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Full Length Research Paper

Tillage effects on physical qualities of a vertisol in the central highlands of Ethiopia

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In the highlands of Ethiopia, tillage methods and frequency affect drainage, soil erosion, moisture conservation, weeding and harvesting of crops. This is through their effects on soil physical, chemical and biological qualities. In this study, four tillage methods for land preparation, "broad bed and furrows"," green manure", "reduced tillage "and the traditional tillage "ridge and furrows" were evaluated for their effects on soil physical quality indicators. The study was superimposed on the field experiment conducted on a vertisol area at Caffee doonsa for five years (1998 to 2002) in the central highland of Ethiopia. Penetration resistance (PR), aggregate stability, water-holding capacity, crust strength and thickness, texture, porosity, saturated hydraulic conductivity, bulk density and water holding capacity were the soil physical quality indicators considered. The result indicated that only PR was significantly (p<0.05) affected, where as the other parameter have shown a slight changes that are consistent with the effects on the bio-chemical parameters as previously reported. Broad bed furrows, and reduced tillage resulted in the highest and the lowest PR, respectively under both the moist and dry soil conditions. Green manure increased aggregate stability and reduced surface crust strength, which was linked to its increased organic matter content and consequent improved microbial activities.

Key words: Broad bed and furrow, green manure, reduced tillage, ridge and furrow, soil quality, land preparation.

INTRODUCTION

Land preparation for crop production often involves tillage with various frequencies depending on the soil type, precursor and planned crops, access to oxen, etc. Tillage is the most commonly used essential soil management practice with various objectives. It eliminates weeds, achieves favorable conditions for sowing, attains emergence and good development of plants, preserves soil organic matter (SOM) and reduces erosion, and eliminates hardpans or compacted layers to increase water infiltration. It also incorporates agro-chemicals and agricultural residues into the soil (Mazuchowski and Derpsch, 1984).

Ranges of tools from sharp stone and wooden plough to tractors and heavy tillage implements depending on the economic development level and feasibility under the prevailing environment are used for tillage. In Ethiopia, 90% of tillage for crop production under the smallholder farmers is carried out with a traditional wooden plough, pulled by a pair of local oxen (Abiye et al., 2002). In the highlands of Ethiopia, tillage frequency, and the feature of the final tillage that affects drainage, soil erosion, moisture conservation, weeding and harvesting is dictated by crop type, soil type, landscape position, and climate and farmers' tradition. In some areas 5 to 9 cultivation passes before sowing is common (Teklu et al., 2003). Excessive tillage exacerbates the loss of soil OM because of mixing of the soil and crop residues, disruption of aggregates, and increased aeration (Doran and Smith, 1987). Tillage changes the soil physical environment by disrupting the pores, packing soils particles together, and altering the volume-mass relations (Gajri et al., 2002). However, little information is available on the effect of tillage using traditional tools like those in Ethiopia.

Vertisols are the fourth most important soils in Ethiopia in terms of area coverage, constituting 7.6 million ha in

Table 1. Some physico-chemical characteristics of the soil in the study area.

Depth below the surface (cm)	Clay content (%)	Smectite (%)	pH (H_2O)	Organic carbon (%)	CEC (cmol kg^{-1})
40	73	96	7.9	0.70	88
80	75	97	8.2	0.76	83
120	75	91	8.0	0.49	79
150	75	96	8.1	0.66	74

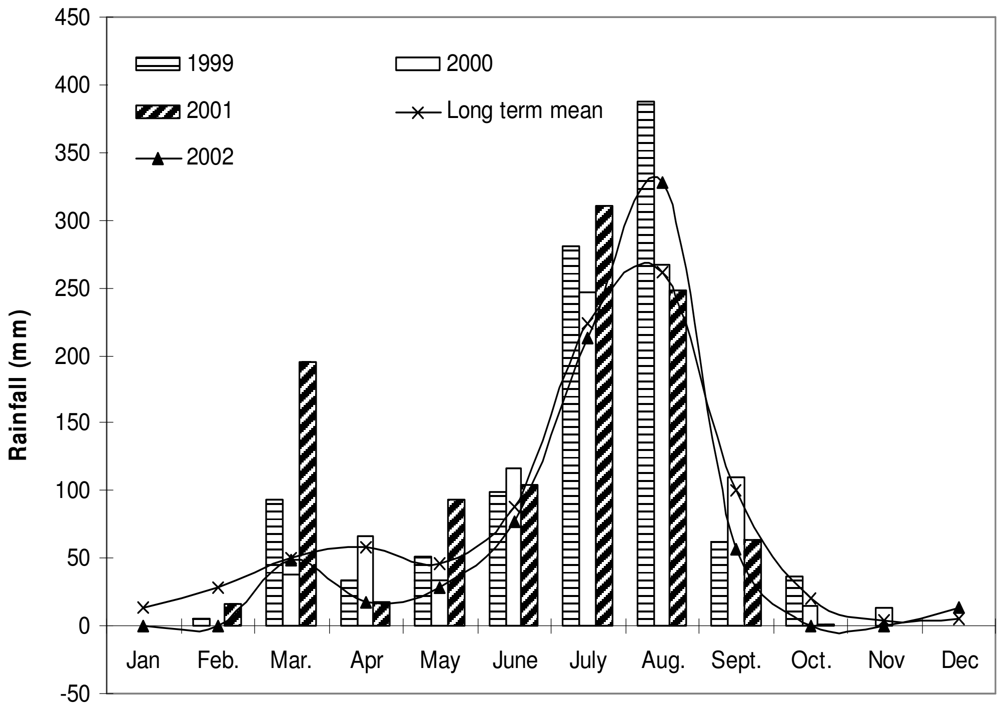

Figure 1. Long-term average and annual rainfall during the experiment periods at the study area.

the central highlands (Jutzi and Mesfin, 1987). Their very slow internal drainage with hydraulic conductivity between 2.5 to 6.0 cm per day leads to severe water logging. Consequently, farmers often plant at the end of the main rainy season to avert the problem, although tillage begins 2 to 3 months earlier. The soils remain bare during the peak rain season with occasional tillage operations enduring vulnerable to soil erosion. Among the options was a use of surface drainage method, known as broad bed and furrow (BBF) constructed by broad bed maker (BBM), which was developed at ICRISAT in India (El-Swaify et al., 1985). The BBM was introduced and modified to fit to the smallholder system in Ethiopia (Abiye and Frew, 1993). While a significant yield increase of some crops was reported due to the use of BBF, which allowed early planting (Abiye et al., 1995; Haque et al., 1996; Muhamed and Abiye, 1996), its effects on soil physical conditions were not well established. This neces- sitated the evaluation of BBF and other alternative tillage methods for land preparation in terms of maintaining physical qualities of the vertisols.

MATERIALS AND METHODS

Field experiment

The experiment was conducted at Caffee doonsa (2400 m asl) in Gimbichu district (08°57’ N, 39°06’E) at about 40 km northeast from Addis Ababa, in the eastern part of Oromia regional state in Ethiopia. This particular study was superimposed on an ongoing experiment in the area, which was running for five consecutive growing seasons (1998 to 2002) when the sampling for this study was made in 2002. Smectite rich clay mineral with high cation exchange capacity and high pH soil (Table 1), and mean annual rainfall of 900 (mm) (Figure 1) and temperature of 17°C characterize the area. The dominant land use is seasonal crops, that is wheat (*Triticum durum* Desf.), tef *(Eragrostis* tef)*, lentil (*Lens culinaries* Medik) and chickpea (*Cicer arietinum*) in rotation, while the marginal lands along the road sides, gully bottoms and flood plains are the major grazing ground (Teklu, 1997). Four methods of land preparation were evaluated on permanent 'Wischmeier' plots (22 × 6 m) (Wischmmeier and Smith, 1978) with

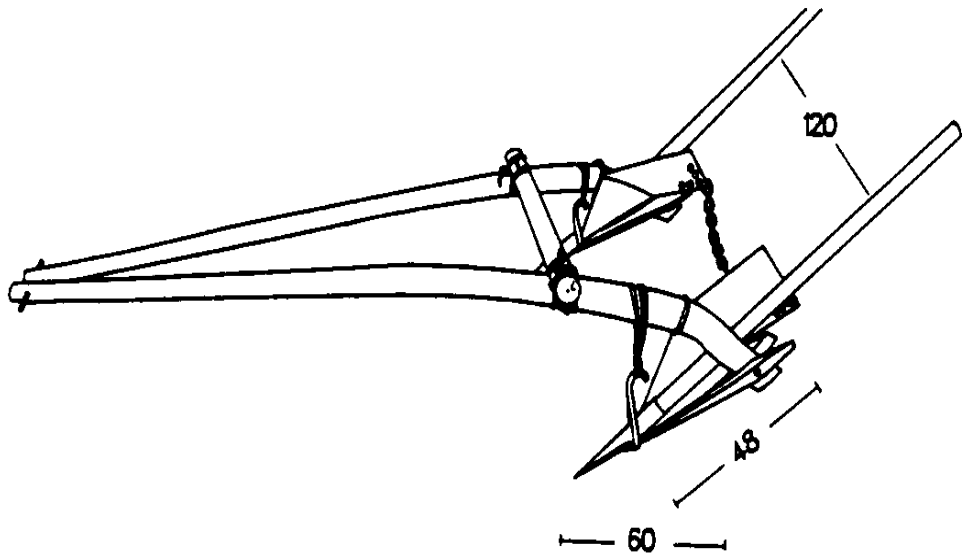

Figure 2. Sketch of the two beams BBM after modification for Ethiopian conditions.

Three replications on randomized complete block design.

The treatments include

Control

This is the traditional tillage practice known as ridge and furrows (RFs) used to avoid the problem of water logging in vertisols. The RFs are constructed with the traditional tine-plough after the seed is broadcast by hand such that the crops grow on the ridges, permitting the excess water to drain out of the field through the furrows or to stand in the furrow to slowly infiltrate or evaporate. They are parallel narrow structures of about 20 cm high and 30 cm wide. The crops are sown late in the season (late August to early September). The land preparation starts early following a small rain during April and May. As it involves occasional tillage operations until planting (August) soil erosion is its major consequence.

Broad bed and furrows (BBFs)

Broad bed and furrows were constructed by the broad bed maker (BBM), which is an oxen-drawn traditional wooden plough, modified for the construction of raised beds and furrows (Figure 2). With an effective bed width of 80 and 20 cm dead furrows, it is intended to facilitate surface drainage through the furrows between the beds (Jutzi and Mesfin, 1987) so that the crops grow on the beds. The crops are sown at the end of June or beginning of July, depending on the onset of the rain.

Green manure (GM)

Green manure refers to a practice where a forage legume is grown as a cover crop during the heavy rain season, in order to protect the soil surface from raindrop impacts and runoff. Vetch (*Vicia desicarpa)* was sown in May using the short rain. This was chopped and ploughed under, while still green ten days before planting and incorporated into the soil by two tillage operations. The test crops were sown after the final tillage in the same manner as RF, except for tef. The practice is one of the major thrusts for reducing soil erosion, when late sowing is unavoidable. It is also believed to improve SOM content and thereby the soil quality and crop productivity.

Reduced tillage (RT)

Reduced tillage plots were kept intact fallow until they were sprayed with non-selective herbicide (glyphosate) at 4 L ha^{-1} ten to fifteen days before sowing. Similar to RF and GM, the crops were sown late August or early September. The seeds were broadcast and covered by a single tillage operation using the local plough for wheat and lentil, while tef was sown on freshly tilled field. The practice was aimed at minimizing pre-sowing soil disturbance, reducing oxidation of SOM, and maintaining some surface cover to reduce soil erosion.

The treatments were kept permanent while three crops: wheat (*Triticum durum* Desf.), lentil (*Lens culinaries* Medik) and tef *(Eragrostis tef)* were rotated following their traditional sequence (Table 2). As tef is water logging tolerant, a flat seedbed was used so that BBF and RF were expressed only through their residual effects. All the cultural practices other than the treatments were implemented according to the recommendation for the respective crops.

Soil sampling and analysis

Composite soil samples with three sub samples were collected from each plot at 0 to 15 and 15 to 30 cm depths for texture and aggregate stability in 2002. Bouyoucos hydrometer method for texture (Bouyoucos, 1962) and wet sieving method for aggregate stability (Arshad et al., 1996) were used. Also, surface crusts were carefully collected by hand after harvesting of lentil in 2002. Pocket penetrometer as described by Awadhwal (1997) and calliper were used to measure the strength and thickness, respectively of the crusts. Soil core samples were collected at 0 to 30, 30 to 60 and 60 to

90 cm depths for BD measurement (Blake and Hartge, 1986; Arshad et al., 1996) every ten days during the growing periods. Correspondingly, auger sampling was made to determine gravimetric moisture content (Lowery et al., 1996). After harvesting of the crop, samples were collected at the depths above for

Table 2. Schedule of major cropping activities under alternative land preparation methods (Teklu et al., 2006).

Date	Cropping activities			
	Broad-bed and furrow	**Green manure**	**Ridge and furrow**	**Reduced tillage**
Wheat phase				
March to April	Tillage	Tillage and sowing of cover crop	Tillage	-
May	Tillage	-	Tillage	-
June	Tillage	-	Tillage	-
July	Broad-bed and furrow preparation and sowing	Chopping and incorporation of green manure	Tillage	Herbicide spray
August	-	Tillage and sowing	Tillage and sowing	Tillage and sowing
September	Weeding	-	-	-
October	-	Weeding	Weeding	Weeding
November	-	-	-	-
December	Harvesting	-	-	-
January		Harvesting	Harvesting	Harvesting
Lentils phase				
March to April	Tillage	Tillage and sowing of cover crop	Tillage	-
May	Tillage	-	Tillage	-
June	Tillage	-	Tillage	-
July	BBF preparation and sowing	Chopping and incorporation of green manure	Tillage	Herbicide spray
August		Sowing	Sowing	Sowing
September	Weeding	-	-	-
October		Weeding	Weeding	Weeding
December	Harvesting	-	-	-
January		Harvesting	Harvesting	Harvesting
Tef phase*				
March to April	Tillage	Tillage and sowing of cover crop	Tillage	-
May	Tillage	-	Tillage	-
June	Tillage	-	Tillage	-
July	Tillage	Chopping and incorporation	Tillage	Herbicide spray
August	Tillage and sowing	Tillage and sowing	Tillage and sowing	Tillage and sowing
September	Weeding	-	-	-
October	-	Weeding	Weeding	Weeding
November	Harvesting	-	-	-
January		Harvesting	Harvesting	Harvesting

* Tef does not require broad-bed and furrow.

Table 3. Effect of land preparation methods on water stable aggregates (WSA) and crust formation during the 2002 growing season.

Treatment	WSA (%)	Standard deviation	Soil crust			
			Thickness (mm)	Standard deviation	Strength (kg cm^{-2})	Standard deviation
Broad bed and furrow	7.4	7.2	7.4	0.00	1.40	0.38
Green manure	10.9	7.2	7.0	0.64	0.97	0.52
Ridge and furrow	9.4	3.6	6.7	0.81	1.35	0.48
Reduced tillage	8.7	5.7	7.5	0.47	1.40	0.53

available water capacity (θ_A). A pressure extractor with 100 kPa and 1500 kPa ceramic plates was used to determine soil water content at field capacity (θ_c) and permanent wilting point (θ_w), respectively. Penetration resistance (PR) was measured in the field using a cone penetrometer (Bradford, 1986; Arshad et al., 1996) during the growing period, when the soil was still moist and after harvest.

Double ring infiltrometer (Lowery et al., 1996) was used to determine the saturated hydraulic conductivity after harvest in 2001 and 2002. Analysis of variance (ANOVA), using general linear models was used to determine differences between the treatments. Covariance analysis was conducted for penetration resistance and moisture content at the time of measurement.

RESULTS AND DISCUSSION

The treatments significantly affected (p<0.05) the penetration resistance while water aggregate stability, available water capacity, hydraulic conductivity and bulk density were slightly affected. As most soil physical properties take longer time to show measurable changes in response to management systems, the minor differences are reported as they are consistent with the effects on the other bio-chemical properties (Teklu et al., 2007) in which an increase in the total organic carbon content and the soil microbial biomass carbon (MBC) under conser- vation tillage practices (RT and GM) for five years (1998 to 2002) was reported. However, the increment in MBC was not proportional to that of the total organic carbon leading to low microbial quotient. The low microbial quotient under RT and GM despite the increased MBC was related to the aggradations of the soil organic matter with a long term soil quality improvement.

Aggregate stability and crusting

Green manure increased water aggregate stability (WAS) (Table 3) and lowered crusting due to its enhanced SOM content (Figure 3). However, the slight increase in SOM content due to RT did not improve aggregate stability. In principle, repeated tillage exacerbates fragmentation of soil aggregates and the loss of SOM while the loss of SOM reduces aggregate stability. Therefore, theoretically, reduced tillage decreases the loss of SOM leading to increased aggregate stability (Havlin et al., 1990). The inconsistent relationship between the SOM level and aggregate stability in this study may be explained by the high clay content of the vertisols, which undermines the role of soil organic matter.

Surface crust strength was reduced under GM, due to the increased aggregate stability, although the thickness was slightly increased. Due to their high smectite content, the vertisols in the area are prone to crusting (Miller, 1987) especially under repeated tillage. As crusts affect runoff, soil moisture distribution, seed germination and development of plants (Graef, 1999), and as stable aggregates resist the splashing and scoring effects of raindrops and runoff or the effects of slaking and structural explosion, the reduction in surface crust strength and increased aggregate stability due to the use of GM is a potential of enhancing soil quality.

Penetration resistance and bulk density

Broad bed and furrows significantly increased PR (p<0.05) both under moist and dry soil conditions (Figure 4), may be because it involved a primary tillage when the soil was dry, followed by four tillage operations at about field capacity moisture content, when the soil approached an optimum moisture content for compaction. In contrast, RT has resulted in the lowest PR, despite its increased crusting. This is because PR was measured up to the depth of 15 cm while the effects surface crust was limited to the upper few millimetres. Thus, reducing the frequency of tillage may reduce soil compaction, improve aeration, and enhance root growth and access to nutrients and water (Thompson et al., 1987). As measurement of PR is relatively easy, it is useful for rapid evaluation of soil strength and structural changes (Lowery and Morrison, 2002). Bulk density and porosity were not affected by the treatments, and all were within an acceptable

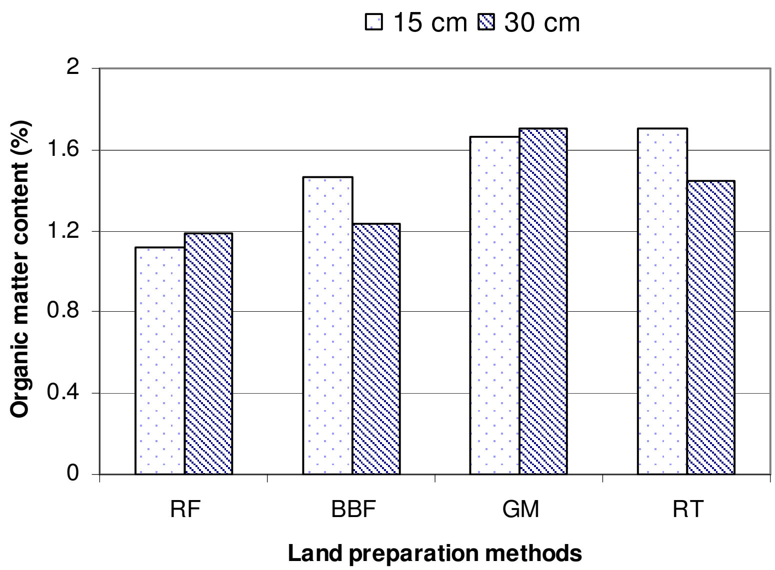

Figure 3. Effect of tillage methods on organic matter content of the soil.

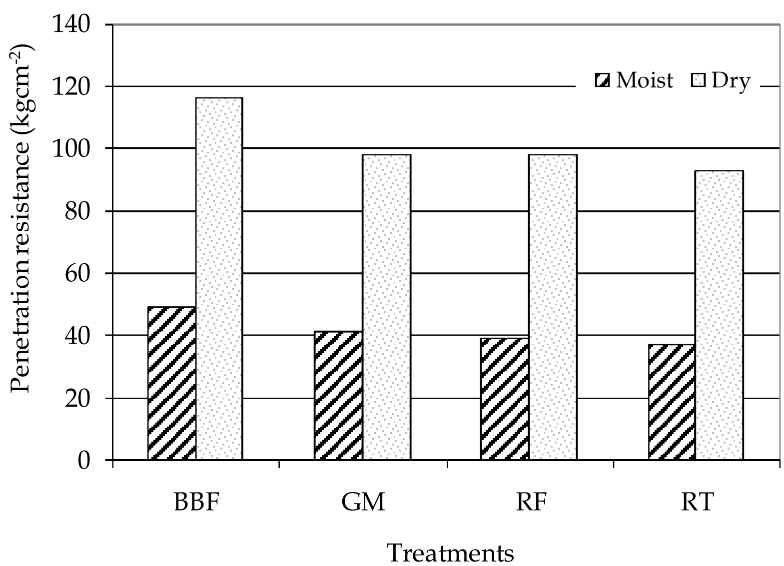

Figure 4. Effect of tillage methods on soil's penetration resistance at moist and dry conditions.

range for clayey soils under agricultural use. This corresponds to the findings of Vazquez et al. (1991) who reported that resistance to penetration to be tenfold more sensitive than BD as indictor of soil compaction.

Soil moisture dynamics

Despite a significant effect of the treatments on surface drainage in which BBF routed the highest runoff (Teklu et al., 2004), the soil moisture content during the growing periods was not significantly affected, confirming the previous findings of Teklu (1997; 1998). However, as shown in Figure 5 a and b, the difference between the treatments tended to increase gradually from 1999 to 2002. In 2002 (a dry year), reduction of soil moisture under BBF was evident as of September (Figure 5b). The lacking difference in soil moisture content especially during the high rainfall years, despite the significant difference in runoff may suggest the existence of additional inflow other than rainfall. Therefore, it is suspected that the profiles might be recharged from the

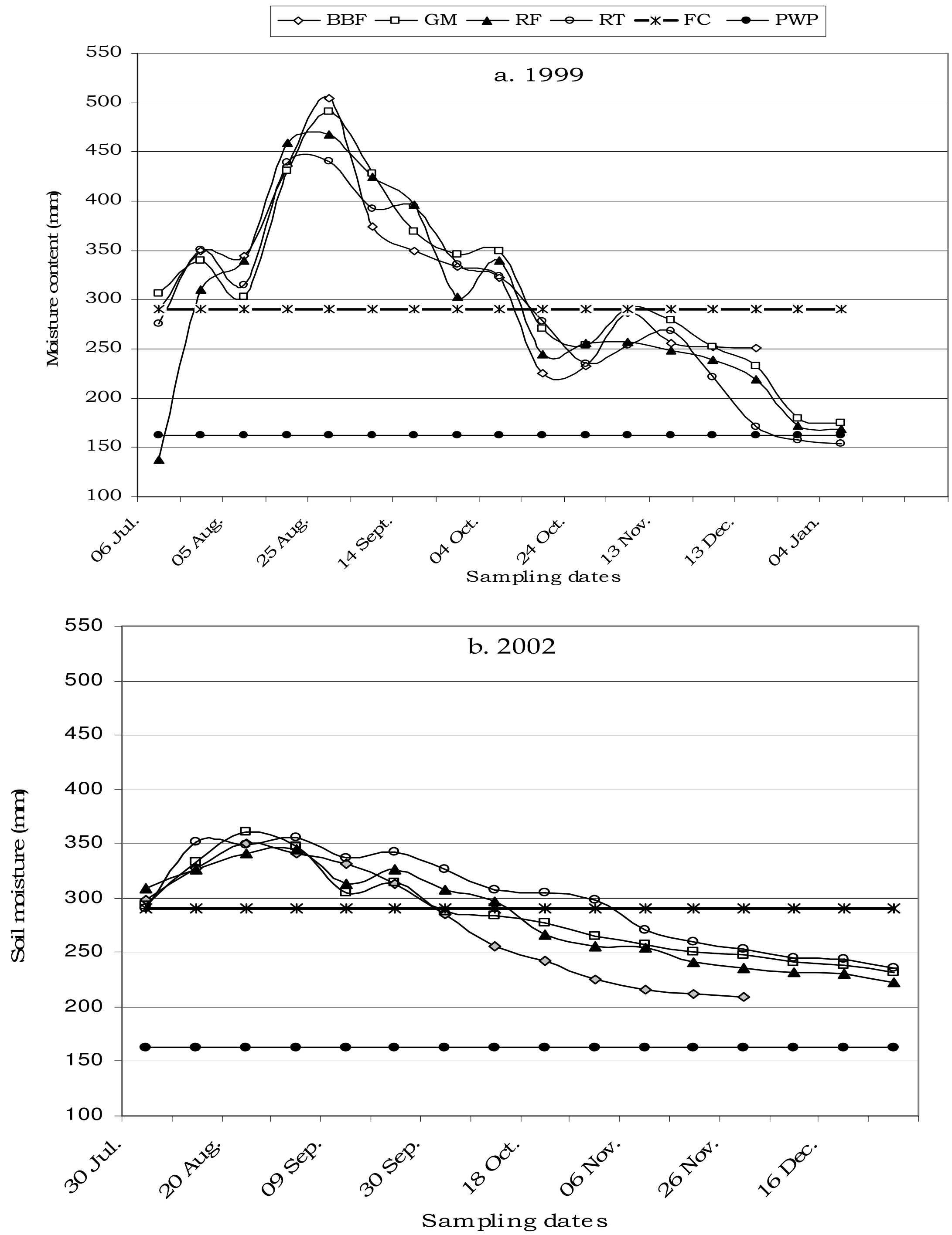

Figure 5 a and b. Effect of tillage methods on soil moisture content (0 to 60 cm depth) under lentil crops during the growing periods of 1999 and 2002.

bottom through capillary rise and, lateral flows.

Water holding capacity

Regardless of the treatments, the soil retained over 23% water at permanent wilting point (PWP) (Table 4). Like the other physical indicators, available water holding capacity (θ_A) was not significantly affected, but GM slightly increased it in the upper 30 cm (20.4%) as opposed to BBF, which slightly reduced (18.3%). The relative increase in θ_A due to GM is consistent with its increasing effects on SOM content and aggregate stability.

Table 4. Effect of land preparation methods on soil water holding capacity.

Treatment	Depth (cm)	FC (Vol. %)	PWP (Vol. %)	AWC (Vol. %)	AWC over the whole depth (90 cm)
	0 to 30	42.9	24.6	18.3	
Broad bed and furrow	30 to 60	43.8	23.9	19.9	198 mm
	60 to 90	44.2	23.2	21.0	
	0 to 30	44.0	23.6	20.4	
Green manure	30 to 60	43.5	24.2	19.3	193 mm
	60 to 90	42.8	24.5	18.3	
	0 to 30	44.2	24.7	19.5	
Ridge and furrow	30 to 60	45.2	25.3	19.9	197 mm
	60 to 90	45.7	26.1	19.7	
	0 to 30	46.0	26.5	19.5	
Reduced tillage	30 to 60	45.9	26.6	19.3	198 mm
	60 to 90	47.2	26.6	20.6	

Table 5. Effect of land preparation methods on the hydraulic conductivity (mm h^{-1}) of the soil.

Treatments	Growing season		
	2001	2002	Mean
Broad bed and furrow	2.8	2.9	2.9
Green manure	2.8	2.5	2.7
Ridge and furrow	1.8	1.1	1.5
Reduced tillage	2.4	2.1	2.3

Hydraulic conductivity

Effect of soil compaction on water flow is characterized by measurement of saturated hydraulic conductivity and water infiltration (Young and Voorhees, 1982). Soil under good condition has a stable structure and continuous pores to the surface. In this study, although the initial infiltration rate could go as high as 60 mm h^{-1} (exceeding the average rainfall intensity), the saturated hydraulic conductivity, which is important for drainage, runoff and soil erosion control was not more than 3 mm h^{-1} (much less than rainfall intensity) due to the inherent property of the soil. This leads to increased runoff and subsequent erosion during the intensive summer rainfall, contributing to the common flooding in Awash River basin, which emerges and is fed by the rainfall in the central highlands. While the infiltration rates decreased in 2002 compared to 2001 (Table 5), BBF slightly increased both the initial infiltration rate and the saturated hydraulic conductivity in both years. This may be explained by the duration between the last tillage received and infiltration measurement, which was the longest for BBF. The mean of the two years showed that the alternative treatments improved the hydraulic conductivity as compared to the control. Corresponding to its effects on aggregate stability and crusting, GM resulted in the highest basic infiltration rate followed by BBF in both years. As Vertisols are severely limited by their basic infiltration capacity, a little improvement may be considerable for better productivity and resource conservation.

Conclusion

After five consecutive years of implementation, the different tillage methods for land preparation resulted in significant effect on penetration resistance, and remarkable and consistent effect on most of the selected soil physical quality indicators, considered. In addition to penetration resistance, the treatment effect was more evident on aggregate stability, compaction, crusting and hydraulic conductivity. Therefore, these can be considered as sensitive soil physical quality indicators, although longer time may be necessary for them to be significantly affected just as texture, BD and porosity to show a measurable response. GM and RT have positively affected the soil physical quality indicators more than BBF and RF did, which is related mainly to their effects on soil OM content. This suggests that land management measures that enhance soil organic matter

content would improve soil physical quality, and therefore, organic matter management can be considered as an important entry point to enhance soil physical quality.

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