management of Vertisols under Semi-arid conditions. IBSRAM Proc. No.6, Bangkok: IBSRAM pp. 173-183.

Jutzi S Getachew A Haque I Abate T Abiye A (1987). Intermediate technology for increased food and feed production from deep black clay soils in the Ethiopian highlands. Paper presented at the FAO/SIDA Seminar on Increased Food Production through Low-Cost Food Crops Technology, Harare, Zimbabwe, 1-17 March 1987.

Landon J R (1991). Booker Tropical Soil Manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. John Wiley & Sons Inc., New York.

Meles M Kindie T Wondimu B (2013). Soil Drainage and Nutrient Management to Improve Productivity of

Waterlogged Vertisols for Small-scale Farmers. Engineering International. 1(2): 30.

Mokwaunye A U (1978). The role of inorganic fertilizers in the chemical degradation of Nigerian savannah soils. Samaru conference paper 14. Expert consultation on methodology for assessing soil degradation. FAO, Rome pp. 16.

Okalebo J R Gathua K W Woomer P L (2002). Laboratory methods for soil and plant analysis. A work manual, 2nd ed. TSB-CIAT and SACRED Africa, Nairobi, Kenya.

Olsen S R Cole C Watanabe F S Dean L A (1954). Estimation of available phosphorous in soils by extraction with sodium bicarbonate. USA Circular. 939: 1-19.

Paulos D Asgelil D Asfaw Z Gezahegn A Abebe K (2001). Advances in Vertisols Management in the Ethiopian Highlands. Proceedings of the International Symposium on Vertisols Management, 28 November to 1 December 2000, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Pushparajah E (1992). Overview of IBSRAM's Vertisols network in Africa. In: IBSRAM, 1992. Report of the 1992 annual review meeting on Africa Land Management of Vertisols in Africa. Network Doc. # 3. IBSRAM: Bangkok. pp. 167-186.

Rowell D L (1994). Soil science, methods and applications. Department of Soil Science, University of Reading. Longman Group UK.

Saikh H Varadachari C Ghosh K (1998a). Changes in carbon, nitrogen and phosphorus levels due to deforestation and cultivation. A case study in Simplipal National Park, India. Plant Soil. 198: 137-145.

Saikh H Varadchari C Ghosh K (1998b). Effects of deforestation and cultivation on soil CEC and contents of exchangeable bases. A cause study in Simplipal National Parc, India. Plant Soil. 240:67-75.

SAS Institute (2001). The SAS system for windows, version 8.2. SAS Institute Inc. Cary, NC, USA.

Sigunga D O Janssen B H Oenema O 1997. Fertilizer nitrogen use efficiency and nutrient uptake by maize (Zea mays L.) in Vertisols in Kenya PhD thesis. Wageningen Agricultural University, The Netherlands.

Sigunga D O Janssen B H Oenema O (2002). Effect of improved drainage and nitrogen source on yields, nutrient up-take and utilization efficiencies by maize (Zea mays, L.) on Vertisols in sub-humid environments. Nutrient Cycling in Agro-ecosystems, 62 (3). pp. 263-275.

Tekalign M Haque I (1987). Phosphorus status of some Ethiopian soils. 1. Sorption characteristics. Plant and Soils. 102(2): 261-266.

Tekalign M Haque I Kamara C S (1988). Phosphorus status of some Ethiopian highland Vertisols. In: Jutzi S C, Haque I, McIntire J and Stares J E S (eds.). Management of Vertisols in sub-Saharan Africa. Proceedings of a conference held at ILCA, Addis Ababa Ethiopia, 31 August - 4 September 1987. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. pp. 232-252.

Tekalign M Haque I (1991). Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available phosphorus. Tropical Agriculture. 68: 1: 2-8.

Teklu E Assefa G Stahr K (2004). Land preparation methods efficiency on the highland Vertisols of Ethiopia. Irrigation and Drainage. 53(1): 69-75.

Walkely A Black C A (1934). Determination of organic matter in the soil by chromic acid digestion. Soil Sci. 63: 251-264.