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RESEARCH ARTICLE

THE EFFECT OF AGROFORESTRY BASED CONSERVATION TILLAGE ON WATER INFILTRATION AND SELECTED SOIL PROPERTIES IN SOUTHERN ETHIOPIA

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ABSTRACT

With the aim of evaluating the effects of agroforestry based conservation tillage (AFCT) on water infiltration and selected soil properties, two tillage types: Agroforestry based Conservation Tillage (AFCT) and Maize based Conventional Tillage (MCT) under three age categories (10, 20 and 30-years) were selected in Wonago District, Southern Ethiopia. A total of 48 composite soil samples (4 replication * 2 tillage types * 3 age categories * 2 soil depth layers: 0-20 cm and 20-40cm) were collected to analyse the soil organic carbon (SOC%) content of the soil together with soil textural fractions (%) and porosity (%). Additional undisturbed core samples were also collected to determine soil bulk density (g cm-3). Water infiltration capacity was measured in the field using double ring infiltrometer. From the three age categories, a total of 18 measurement points (3 replication * 2 tillage types * 3 age categories) were carried out for one full hour and changes in water levels were recorded at time increments of 1, 2, 5, 10, 15, 20, 30, 40 and 60 min for calculation of rate and cumulative water infiltration. The result showed that the soil textural fractions (sand, silt and clay) significantly varied ($\rho<0.001$, $P<0.001$ and $P = 0.002$, respectively) with age of land use management. Soil bulk density, Pt and SOC varied significantly with tillage types ($\rho<0.001$) and soil depth ($\rho<0.001$). Water infiltration (rate and cumulative) significantly varied ($\rho< 0.001$) with tillage types: higher in the AFCT than in the MCT. Lower soil bulk density and higher SOC were observed in the top 0-20 cm soil layer under the AFCT than in the MCT. Soil bulk density increased while Pt and SOC decreased with soil depth in both tillage types. Improvement in the water infiltration under AFCT was due to higher soil organic carbon (SOC) input and less soil disturbance. Thus, reducing the frequency of soil disturbance through application of agro forestry based conservation tillage would help to improve water infiltration capacity and other soil qualities.

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INTRODUCTION

Soil degradation due to using inappropriate tillage practice is a vital issue throughout the world, particularly in developing countries. Soil tillage influences the soil natural phenomena and ecological processes leading to a remarkable change in soil properties. Young (1989) has reported that inappropriate agricultural practices like conventional tillage has caused soil degradation including deterioration of physical, chemical and biological properties. Conventional tillage system deprives soil's capacity to hold water and its intake, deteriorates structure stability and compactness, nutrient supply and storage as well as its biological life (Lal, 2004; Fantaw Yimer *et al*., 2008; Marcela, 2009). Tilling the soil intensively and frequently as soil management practice affect the physico-chemical properties of the soil (Oguike and Mbagwu, 2009) and remarkably impair water infiltration of the soil (Gregory *et al*., 2005). Disaggregation of the soil structure and oxidation of organic matter is also a common feature of conventional tillage. Moreover, in areas where conventional tillage is a common practice, soil carbon is lower due to low level of plant residue and organic matter input, increased soil loss through erosion and increased bulk density of the soil system (Reddy, 2005; Marcela, 2009; Osuji *et al*., 2010). In order to minimize the effect of conventional tillage, in recent years, the world has been shifting towards using conservation tillage as a mechanism of maintaining soil health. When this system combined with agroforestry system, the positive impact on the soil becomes more meaningful. Agroforestry (based conservation tillage) as a land use system, receiving greater attention in many countries to protect the soil from various types of degradation and it is a tool for achieving sustainable agricultural farming and improving the quality of life (*UNCCD*

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2003; *ICRAF,* 2004). There are different kinds of AF systems like improved fallows, contour hedgerows and others involving permanent cover play an important role in arresting and reversing soil degradation via their ability to improve chemical as well as physical properties of the soil (Udawatta *et al.*, 2002). Okigbo and Lal (1985) have reported that vegetations that remain on a farm can facilitate and maintain hydrological balance and minimize run-off components of the hydrological cycle through enhancing water infiltration. Many scholars (for instant; Dexter, 2004; Fikadu, 2006; Fantaw Yimer *et al*., 2008; Acharya & Kafle, 2009) have shown the impact of agroforestry system in enriching the water infiltration capacity of the soil through providing organic matter in to the soil system. The presence of organic matter in agroforestry based conservation tillage further increase soil fauna and flora and lower bulk density when compared to conventional tillage system. The presence of trees in the farm coupled with minimum soil disturbance improves most soil properties like soil organic matter, soil aggregation, water infiltration and decrease in bulk density (Tsimba *et al*., 1999; Brady, 2002; Murphy *et al*., 2006; Romaneckas *et al*., 2009).

In the study area, practically there is no farming practice where one or more tree species are not integrated. Weedy plant species play a vital role in nutrient cycling. The perennial crops protect the soil from erosive forces and induce the rain water to seep slowly into the soil profiles. The soil management practice in the study area is predominantly of indigenous farming system or traditional agroforestry with application of conservation tillage system. This tillage practice provides the soil more strength and gives structural stability. Farmers in the study area also allocated their land for mono-cropping system (conventional tillage system). The crop (Maize) cultivation involves ox-plowing using simple and shallow plows that till the soil (using traditional *Maresha*) to a depth of 15 cm on average. This traditional Maresha (Figure 1) with its full setup off course could be used in most part of Ethiopia. The whole system of this implement is made up of locally available wood, cattle skin as a strap on the rear side of the beam and on the yoke (Figure 1).

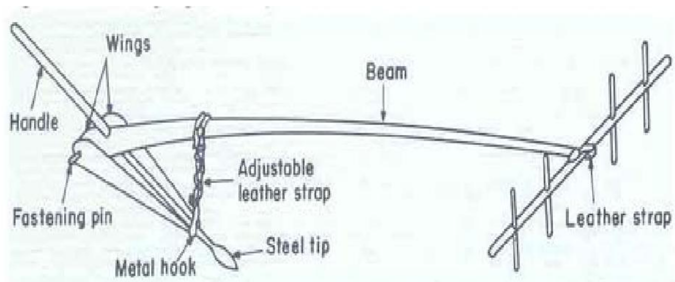

Figure 1. Traditional *Maresha* used in the study area

This traditional tillage implement is commonly drafted by oxen (Gebregziabher *et al*., 2006). The first plowing time for maize crop here in the study area is done as soon as on the onset of the first rain season. Because of its V-shaped ploughing by Maresha, the local farmers have to do repeated tillage with any two consecutive tillage operations carried out perpendicular to each other. As a result, the soil is pulverized resulting in weak soil structure and compact formation. Farmers plough 2 - 3 times before sowing maize in the study area. Because of repeated tillage at shallow depths, commonly 15cm, plough pans may form below the plough layer. The V- shaped furrows also result in higher relative surface area exposure leading to an increased loss of moisture through evaporation. People often remove maize residues after harvest either for fuel wood or animal feed. Thus, no crop residue remains in the field each season for either mulching or organic amendment to the soil. However, the farmers have access to commercial fertilizers and sometimes use manure and compost in their farm plots near to their homesteads. Concerning the chemical fertilizers, Urea and DAP were the common inputs used in the study area for maize crop production on conventional tillage system. DAP (Diammonium phosphate, (NH4)2HPO4)) was used simultaneously at the time of sowing maize (Zea mays). On the other hand, Urea (with 46% of Nitrogen) was used after the crop develops 2-3 leaves. No chemical fertilizers have been used in agro forestry based conservation tillage system. On the other side, in the agro forestry based conservation tillage system, animal plowing using traditional *Maresha* is difficult to apply. Thus, farmers use small hand equipments like hand hoe for land preparation. They also leave weedy herbaceous in the fields with the objectives of mulching and addition of organic matter in to the soil system. Therefore, nutrient cycling and soil protection from erosive forces and inducing rainwater to percolate in to the soil profile become the possible advantages derived from the system. In addition, the local farmers have been planting tree species like Millettia ferruginea, Ficus vasta and Erythrina abyssinica, for soil amelioration.

Apart from an initial reconnaissance (Kippie, 2002) and recent report on characterization and classification of the soils of the study area (Wendemeneh, 2010), there has been no study conducted so far to evaluate the effect of agroforestry based conservation tillage (AFCT) on water infiltration and selected soil properties. Moreover, the research area also becomes an area of particular concern due to the presence of high human population pressure. As a consequence, there has been shifting of (removal of agroforestry components like trees for timber production) agroforestry based conservation tillage (AFCT) into mono-cropping practice (maize based conventional tillage, MCT) for the sake of reducing the alarmingly increasing food shortage in the area. This shifting has a tremendous effect on water infiltration capacity as well as on the properties of the local soil. Therefore, this research was intended to evaluate the effect of agroforestry based conservation tillage (AFCT) on water infiltration capacity and on selected soil properties.

MATERIALS AND METHODS

Description of the study area

The study was carried out in *Wonago* district, *Gedeo Zone*, Southern Ethiopia (Figure 2). The study area is located 375 km and 100 km south of Addis Ababa and Hawassa respectively. Geographically it is located 6 ^{0}13'-6^{0}26' North latitude and 38^{0}13'-38^{0} 24' East longitudes. The altitude ranges from 1270 to 2070 m above sea level. The study area is characterized by a bimodal rainfall distribution with a maximum between March to June (main rainy season), and a relatively minimum rainfall between August to October (Figure 3). The mean annual temperature was 20.7 ^{0}C, while the mean monthly temperature ranges from 20.1 to 21.9 ^{0}C (National Meteorological Services Agency of Ethiopia, 2010). The dominant soil type in the study area is Nitisol (Mesfin *et al.*, 2015). Its surface horizon is also characterized by a granular to crumb structure, porous and well aerated with good internal drainage potentials that can be suitable for a wide range of agricultural uses.

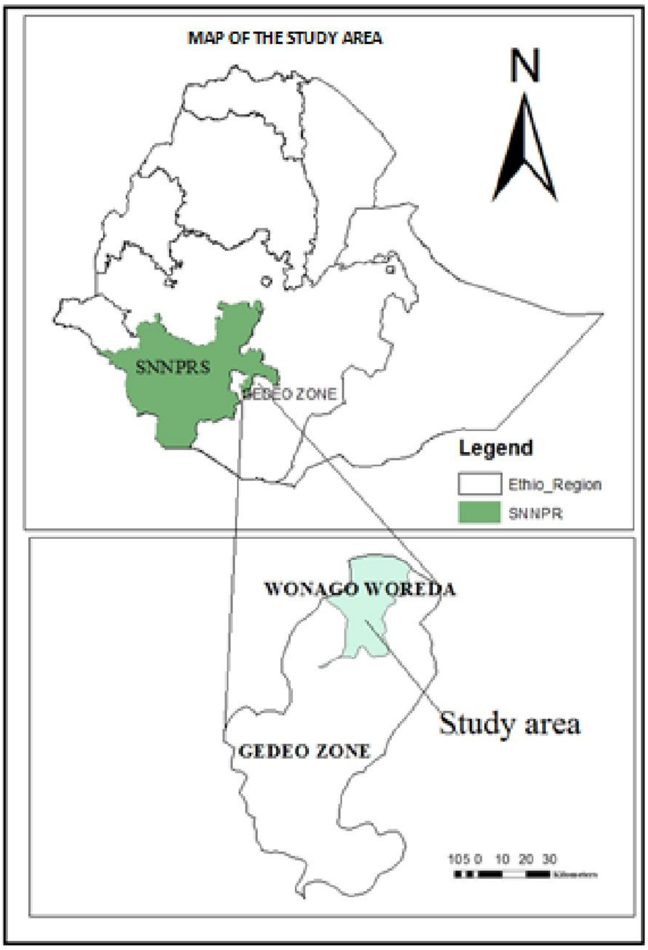

Figure 2. Location map of the study area

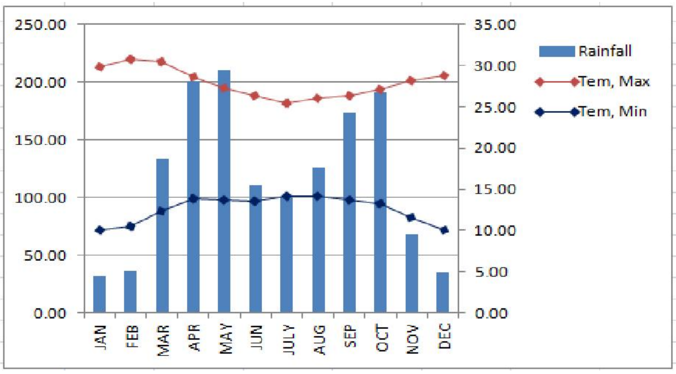

Figure 3. Mean monthly rainfall and temperature of the study area

It has an argillic B (Bt) horizon due to higher accumulation of clay compared to the overlying surface horizon. Two land uses [agro forestry based conservation (AFCT) and maize based conventional tillage (MCT), [hereafter referred to as “land use types”] both under 10, 20 and 30 years of land use management were selected. The land use types were contiguous and have similar environmental conditions (uniformity in soil conditions, slope and rainfall) except the land use management practices. Experimental design and layouts were performed by using a transect line (Anderson and Ingram, 1993) and laid down in randomized complete block design (RCBD) with simple factorial (for soil analysis) where locations served as blocks containing the two treatments (AFCT and MCT). The experiment had a total of 48 (2 treatments_ 4 replications_ 3 age categories_ 2 soil depth layers: 0-20 cm, 20-40 cm) sampling units on which soil samples for studying selected soil properties was collected. For infiltration capacity, double ring infiltrometers were used.

Soil sampling and analysis

To determine the selected soil properties, soil samples were collected from excavated soil pits at depths of 0-20cm and 20-40cm along a transect line using an 'X' design pits were dug at four corners and at the center of the plot. The sampling plots were set at 10-years, 20-years and 30-years age of land management and then a composite soil sample (except bulk density) was made for each selected soil properties. About 0.5 kg collected soil samples were then air-dried, crashed, homogenized and made to pass through 2mm sieve for physical and chemical soil laboratory analysis. The soil textural fractions were determined following the hydrometer method after the soil was dispersed using sodium hexametaphosphate solution in the laboratory (USDA, 1972). SOC was determined according to the Walkley and Black method (Schnitzer, 1982). Soil bulk density was determined after an oven drying at 105^{o}C for 24hrs. Total porosity was determined according to Oguike and Mbagwu (2009) assuming a particle density (Pd) of 2.65 gcm^{-3}. Undisturbed soil samples were also collected separately using core sampler from each soil depth for the determination of soil bulk density.

Water infiltration measurements

To determine the infiltration capacity for each land use type and age category (10, 20 and 30 years land use management), three replicate infiltration measurements were conducted (3_age category * 2_land use types * 3_replicates). The choice of sites for the measurement was based on similarity in micro-topography. The infiltration rate was determined by using a double-ring infiltrometer (Bertrannd, 1965). From the three age categories, a total of 18 measurement points (three points per system) were carried out for one full hour and changes in water levels were recorded at time increments of 1, 2, 5, 10, 15, 20, 30, 40 and 60 min for calculation of rate and cumulative water infiltration. The weather at the time of all measurements was sunny.

Statistical analysis

Statistical differences were tested using two way analysis of variance (ANOVA) following the General Linear Model (GLM) procedure of SPSS version 16.0 for windows (SPSS Inc., Chicago, USA).

Tukey’s Honest Significance Difference (HSD) test was used for mean separation when the analysis of variance showed statistically significant differences ($P<0.05$).

RESULTS AND DISCUSSION

Water Infiltration

Infiltration rate and cumulative infiltration of water significantly varied with respect to land use types (*P*<0.001, Table 1) and ages of land use management (*P* = 0.001, *P* = 0.019 respectively, Table 1) for all separate time increments. Land use types and age of land use management have also shown a significant interaction effect (P < 0.001, Table 1) on water infiltration rate. The overall mean of water infiltration rate and cumulative infiltration were higher under AFCT (Table 2 and 3, Figure 4 and 5) than in MCT at each separate time. This was due to the presence of high soil organic carbon (SOC %) under AFCT which has improved the soil porosity, soil aggregates and structures (Reddy, 2005; Anderson *et al*., 2008; Fantaw Yimer *et al*., 2008). Moreover, the increase in infiltration rate and cumulative infiltration on AFCT (Table 2 and 3, Figure 4 and 5) were due to the presence of live/dead root channels and soil macro-fauna in the soil (Reddy, 2005; Osuji *et al*., 2010).

Table 1. Summary of ANOVA results of infiltration rate (cm/min) and cumulative infiltration (cm) of Wonago District, Southern Ethiopia

Source of Variation	df	Infiltration Rate		Cumulative Infiltration	
		MS	p	MS	P
LU	1	101.025	<0.001	19,312.68	<0.001
Age	2	8.455	0.001	2514.70	0.019
LU X Age	2	9.029	<0.001	1617.77	0.076
Error	156	1.080		616.60	
Total	162				

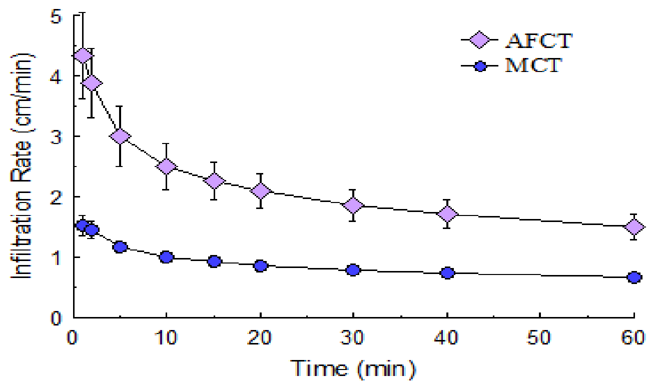

Figure 4. Soil infiltration rate as influenced by land use types (Agroforestry based Conservation Tillage (AFCT) Vs Maize based Conventional Tillage (MCT) at Wonago District, Southern Ethiopia

Soils under conventional tillage have a relatively low infiltration rate and cumulative infiltration compared to conservation tillage (Fantaw Yimer *et al.,* 2008). The low water infiltration on MCT could attribute to compaction and structural deteriorations of the top surface soil because of frequent tillage operation (Reddy, 2005; Jimenez *et al.,* 2006; Fantaw Yimer *et al*., 2008). This degradation brings about the losses in macropore space and a discontinuity in pore space/channel between the cultivated surface and the sub-surface soil. Moreover, the presence of high clay fraction (at 0-20 cm depth) and higher bulk density on MCT relative to AFCT might have responsible for the occurrence of low water infiltration (Anderson *et al*., 2008). The overall mean of water infiltration rate at initial time (1 min) was much higher (198.7%, 150.4% and 172.4%) than water infiltration rate at 60 min along with 10, 20 and 30 years of land use management (Table 2) respectively

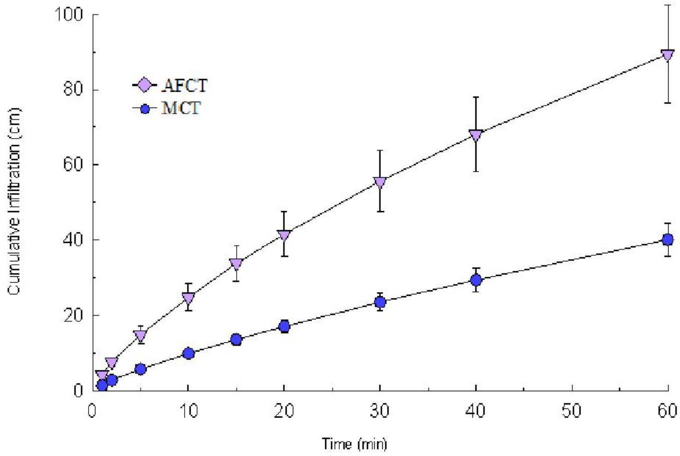

Figure 5. Soil cumulative infiltration rate as influenced by land use types (Agroforestray based Conservation Tillage (AFCT) Vs Maize based Conventional Tillage (MCT) at Wonago district, Southern Ethiopia

Initially, the pore spaces may be free of water and as a result more water move into the soil rapidly especially under AFCT land use type. As time goes, the pores either become near to saturation due to downward gravitational water movement or clogged by fine textured (since clay is the dominant textural class) soils and reach to minimum (Anderson *et al*., 2008**)**. The reduction in water infiltration as time goes becomes very rapid on MCT relative to AFCT land use types. Moreover, the increase in soil bulk density due to lower level of soil organic carbon (%) and compaction could also result a decrease in water infiltration capacity of the soil (Anderson *et al*., 2008; Fantaw Yimer *et al*., 2008; Marcela, 2009). With respect to age of land use management (10, 20 and 30 years), the overall mean of 30 years AFCT land use management has shown higher infiltration rate (Table 2) as well as cumulative infiltration (Table 3, Figure 6).

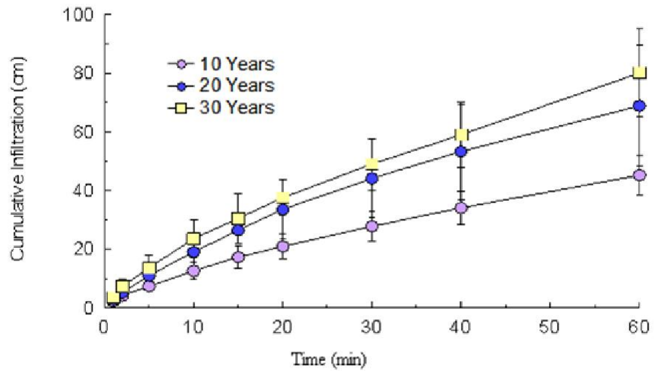

Figure 6. Cumulative infiltration curve of each ages of land management

Table 2. Mean values (+ SEM) of soil infiltration (cm/min) across different land use types and with respective age categories at different time intervals at Wonago District, Southern Ethiopia

Time (min)	Land Use	Age of land management				
		10-Years	20-Years	30-Years	Overall	ANOVA
1	AFCT	3.0(±0.78)	4.0(±0.5)	6.03(±1.71)	4.34(±0.72)^{a}	
	MCT	1.53(±0.03)	1.77(±0.29)	1.27(±0.43)	1.52(±0.17)^{b}	**
	Overall	2.27(±0.48)^{a}	2.88(±0.56)^{b}	3.65(±1.33)^{cb}		*
2	AFCT	2.72(±0.58)	3.65(±0.4)	5.28(±1.37)	3.88(±0.58)^{a}	
	MCT	1.5(±0.05)	1.65(±0.26)	1.2(±0.40)	1.45(±0.15)^{b}	**
	Overall	2.11(±0.38)^{a}	2.65(±0.49)^{b}	3.2(±1.11)^{cb}		*
5	AFCT	1.9(±0.44)	3.03(±0.40)	4.04(±1.17)	2.99(±0.49)^{a}	
	MCT	1.08(±0.02)	1.39(±0.14)	1.01(±0.26)	1.16(±0.10)^{b}	**
	Overall	1.49(±0.27)^{a}	2.21(±0.41)^{b}	2.53(±0.86)^{cb}		*
10	AFCT	1.68(±0.43)	2.56(±0.35	3.22(±0.85	2.49(±0.37)^{a}	
	MCT	0.85(±0.022	1.24(±0.14	0.89(±0.25)	0.99(±0.10)^{b}	**
	Overall	1.26(±0.27)^{b}	1.90(±0.34)^{c}	2.1(±0.65)^{dc}		*
15	AFCT	1.55(±0.40)	2.38(±0.33)	2.86(±0.73)	2.26(±0.32)^{a}	
	MCT	0.76(±0.021	1.17(±0.1)	0.82(±0.22)	0.92(±0.10)^{b}	**
	Overall	1.15(±0.25)^{b}	1.78(±0.31)^{c}	1.84(±0.57)^{dc}		*
20	AFCT	1.39(±0.31)	2.27(±0.33)	2.6(±0.65)	2.1(±0.29)^{a}	
	MCT	0.71(±0.02)	1.1(±0.12)	0.76(±0.20)	0.86(±0.09)^{b}	**
	Overall	1.05(±0.21)^{b}	1.68(±0.30)^{c}	1.68(±0.51)^{dc}		*
30	AFCT	1.19(±0.3)	2.26(±0.6)	2.12(±0.34)	1.86(±0.27)^{a}	
	MCT	0.66(±0.03)	0.69(±0.19)	1.01(±0.08)	0.79(±0.08)^{b}	**
	Overall	0.93(±0.16)^{b}	1.47(±0.45)^{c}	1.57(±0.3)^{dc}		*
40	AFCT	1.07(±0.22)	2.03(±0.54)	2.01(±0.32)	1.71(±0.25)^{a}	
	MCT	0.63(±0.03)	0.64(±0.18)	0.96(±0.08)	0.74(±0.08)^{b}	**
	Overall	0.85(±0.14)^{b}	1.34(±0.40)^{c}	1.48(±0.28)^{dc}		*
60	AFCT	0.93(±0.18)	1.74(±0.46)	1.81(±0.28)	1.49(±0.22)^{a}	
	MCT	0.59(±0.02)	0.56(±0.17)	0.86(±0.06)	0.67(±0.07)^{b}	**
	Overall	0.76(±0.11)^{b}	1.15(±0.34)^{c}	1.34(±0.25)^{dc}		*

Values with the same letters on the rows and columns are not significantly different at P<0.05

* Denotes significantly different at P<0.05, ** Denotes highly significantly different at P<0.05, ns, denotes not significant

Table 3. Mean values (±SE) of cumulative infiltration (cm) in relation to land use types, and age of land use management at 1 and 60 min at Wonago District, Southern Ethiopia

Time	Land use	Age of land management				
(min)	types	10-years	20-years	30-years	Overall	ANOVA
1	MCT	1.77(±0.29)	1.53(±0.03)	1.27(±0.43)	1.52(±0.17)^{a}	
	AFCT	3.00(±0.78)	4.00(±0.50)	6.03(±1.71)	4.34(±0.72)^{b}	**
	Overall	2.39(±0.48)^{a}	2.77(±0.56)^{ab}	3.65(±1.33)^{b}		*
60	MCT	11.14(±0.93)	8.31(±0.09)	7.84(±2.43)	9.10(±0.90)^{a}	
	AFCT	15.21(±3.37)	23.83(±3.2)	30.06(±8.04)	23.03(±3.40)^{b}	**
	Overall	13.18(±3.37)^{a}	16.07(±3.2)^{ab}	18.95(±6.22)^{b}		*

Table 4. Summary of ANOVA for Soil Textural Fraction (Sand %, Silt % and Clay %), SMC (%), Bd (g/cm3), SOC (%), and Pt (%)

Source of	df	Sand		Silt		Clay		SMC		Bd		SOC		Pt	
Variation		MS	P	MS	P	MS	P	MS	P	MS	P	MS	P	MS	P
LU	1	385.33	0.003	52.083	0.102	720.75	<0.001	547.49	<0.001	0.04	<0.001	3.98	<0.001	57.68	<0.001
SD	1	21.33	0.463	0.083	0.947	18.75	0.476	254.7	<0.001	0.048	<0.001	1.26	<0.001	70.526	<0.001
Age	2	529.00	<0.001	194.25	<0.001	274.75	0.002	9.12	0.346	0.03	0.825	0.021	0.595	0.45	0.84
LU*SD	1	65.33	0.203	4.083	0.641	36.75	0.320	14.42	0.196	0.05	0.788	0.014	0.559	0.35	0.72
LU*Age	2	54.33	0.259	5.5 83	0.741	91.75	0.093	107.35	<0.001	0.018	<0.001	0.456	<0.001	27.66	<0.001
SD*Age	2	16.33	0.659	2.583	0.870	7.75	0.808	2.02	0.786	0.001	0.54	0.006	0.856	1.80	0.51
LU*SD*Age	2	0.333	0.991	12.589	0.512	16.75	0.632	4.47	0.589	0.002	0.379	0.007	0.997	2.58	0.38
Error	36	38.778		18.477		36.085		8.32		0.002		0.04			
Total	48														

LU = Land use, SD= Soil depth, SMC = Soil Moisture Content, Bd = Bulk density, SOC= Soil Organic Carbon, P_t = Total Porosity

Table 5. Mean values (±SE) of soil textural fractions (%) across different land use types and with respective age categories at Wonago District, Southern Ethiopia

Variables	Land use type	Soil depth (cm)	Age of Land Management 10-years	20-years	30-years	Overall	ANOVA
Sand	MCT	0-20	24.5(±1.71)	28.0(±1.10)	32.0(±2.35)	28.20(±1.31)^{a}	
		20-40	27.5(±4.72)	33.0(±1.08)	35.5(±2.36)	32.00(±1.91)^{a}	ns
		Overall	26(±2.39)^{a}	30.5(±1.18)^{b}	33.75(±1.67)^{c}		*
	AFCT	0-20	28.5(±2.22)	34.0(±1.08)	35.0(±4.3)	32.50(±1.73)^{a}	
		20-40	26.5(±1.71)	31.0(±1.87)	32.0(±3.51)	29.83(±1.49)^{a}	ns
		Overall	27.5(±1.35)^{b}	32.5(±1.15)^{c}	33.5(±2.63)^{c}		*
Silt	MCT	0-20	23.0(±1.41)	23.0(±2.74)	24.5(±0.87)	23.50(±0.98)^{a}	
		20-40	22.5(±2.06)	23.5(±1.85)	23.0(±1.87)	23.00(±1.02)^{a}	ns
		Overall	22.75(±1.16)^{a}	23.25(±1.53)^{b}	23.75(±0.99)^{b}		ns
	AFCT	0-20	23.5(±0.50)	24.0(±1.68)	24.5(±0.29)	24.00(±0.55)^{a}	
		20-40	22.0(±0.41)	23.5(±1.55)	24.0(±2.08)	23.17(±0.83)^{a}	ns
		Overall	22.75(±0.41)^{a}	23.75(±1.06)^{b}	24.25(±0.98)^{b}		ns
Clay	MCT	0-20	52.5(±2.63)	49.0(±1.78)	43.5(±3.10)	48.33(±1.74)^{a}	
		20-40	50.0(±4.54)	43.5(±2.06)	41.5(±1.55)	45.00(±1.91)^{a}	ns
		Overall	51.25(±2.48)^{a}	46.25(±1.63)^{b}	42.5(±1.65)^{b}		*
	AFCT	0-20	48.0(±2.16)	42.0(±0.71)	40.5(±4.03)	43.50(±1.70)^{a}	
		20-40	51.5(±1.84)	45.5(±1.44)	44.0(±1.83)	47.00(±1.33)^{a}	ns
		Overall	49.75(±1.47)^{b}	43.75(±0.99)^{c}	42.25(±2.15)^{c}		*

Values with the same letters on the rows and columns are not significantly different at $P<0.05$. * Denotes significantly different at $P<0.05$, ns denotes not significant.

Table 6. Mean values (±SE) of bulk density (Bd, g cm^{-3}) across different land use types and with respective to age categories at Wonago District, Southern Ethiopia

Variables	Land use type	Soil depth (cm)	Age of Land Management 10-years	20-years	30-years	Overall	ANOVA
BD	MCT	0-20	1.02(±0.01)	1.10(±0.01)	1.17(±0.01)	1.10(±0.01)^{a}	
		20-40	1.19(±0.01)	1.17(±0.04)	1.22(±0.01)	1.19(±0.01)^{b}	**
		Overall	1.11(±0.02)^{a}	1.14(±0.02)^{a}	1.20(±0.01)^{a}		ns
	AFCT	0-20	1.13(±0.01)	1.07(0.02)	1.04(±0.03)	1.08(±0.02)^{a}	
		20-40	1.16(±0.04)	1.15(±0.02)	1.12(±0.01)	1.14(±0.01)^{b}	**
		Overall	1.15(±0.02)^{b}	1.11(±0.02)^{b}	1.08(±0.02)^{b}		ns

Values with the same letters on the rows and columns are not significantly different at $P<0.05$. ** Denotes highly significantly different at $P<0.05$, ns, denotes not significant.

Table 7. Mean values (±SE) of Total porosity (P_t, %) in relation to land use types, soil depth (cm) and age of land management at Wonago District, Southern Ethiopia

Variables	Land use Types	Soil Depth (cm)	Age of land management 10-years	20-years	30-years	Overall	ANOVA
Pt	MCT	0-20	57.90(±0.48)	57.20(±0.55	54.78(±0.34)	56.63(±0.47)^{a}	
		20-40	55.45(±0.44)	54.36(±1.43)	53.25(±0.29)	54.35(±0.53)^{b}	**
		Overall	56.68(±0.55)^{a}	56.05(±0.89)^{a}	54.02(±0.35)^{a}		ns
	AFCT	0-20	56.95(±0.54)	59.53(± 0.63)	60.68(±1.25)	59.05(±0.65)^{a}	
		20-40	53.56(±1.33)	56.14(±0.67)	57.29(±0.56)	55.66(±0.52)^{b}	**
		Overall	55.26(±0.69)^{b}	57.84(±0.76)^{b}	58.99(±0.89)^{b}		ns

Values with the same letters on the rows and columns are not significantly different at $P<0.05$. ** Denotes highly significantly different at $P<0.05$, ns, denotes not significant.

This was probably due to the influence of SOC accumulation in the soil from plant litter fall as well as from remaining of dead plant root biomass in the soil, with its implication for soil fertility maintenance. This is in line with the reports of Nandwa (2001), Albrecht and Kandji (2003) and Shrestha (2004).

Soil Textural Fraction and Bulk Density

Sand, silt and clay soil textural fractions have shown significant variation with ages of land use management ($P<0.001$, $P<0.001$ and $P = 0.002$ respectively, Table 4). The overall mean of sand and silt soil fractions were higher in AFCT (Table 5) than in MCT with age of land use management and increases along age of land use management. On the other hand, the overall mean of clay fraction was higher in MCT (Table 5) than in AFCT, and decreases with age of land use management on both land uses types.

The increases in sand and silt soil fractions and a decrease in clay fractions, with age (10, 20 and 30 years) might have resulted from the high mean annual precipitation in the study area (1277 mm) that selectively transported and/or leached clay fractions from the top soil surface leaving sand and silt. This is in agreement with the reports of Mosaddeghi *et al.* (2000), Brye (2003), Igué (2004), Gami *et al.* (2006), Fantaw Yimer *et al.* (2008) and Rajeswari *et al.* (2009) in that clay fraction decreased due to selective removal of it by rain water erosion in response to ages of land use management (as age increases, clay fraction was decreased on both land use types).

Soil bulk density significantly varied with land use type ($P<0.001$, Table 4) and soil depth ($P<0.001$, Table 4). The interaction effects of land use types and age of land management has also resulted a significant effect on soil bulk density ($P <0.001$, Table 4). The value became lower under AFCT (except for 10-years) than in MCT (Table 6) land use management. The higher value at 10-years of land use management in AFCT was due to the effect of initial soil compaction relative to 20 and 30 years (He *et al*., 2009). However, after 10-years, the bulk density in AFCT was lower (Table 6) while higher in MCT land use management. This was due to the continuous addition and accumulation of higher soil organic matter on the top soil layer (0-20cm) under AFCT (Murphy *et al*., 2006; Rashidi *et al*., 2008; Marcela, 2009; Tigist Oicha *et al*., 2010).

Under MCT, the presence of continuous tillage operation and thereby lowering of SOC (through rapid mineralization of SOM) might have contributed for increased soil bulk density along with years of land use management (10,20 and 30 years) (Mosaddeghi *et al*., 2000; Igue, 2004; Mulugeta Lemenih, 2004; Igwe, 2005; Oorts, 2006; Strudley *et al*., 2008; He *et al*., 2009; Marcela, 2009). In addition, the removal of crop residue (maize) for fuel wood and animal (feed) consumption has also contributed for the higher soil bulk density under MCT.

With respect to soil depth, the presence of less soil aggregation and root penetration, plough pan formation (due to repeated ploughing at shallow depth) as well as pressure exerted by overlying soil layer have caused higher bulk density in the 20-40 cm soil depth (Arvidsson *et al*., 2000; Mosaddeghi *et al*., 2000; Mulugeta Lemenih, 2004; Melesse Temesgen, 2007).

Total porosity (P_t %)

Total porosity (P_t %) has showed significant ($p <0.001$, Table 4) variations with land use type and soil depth. The combined effect of land use types and age of land use management also has a significant interaction effect on the total porosity of the soil ($P <0.001$, Table 4). The overall mean of total porosity (P_t) was higher in AFCT (Table 3) than in MCT. Though the mean difference with age of land use management was not significant, the overall mean of P_t has showed an increasing trend with age of land use management under AFCT than in MCT (Table 7). The presence of higher P_t in AFCT was as a result of higher soil organic carbon in the soil (Oguike and Mbagwu, 2009).

As SOC (%) content decreased from AFCT to MCT, total porosity was also reduced accordingly. The formation of stable soil aggregate in AFCT due to higher SOC (%) input has contributed for higher porosity (Mosaddeghi *et al*., 2000; Marcela, 2009; Romaneckas *et al*., 2009; Tigist Oicha *et al*., 2010) and this could increase water infiltration capacity of the soil under AFCST system. Previous studies (e.g. He *et al*., 2009; Rajeswari *et al*., 2009; Tripathi *et al*., 2009) have demonstrated that litter fall and crop residue that act as mulches on the surface soil can effectively reduce surface run-off and increase water infiltration capacity of the soil.

Table 8. Mean values (±SE) of Soil organic carbon (%) in relation to land use types, soil depth (cm) and age of land management at Wonago District, Southern Ethiopia

Variables	Land use Types	Soil Depth (cm)	Age of Land Management 10-years	20-years	30-years	Overall	ANOVA
SOC	MCT	0-20	1.44(±0.03)	1.20(±0.04)	1.13(±0.09)	1.26(±0.06)ᵃ	
		20-40	1.14(±0.12)	0.97(±0.05)	0.80(±0.09)	0.97(±0.07)ᵇ	**
		Overall	1.29(±0.08)ᵃ	1.09(±0.07)ᵃ	0.97(±0.08)ᵃ		ns
	AFCT	0-20	1.71(±0.14)	1.84(±0.08)	2.07(±0.08)	1.87(±0.07)ᵃ	
		20-40	1.34(±0.09)	1.43(±0.14)	1.67(±0.15)	1.48(±0.08)ᵇ	**
		Overall	1.53(±0.10)ᵇ	1.64(±0.11)ᵇ	1.87(±0.09)ᵇ		ns

Values with the same letters on the rows and columns are not significantly different at $P<0.05$. * Denotes significantly different at $P<0.05$, ns denotes not significant.

Soil organic carbon (SOC %) content

SOC significantly varied with land use types (P < 0.001, Table 4) and soil depth (P < 0.001, Table 4). The interaction effect of land use type and ages of land management was also significant (P <0.001, Table 4). The overall mean of SOC was higher in soil under AFCT (16.43%, 52.63% and 88.35%) than in MCT with respect to age of land management (10, 20 and 30 years), respectively (Table 8). This was due to the lower organic carbon turnover rate as a result of minimum soil disturbance, less water erosion occurrence (due to the presence of crop residue and perennial crops) and long period accumulation of higher amounts of organic matter from litter fall in the AFCT (Post *et al*., 2000; Gupta *et al*., 2006; Worku Burayu *et al.,* 2006; Sithambaranathan, 2009). This in turn facilitate for the higher occurrence of water infiltration rate in AFCT. The lower SOC in MCT (Table 8) in relation to AFCT with ages (10, 20 and 30 years) was due to oxidation of OM (high turnover and decomposition rate) due to frequent soil disturbance (high tillage intensity favor rapid OM breakdown) (Solomon *et al*., 2000; Fantaw Yimer *et al*., 2006; Liu *et al.*, 2006; Strudley *et al*., 2008). Furthermore, the insufficient input of organic materials in soil under the MCT due to whole harvest and burning of crop residue (Solomon *et al*., 2000; Igue, 2004; Mulugeta Lemenih, 2004) also contributed to the lower level of SOC content.

The vertical distribution of soil organic carbon appeared to differ with land use management. Irrespective of land uses, the top surface soils (0-20 cm depth) showed a markedly higher SOC content compared to the 20-40 cm depth layer. The decrease in SOC with depth was more under MCT than in the AFCT (Table 8). He *et al*. (2009) and Hiederer (2009) reported similar results of a decrease in SOC with soil depth due to the presence of small amount of organic matter at the lower depths. On the other hand, household waste disposal and compost addition as well as dead weeds left in the farm plots might have increased the SOC at the top surface layer under the AFCT.

Conclusion

Soil manipulations through adoption of either agro forestry based conservation or maize based conventional tillage were the principal anthropogenic factor that causes variations in water infiltration capacity of the soil. Understanding the effect of these land use management practices on water infiltration and on other soil property that affect water infiltration rate are quite important for the prediction of soil behavior and its response to different management options. The investigated soil under AFCT has shown improvements in water infiltration capacity, soil bulk density, porosity and SOC content of the soil favoring good soil structure, aeration and root penetration. These improvements were a direct result of high SOM and less soil disturbance in AFCT. Therefore, AFCT is a good management option for rehabilitation and improvement of soil qualities for increased water infiltration capacity of the soil.

The soil under MCT has shown poor water infiltration capacity and other soil properties which in turn become a reflection for crop production. Thus, these soil properties should be maintained and restored through appropriate soil management practices (e.g. application of minimum tillage, mulching, planting multi-purpose trees, adding manure and compost). There should be a shift in the soil management practice from MCT to appropriate AFCT.

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