ORIGINAL ARTICLE

Effect of Tillage Systems and Residue Management on Penetrometer Resistance of Nitisols under Maize Production in Western Ethiopia

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ABSTRACT

Penetrometer resistance is one of soil physical properties influenced by tillage systems and crop residue management. Therefore, a field experiment was conducted to determine integrated effects of tillage systems and crop residue management on penetrometer resistance of Nitisols under maize production at five locations in western Ethiopia. Three tillage systems (minimum tillage with residue retention = MTRR, minimum tillage with residue removal = MTRV and conventional tillage = CT) and three N fertilizer levels (69, 92 and 115 N ha^{-1}) were combined in complete factorial arrangement. The experiment was laid out in a randomized complete block design with three replications. The experimental plots were kept permanent for five cropping seasons to observe carry-over effects on soil penetrometer resistance. Tillage systems and depth intervals had significant ($P<0.05$) influence on penetrometer resistance of Nitisols at all five locations. Maize grain yield was significantly ($P<0.05$) affected by tillage systems and N application. After five years, penetrometer resistance of Nitisols within 0-15 cm soil layer was higher under MTRR than CT, while MTRV revealed the highest soil strength. Below 15 cm soil layers, the penetrometer resistance of the CT soils tended to be slightly higher than that of the MTRV and MTRR soils. The penetrometer resistance of Nitisols was below the threshold value of 2 MPa at field capacity. Maize grain yield was significantly higher with MTRR, followed by MTRV and CT. The MTRR increased grain yield by 6.6 and 12% as compared to MTRV and CT, respectively. Nitrogen fertilizer application increased grain yield regardless of tillage systems. Application of 92 kg N ha^{-1} was significantly higher to 69 kg N ha^{-1}, but on par with the 115 kg N ha^{-1} application, implying 92 kg N ha^{-1} application could be optimum level for both MTRR and CT systems. Root penetration of maize in the Nitisols could not be impeded by soil penetration resistance after five consecutive years practice of CT, MTRV and MTRR in the study and similar areas.

Key words: Crop residue, maize, Nitisols, penetrometer resistance, tillage system

INTRODUCTION

Soil tillage is probably as old as settle agriculture. It has been therefore an integral part of traditional and/or conventional agriculture. The concept of minimum tillage, a combination of ancient and modern agricultural practices, was first introduced in the early 1950's when tillage was substituted by herbicides in pasture renovation (Moody *et al.,* 1961). Soil tillage plays an important role in the dynamic processes governing soil fertility and quality. It is possible that with properly designed tillage practices to alleviate soil related constraints in achieving potential productivity and utility. However, improperly designed tillage practices can set in motion a wide range of degradative processes (Lal, 1993).

The conventional tillage system for maize production in Western Ethiopia involves multiple passes with oxen plow over three months period prior to planting. This usually results in a fine seedbed that is bare with pulverized soil. In a state like this the soil is very vulnerable to degradation because the rainfall is often intense. Consequently, conventional tillage system was found not sustainable for maize production in western Ethiopia and should therefore be replaced by minimum tillage that enhance crop productivity (Tolessa *et al.,* 2007) and improve soil properties (Tolessa *et. al,* 2014a,b).

The two most prominent features of minimum tillage compared with conventional tillage are retention of crop residues on soil surface and reduced mechanical manipulation and mixing of the soil. Minimum tillage maintains high surface soil residue coverage, has resulted in significant changes of soil physical properties, especially in the upper few centimeters (Lal 1976; Mahli *et al.*, 1992). However, the actual effects of such change depend on several factors including differences in antecedent soil properties, climatic conditions, history of cultural management, extent and type of tillage (Mahboubi *et al.,* 1993). The degree and extent of changes brought about by minimum tillage are determined largely by the amount of crop residue produced and retained annually, the degree of reduction in tillage, and the length of time that the system is practiced (Blevins *et al.*, 1983).

Griffith *et al.* (1986) suggested placement of crop residues associated with minimum tillage often has a greater influence on soil properties than the degree of pulverization which is coupled with conventional tillage. In some instances therefore reduced soil mixing combined with retention of crop residues on the surface markedly change physical, chemical and biological properties through the soil profile over time (Lal, 1976; Doran, 1980; Blevins *et al*, 1983; Mahboubi *et al.*, 1993; Tolessa *et. al.,* 2014a,b).

Soil physical properties that could be altered with tillage systems include penetrometer resistance, water holding capacity, bulk density, structure, porosity and temperature (Lal 1976; Blevins *et al.*, 1983; Mahboubi *et al.,* 1993; Griffith *et al.*, 1986). Lal (1976) reported that because of greater earthworm activity and less crusting, the bulk density and hence penetrometer resistance of minimum tilled plot was not as high as that of conventional tilled plot. On the contrary other researchers (Bauder *et al.*, 1981; Epperlein, 2001) reported higher soil resistance to penetration with minimum tillage than with conventional tillage. Therefore objective of this study was to determine the integrated effects of tillage systems and crop residue management on penetrometer resistance of Nitisols under maize production in Western Ethiopia.

MATERIALS AND METHODS

Experimental sites

The study was conducted at five locations (Bako, Shoboka, Tibe, Ijaji and Gudar) in western Ethiopia. Bako is located at 09^0 01′N and 37^0 02′E, Shoboka at $09^006'$ N and $37^021'$E, Tibe at $09^029'$N and $37^032'$E, Ijaji at $09^043'$N and $37^047'$E, and Gudar at $08^009'$N and $38^008'$E latitude and longitude, respectively. The altitude for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 meter above sea level, respectively. At all five sites the soil was classified as Nitisols (FAO, 1998). Some of the physical and chemical characteristics of these Nitisols before commencement of the trials are summarized in Table 1. The soil depths of the profiles varied from 135 to 200 cm and clay was the predominant texture throughout the soil horizons. The textural class of the Nitisols differed from loam at Ijaji site to clay at the Shoboka site. Similar differences of 0.61 units in pH, 1.08% in organic C, 0.04% in total N, 3.9 mg kg^{-1} in extractable P and 85 mg kg^{-1} in exchangeable K were recorded between the five sites.

The pH of topsoil ranged from 5.41 (strongly acidic) in Tibe to 6.02 (slightly acidic) in Gudar. Soil pH increases with depth at all sites indicating leaching of basic cations from the surface soil to the lower depths. The soils are low to medium in organic matter, total N and extractable P contents, while medium in exchangeable potassium content according to the category by Hazelton and Murphy (2007).

Field trial layout

At each site three tillage systems: minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT) and three N fertilization levels (69, 92 and 115 kg N ha^{-1}) were combined in complete factorial arrangement. The experiment was laid out in randomized complete block design with three replications. The experimental plots were kept permanent for five cropping seasons to observe the carry-over effects of the treatments on soil penetrometer resistance.

Agronomic practices

Before commencement of the experiment the fields at all sites were under conventional maize production. During the entire trial periods immediately after harvesting maize residues were cut at ground level and uniformly spread on MTRR plots and removed from MTRV plots. For the MTRR and MTRV treatments soil disturbance was restricted to the absolute minimum, viz. the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, the soil was plowed three times with the local oxen-plough 'maresha' prior to sowing to obtain a suitable seedbed for the CT treatments.

Data collection

Measuring penetrometer resistance of soils

The penetrometer resistance of the soil in each plot at all the five sites was measured at flowering stage of maize crop. At this stage water content of the soil was approximately at field capacity. A slide cone penetrometer of Eijkelkamp with a base area of 5 cm^2 was used. The penetrometer was pushed manually into the soil at a randomly selected spot per plot. Readings were taken at 5 cm intervals from the surface to 30 cm depth.

Soil sample collection and analysis

Soil samples were collected just before trials commencement from 0-20 cm soil layer from all the five sites for characterization. A 5 cm diameter auger was used to sample five randomly selected spots per plot. These sub-samples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored until analysis. Soil particle size distribution was determined by hydrometric method (Bouyoucos, 1962). Soil pH was measured using digital pH meter in 1:2.5 soil/water suspension. Organic C was determined following wet digestion method as described by Walkey and Black (1934), while Kjeldahl procedure was used for the determination of total N as described by Bremner and Mulvancy (1982). The extractable P was measured by Bray II method (Bray and Kurtz, 1945). The exchangeable K was determined with neutral normal NH_4OAc solution using flame photometer (Van Reeuwijk, 1992).

Data analysis

The collected data were analyzed using the SAS statistical software Version 9.2 (SAS, 2008). Means for each parameter were separated by the least significant difference (LSD) test at 5 % probability level (Steel and Torrie, 1980)

RESULTS AND DISCUSSION

Effects of tillage systems on penetrometer resistance of Nitisols

Tillage systems and depth intervals had significant ($P<0.05$) influence on penetrometer resistance of Nitisols at all the five sites (Figure 1). The penetrometer resistances of soils were increased with depth irrespective of sites and tillage systems. However, penetrometer resistance was differed significantly between tillage systems to a depth of 15 cm at Bako and to only 10 cm at Shoboka, Tibe, Ijaji and Gudar. In this upper 0-15 cm soil layer the lowest penetrometer resistance was recorded in the CT soils, followed by the MTRR and then the MTRV soils. Below 15 cm soil layers the penetrometer resistance of the CT soils tended to be slightly higher than that of the MTRV and MTRR soils.

The pattern of penetrometer resistance is in agreement with other findings (Bauder *et al.*, 1981; Epperlein, 2001). When the soil is placed under MTRR, the surface soil layer may become more compacted than under CT (Ehlers *et al.*, 1983). However, in the deeper soil layers, compaction is generally no greater under MTRR than CT and may be lower (Gantzer and Blake, 1978). Malhi and O'Sullivan (1990) observed higher penetration resistance in surface soils after 5 years under MTRR as compared to CT. Similarly, Malhi *et al.* (1992) determined after 7 years of tillage treatments, penetration resistance in the surface 10 cm of the soil was higher under MTRR than CT, but did not differ in the 10-20 cm or 20-30 cm depths. According to McFarland *et al.* (1990) penetrometer resistance at the 15-20 cm depth was greater under CT than under MTRR likely due to the greater amount of equipment traffic and plowing required in the CT system.

Penetration resistance approximates soil compaction. Various penetration resistance studies have been conducted to correlate soil strength with plant growth and to establish the limiting penetration resistance for root growth (Ehlers *et al.*, 1983) or shoot emergence (Ball and O'Sullivan, 1982).

The penetrometer resistance of 2 MPa or higher at field capacity usually impede crop root penetration (Taylor and Gardner, 1963; Voorhees *et al*., 1975; Gupta and Larson, 1982). Therefore, this threshold value was not reached at all sites.

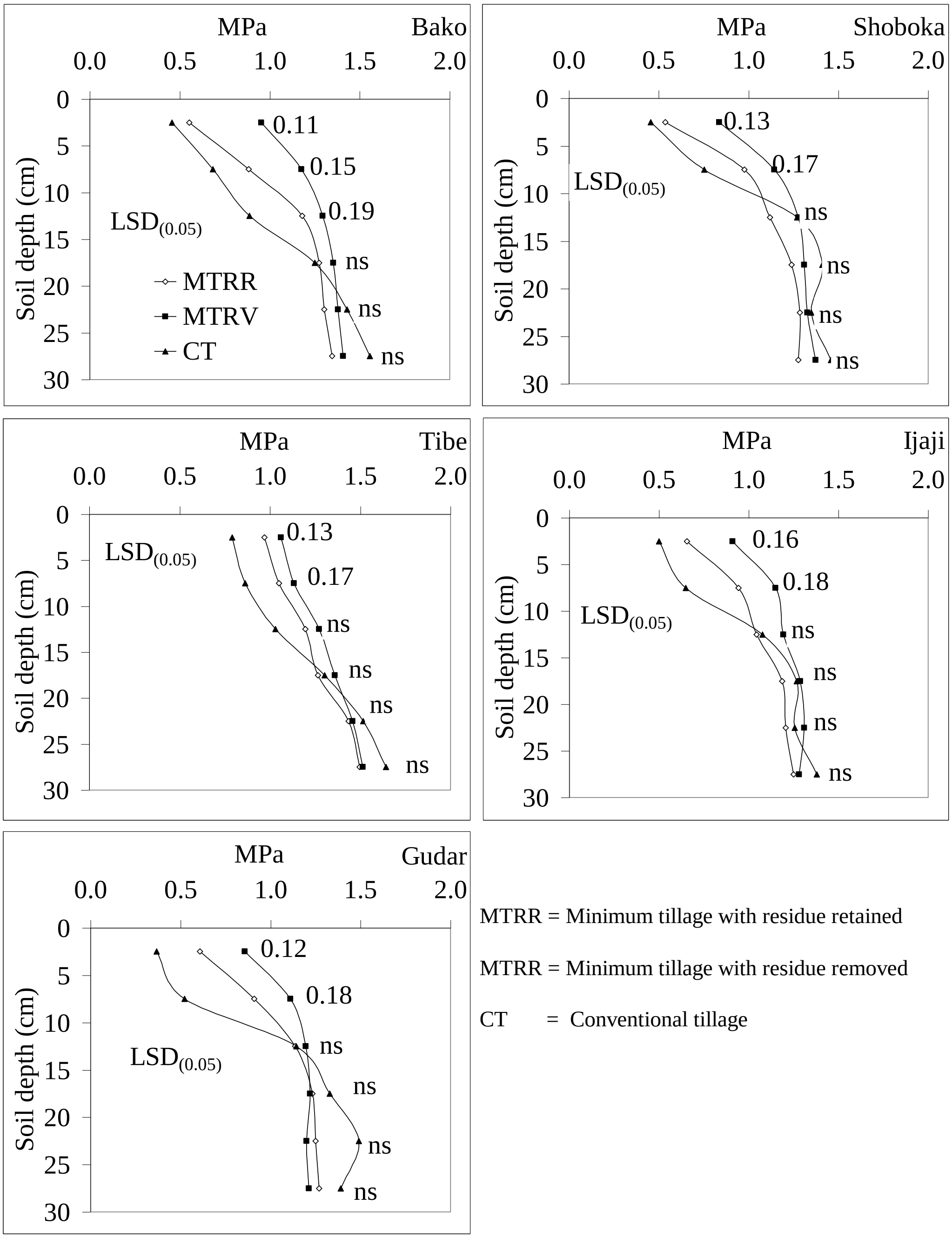

Figure 1. Effect of tillage systems on the penetrometer resistance of Nitisols under maize production as measured at six depth intervals at five sites in western Ethiopia

Effects of tillage systems and NP rates on grain yield of maize

Tillage system and N fertilizer application significantly ($P<0.05$) affected maize grain yields (Table 2). However, the interaction between tillage systems and N application was non-significant. On average, maize grain yield of MTRR was 400 and 705 kg ha^{-1} higher than that of MTRV and CT, resulting in yield increase of 6.6 and 12.2%, respectively. Application of N increased maize grain yield regardless of tillage system. A progressive increase in maize grain yield was recorded with incremental levels of N applied. Further, grain yield response was more noticeable in the first than the second incremental level of N. Application of 92 kg N ha^{-1} was significantly superior to 69 kg N ha^{-1}, but on par with the 115 kg N ha^{-1} application, implying 92 kg N ha^{-1} application could be optimum level for both MTRR and CT systems. Legg *et al.* (1979) and Thomas and Frye (1984) also recommended equal amount of N fertilizer application for optimum crop production for both MTRR and CT systems.

Table 1. Some physical and chemical properties of Nitisols at the study sites.

Sites	Depth (cm)	Horizon	Sand	Silt	Clay	pH (H_2O)	OC	Total N	*P	K
			%				%		mg kg^{-1}	
Bako	0-25	A	35.1	31.6	33.3	5.59	1.77	0.15	12.6	192
	25-70	Bt1	35.5	23.4	41.1	5.64	0.96	0.09	11.4	146
	70-130	Bt2	24.2	21.3	54.5	5.61	0.66	0.07	8.5	131
	130-200$^+$	Bt3	28.8	11.1	60.1	5.73	0.55	0.06	5.3	103
Shoboka	0-40	A	34.7	23.3	42.0	5.52	1.65	0.14	11.5	155
	40-80	Bt1	27.1	26.1	46.8	5.60	1.11	0.10	8.7	148
	80-120	Bt2	40.6	10.3	49.1	5.84	0.86	0.08	8.9	119
	120-160$^+$	Bt3	33.4	14.2	52.4	6.03	0.68	0.07	6.5	95
Tibe	0-20	Ap	26.7	35.2	38.1	5.41	1.46	0.12	8.7	146
	20-90	Ab	15.3	21.0	63.7	5.49	0.99	0.09	6.8	120
	90-140	Bt1	23.0	18.1	58.9	5.67	0.65	0.07	5.7	103
	140-160$^+$	Bt2	25.6	17.2	57.2	5.86	0.45	0.05	4.3	86
Ijaji	0-30	A	44.7	32.3	23.0	5.69	1.93	0.16	10.3	231
	30-65	Bt1	39.5	19.3	41.2	5.74	1.07	0.10	7.8	204
	65-95	Bt2	33.5	23.7	42.8	5.92	0.85	0.09	8.3	176
	95-140	Bt3	35.4	20.4	44.2	6.03	0.76	0.08	6.5	143
	140-165$^+$	BC	36.0	15.3	48.7	5.87	0.58	0.06	4.1	138
Gudar	0-50	A	18.8	42.5	38.7	6.02	1.69	0.14	9.6	159
	50-110	B	25.8	39.1	35.1	6.64	0.91	0.09	7.5	113
	110-135	C	31.7	37.7	30.6	6.81	0.75	0.08	4.4	91

*Bray II extraction procedure

Table 2. Effect of tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and nitrogen fertilization on maize grain yield combined over locations.

N level (kg ha^{-1})	Tillage system (T)			Mean
	MTRR	MTRV	CT	
69	5953	5595	5210	5586
92	6513	6173	5868	6185
115	6953	6450	6227	6543
Mean	6473	6073	5768	
$LSD_{(0.05)}$	T or N = 394	T x N = ns		

CONCLUSIONS

Three contrasting tillage systems, viz. MTRR, MTRV and CT significantly influenced the penetrometer resistance of Nitisols in western Ethiopia. The penetration resistance of Nitisols increased with depth regardless of sites and tillage systems. After five years, MTRR revealed higher soil penetration resistance within 0-15 cm soil depth than CT, while MTRV showed the highest soil strength. Below 15 cm soil layers, the penetrometer resistance of the CT soils tended to be slightly higher than that of the MTRV and MTRR soils. The penetration resistance of Nitisols was below the threshold value of 2 MPa at field capacity. MTRR significantly increased maize grain yield by 6.6 and 12.2% compared to MTRV and CT, respectively. Application of 69 kg N ha^{-1} was significantly inferior to 92 kg N ha^{-1} and 92 kg N ha^{-1} was on par with the 115 kg N ha^{-1}application. Thus, 92 kg N ha^{-1} application was found optimum for both MTRR and CT. It is therefore concluded that root penetration of maize in the Nitisols could not be hindered by soil penetration resistance after five consecutive years practice of CT, MTRV and MTRR.

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