Effects of tillage on soil physical properties and root growth of maize in loam and clay in central China

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ABSTRACT

Subsoil compaction can result in unfavourable soil physical conditions and hinder the root growth of maize. The effects of deep tillage and conventional tillage on soil physical properties and root growth of maize were studied during 2010–2011 at two sites (loam at Hebi and clay at Luohe) in central China. The results showed that soil penetration resistance, bulk density, water content and root length density were significantly affected by tillage, soil depth and year. Deep tillage had lower penetration resistance and lower soil bulk density, but higher soil water content than conventional tillage across years and depths. Averaged over the whole soil profile, deep tillage not only significantly decreased penetration resistance and soil bulk density, but significantly increased soil water content and root length density on loam, while deep tillage only significantly increased the root length density on clay. We conclude that deep tillage on the loam is more suitable for the root growth of summer maize.

Keywords: soil compaction; penetration resistance; deep tillage; conventional tillage; root length density

Soil compaction of agricultural soils is a global well recognized problem (Hamza and Anderson 2005) due to deteriorated soil environment and adverse effects of intensive use of farm machinery on crop yield (Hamza et al. 2011). In China, subsoil compaction is also caused by inappropriate tillage, traffic and field operations on poor time (Zhang et al. 2006). According to our investigation in 2008, the average soil bulk density at 5–10 cm depth is 1.38 t/m^3, while the average soil bulk density at the plowpan is 1.52 t/m^3 in central China. The soil bulk density is much higher than the proper soil bulk density for maize which is 1.2–1.3 t/m^3 (Li and Zhou 1994). Soil compaction can cause unfavorable soil physical, chemical and microorganism conditions in subsoil which hinder root growth and crop yield (Hamza and Anderson 2005, Mosaddeghi et al. 2009). Soil compaction has become the main impediment that restricts the yield-increasing of maize in central China.

Tillage is one of the most effective ways to reduce soil compaction (Daniells 2012). Soil physical properties and crop growth are affected by tillage systems (Mosaddeghi et al. 2009). However, the effects on root between different tillage systems have not been consistent. Some researchers found that deep tillage reduced soil strength and soil bulk density (Laddha and Totawat 1997), improved water storage in the soil, enhanced the root growth (Holloway and Dexter 1991), increased crop production (Ghosh et al. 2006). In contrast to the above reports, Mosaddeghi et al. (2009) found that soil conditions under a no-tillage conservation system were better than those under conventional system in arid and semi-arid environments.

Considering the adverse effects of soil compaction in field, the government of China has began to pay allowance to the farmers who adopt the deep moldboard tillage instead of the conventional low moldboard tillage since 2009, encouraging farm-

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ers to solve the soil compaction by deep tillage. However, there is little information about the effects of deep moldboard tillage on soil properties and root growth in different soil types. Therefore, a two-site study was conducted at two typical and representational soil types in central China. The objectives of this study were to investigate the effects of tillage depth on soil physical properties and root length density of summer maize at two soil types in central China.

MATERIAL AND METHODS

Study sites and soil properties. Two field experiments were conducted during 2010–2011 at Hebi (35°67'N, 114°98'E) and Luohe (33°57'N, 113°98'E) in the central China. Both sites have a continental monsoon type climate. The data on solar radiation and temperature during the study period were collected from an adjacent weather station and are presented in Figure 1. There are winter wheat-summer maize rotation at Hebi and Luohe. For several decades, soil tillage is conducted after the harvest of maize and before the winter wheat sowing. Soil tillage is always conventional shallow tillage (20 cm depth) with moldboard plough, followed by a disk harrow for seedbed preparation. Summer maize is sowed under no-tillage condition. The two year experiments were conducted on the same site with the same plots. Soil basal samples were collected at the beginning of experiment. The main physical and chemical properties of soils in the two study sites are presented in Table 1.

Experiment design and crop cultivation. The experiment was designed as a complete randomization with three replications. Soil tillage was conducted before the winter wheat sowing. Conventional tillage (CT) was moldboard plowed to a depth of 20 cm, deep tillage (DT) was moldboard plowed to a depth of 30 cm, followed by a disk harrow for seedbed preparation. Throughout the study periods, residues of winter wheat and maize were cut into small pieces less than 5 cm length, and residues of maize were plowed into the soil with tillage, residues of winter wheat were left on the soil surface. Summer maize was sowed under no-tillage condition. The area of each tillage plot was 60 m × 20 m. The summer maize hybrid Zhengdan 958 was sown at a density of 67 500 plant/ha on June 7 at Hebi and June 5 at Luohe during the two study years. Basal fertilizer of 135 kg/ha N as urea, 60 kg P/ha as diammonium phosphate and 150 kg K/ha as potassium sulfate were applied just before sowing. 135 kg/ha N as urea was applied at 12-leaf full expansion. All culture practices were the same in all plots.

Soil physical measurement. Soil physical properties were measured on 7 October in 2010 and

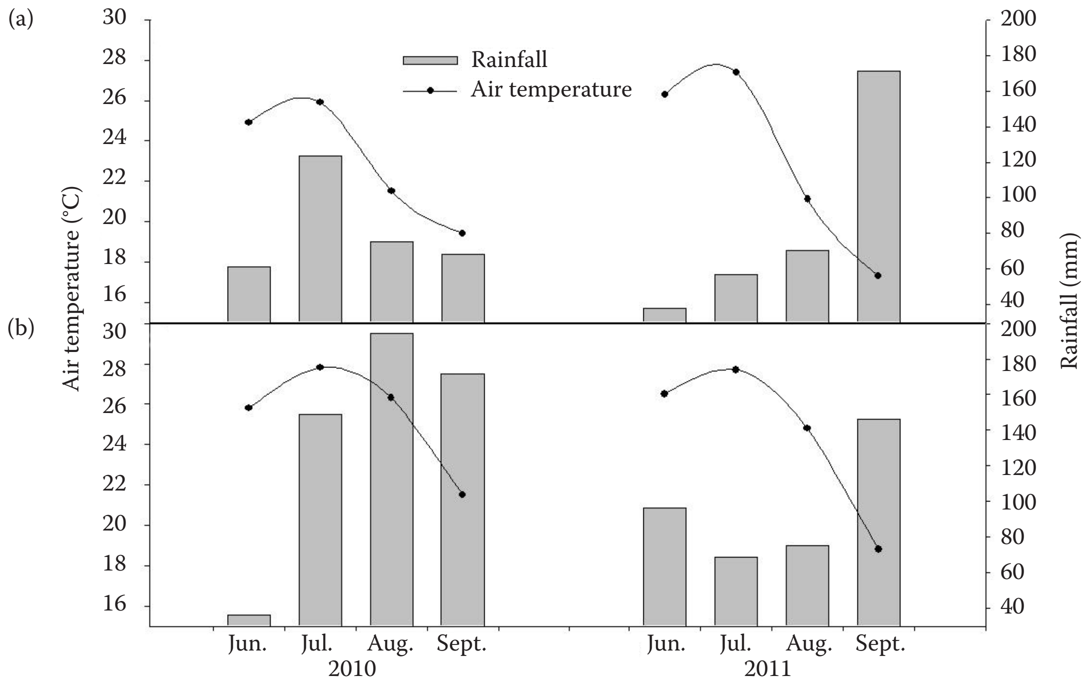

Figure 1. Mean monthly temperature and monthly precipitation at (a) Hebi and (b) Luohe during the study period

Table 1. Soil texture and characteristics of the soil at Hebi and Luohe before the experiments

Site	Soil texture[a]		0–10	10–20	20–30	30–40
			(cm)			
Hebi	Loam sand/silt/clay = 31/47/22	bulk density (t/m^3)	1.26	1.34	1.55	1.48
		organic C (g/kg)	9.87	8.67	4.40	4.91
		total N (g/kg)	1.21	1.16	1.20	0.75
		available P (mg/kg)	13.15	15.06	5.22	3.71
		available K (mg/kg)	159.55	133.26	123.65	137.26
Luohe	Clay sand/silt/clay = 12/41/47	bulk density (t/m^3)	1.32	1.34	1.54	1.59
		organic C (g/kg)	8.35	9.16	5.66	6.29
		total N (g/kg)	2.11	2.16	1.55	1.15
		available P (mg/kg)	32.46	27.33	13.75	3.14
		available K (mg/kg)	145.74	138.33	143.78	135.61

[a]Soil texture is defined according to the USDA textural classification

4 October in 2011 when the maize was at grain physiological maturity. Three separate locations in each plot were chosen to measure soil penetration resistance, bulk density and water content. Soil penetration resistance was measured to a depth 40 cm with a core penetrometer (SC 900, Spectrum Technologies, Inc. , Illinois, USA) made to comply with ASAE standard and has a 30° core angle and base diameter of 12 mm. The soil bulk density was measured by the core method (Chan 1981). Three soil cores were taken each plot to 40 cm depth and cut into 10 cm increments. The soil core samples were oven dried at 105°C for 48 h for the bulk density and gravimetric soil water content determinations.

Root measurement. Maize roots were sampled with the soil-core method at V6 (6th leaf), VT (tasseling) and R6 (physiological maturity) stages. Each plot was sampled at three separate locations, and all sampling locations were in areas without wheel track. The soil cores (diameter and length of 8 cm and 10 cm, respectively) were taken to a depth of 40 cm in each plot by a hand-held power sampler. The cores were taken as close as possible to the stalk of the maize plants where the highest rooting density was presumed to occur. Roots were rinsed from the soil-root core samples by using a 2 mm mesh screens under running tap water. Roots were scanned with a scanner (Epson V700, Jakarta, Indonesia). The root sample was placed in a glass rectangular dish (15–20 cm) with a layer of water about 4–5 mm deep to untangle the roots and minimize root overlap. Because the roots harvested at tasseling and maturity were very large, a root sample was separated into subsamples when necessary until they could be placed into the rectangular dish. The images were analyzed using the software WinRHIZO version 5.0 (Regent Instruments Inc., Quebec, Canada). After calculation, the total root length of the whole root sample was obtained. The root length density (RLD) was calculated by dividing the total root length by the volume of the corresponding soil-core section (Qin et al. 2006).

Statistical analysis. Means were calculated for the three replicates from each treatment. Analysis of variance (ANOVA) was conducted using SAS (SAS Institute Inc., North Carolina, USA). Differences between two years and between two tillage systems were compared by the Student *t*-test. Differences among four soil depths were compared by the least significant difference (*LSD*). Differences between the means were considered to be statistically significant at $P < 0.05$.

RESULTS AND DISCUSSION

The soil penetration resistance was affected by year, tillage and soil depth (Table 2). The penetration resistances at Hebi and Luohe in 2011 were lower by 6.1% and 4.4%, respectively, than in 2010 with the increase of deep tillage (Table 3). Across years and soil depths, DT had 4.3% lower penetration resistance than CT at Hebi, while there was no significant difference in penetration resistance at Luohe. Similar results were found in the previous studies (Ghosh et al. 2006). On the loam, the penetration resistance of DT at 20–30 cm depth was significantly lower than CT in the both years (Figure 2). On the clay, the penetration resistance of DT at

Table 2. Analysis of variance of soil bulk density, soil water content and root length density of maize as affected by year, site, tillage and soil depth

Site	Source of variation	Penetration resistance	Soil bulk density	Soil water content	Root length density
Hebi	year (Y)	**	ns	**	*
	tillage (T)	**	**	**	**
	soil depth (D)	**	**	**	**
	Y × T	ns	ns	*	*
	Y × D	**	ns	**	**
	T × D	**	**	*	ns
	Y × T × D	ns	ns	**	*
Luohe	year	**	ns	**	**
	tillage	ns	ns	ns	**
	soil depth	**	**	**	**
	Y × T	ns	ns	ns	*
	Y × D	ns	ns	ns	**
	T × D	*	**	ns	**
	Y × T × D	ns	ns	**	**

ns – not significant; $^*P < 0.05$; $^{**}P < 0.01$

0–15 cm depth was higher than CT, while that of DT at 20–30 cm depth was significantly lower than CT in the two study years. The penetration resistance below 35 cm depth was not affected by the tillage system. This suggests that deep tillage can decrease soil penetration resistance below 20 cm depth, although the penetration resistance at 0–10 cm increased.

Table 3. Soil bulk density, soil water content and root length density of maize at maturity as influenced by year, site, tillage system and soil depth

Site	Main effect		Penetration resistance (MPa)	Soil bulk density (t/m^3)	Soil water content (%)	Root length density (cm/cm^3)
Hebi	year[a]	2010	1.65[a]	1.39	20.68[b]	0.34[b]
		2011	1.55[b]	1.39	21.79[a]	0.36[a]
	tillage system[a]	CT	1.64[a]	1.42[a]	20.81[b]	0.29[b]
		DT	1.57[b]	1.36[b]	21.65[a]	0.41[a]
	soil depth[b] (cm)	0–10	0.36[d]	1.26[c]	22.41[a]	0.59[a]
		10–20	0.66[c]	1.35[b]	21.22[b]	0.37[b]
		20–30	2.56[b]	1.48[a]	21.24[b]	0.25[c]
		30–40	2.83[a]	1.47[a]	20.06[c]	0.18[d]
Luohe	year[a]	2010	1.82[a]	1.45	21.27[b]	0.30[b]
		2011	1.74[b]	1.45	22.35[a]	0.32[a]
	tillage system[a]	CT	1.77	1.45	21.83	0.27[b]
		DT	1.78	1.45	21.79	0.35[a]
	soil depth[b] (cm)	0–10	0.64[d]	1.33[c]	22.82[a]	0.65[a]
		10–20	0.81[c]	1.34[c]	22.45[ab]	0.30[b]
		20–30	2.77[b]	1.54[b]	21.83[b]	0.17[c]
		30–40	2.90[a]	1.59[a]	20.14[c]	0.12[d]

[a]means of the main factor followed by different letters are significantly different at $P < 0.05$ according to *t*-test; [b]means of the main factor followed by different letters are significantly different at $P < 0.05$ according to *LSD*; CT – conventional tillage; DT – deep tillage

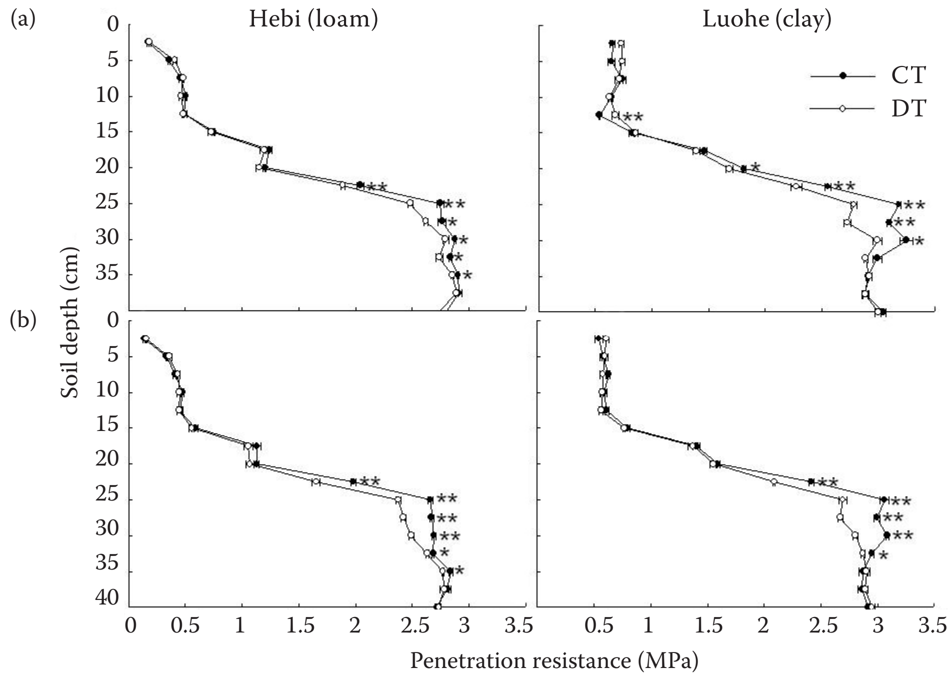

Figure 2. Soil penetration resistance as a function of tillage system and soil depth at Hebi and Luohe in (a) 2010 and (b) 2011. CT – conventional tillage; DT – deep tillage

Across years and soil depths, DT had 4.2% lower soil bulk density than CT at Hebi, while there was no significant difference in soil bulk density at Luohe (Tables 2 and 3). Laddha and Totawat (1997) found that deep tillage proved superior to shallow tillage in reducing the bulk density and increasing soil porosity. On the loam, the soil bulk density of DT at 0–20 cm depth was higher than CT, while that of DT at 20–40 cm depth was significantly lower than CT in the both years, except for the soil bulk density at 10–20 cm in 2011 (Figure 3). On the clay, the soil bulk density of DT at 0–20 cm

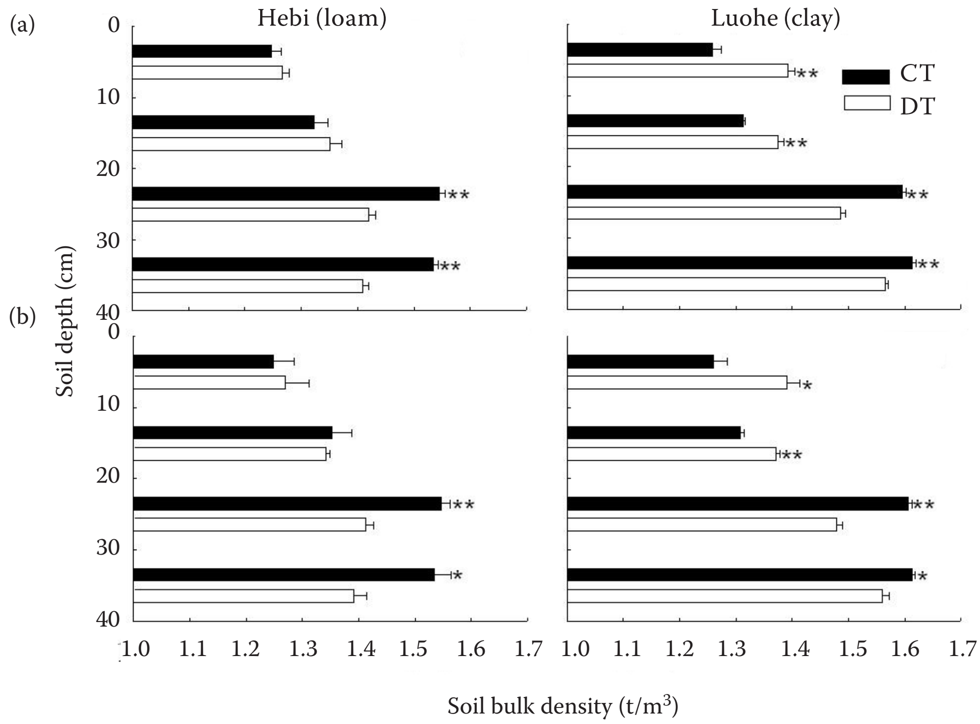

Figure 3. Soil bulk density as a function of tillage system and soil depth at Hebi and Luohe in (a) 2010 and (b) 2011. CT – conventional tillage; DT – deep tillage

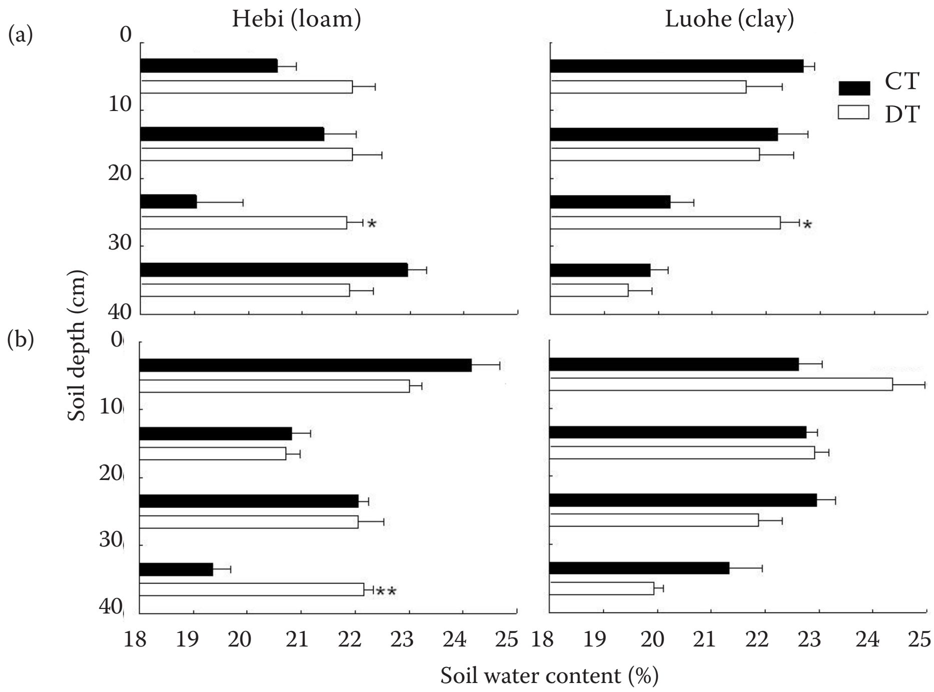

Figure 4. Soil water content as a function of tillage system and soil depth at Hebi and Luohe in (a) 2010 and (b) 2011. CT – conventional tillage; DT – deep tillage

depth was significantly higher than CT, while that of DT at 20–40 cm depth was significantly lower than CT in the two study years.

Significant difference in soil water content between CT and DT was found at 20–30 cm soil depth in 2010 (Figure 4). In 2011, the soil water content of DT at 30–40 cm depth was significantly higher than CT on loam. However, there was no significant difference in the soil water content between CT and DT on clay, due to a large rainfall before the maturity of maize. Busscher and Bauer (2003) also proved that water content data did not generally

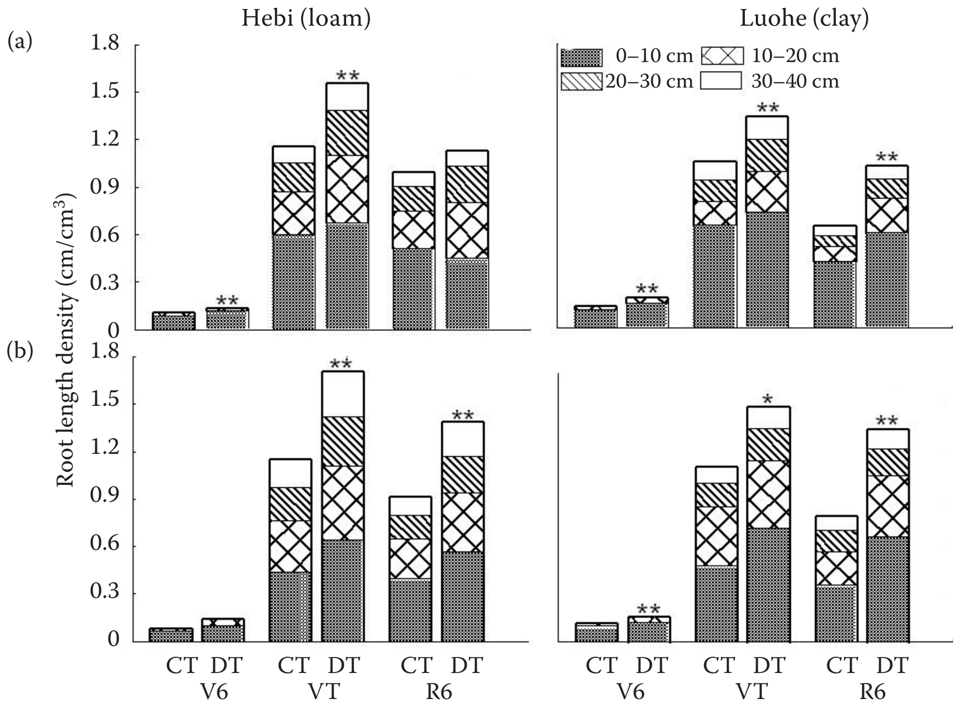

Figure 5. Root length density as a function of tillage system and soil depth at Hebi and Luohe in (a) 2010 and (b) 2011. CT – conventional tillage; DT – deep tillage; V6 – 6th leaf; VT – tasseling; R6 – physiological maturity stages

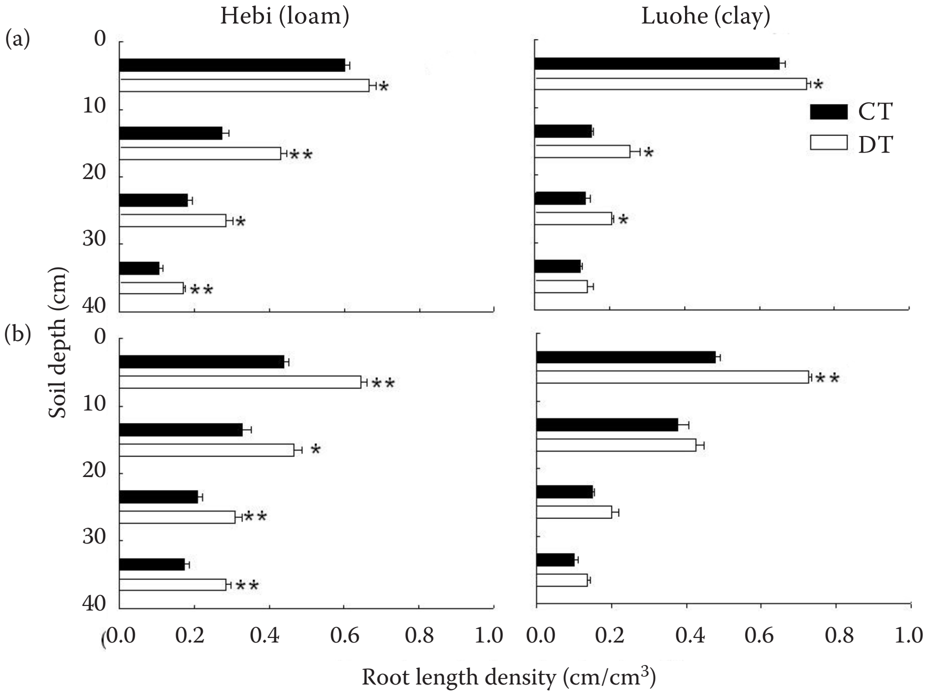

Figure 6. Root length density at tasseling (VT) stage as a function of tillage system and soil depth at Hebi and Luohe in (a) 2010 and (b) 2011. CT – conventional tillage; DT – deep tillage

vary with tillage treatments, but water content and soil strength were negatively correlated when all depths were averaged together.

The root length densities at Hebi and Luohe in 2011 were higher by 5.9% and 6.7%, respectively, than in 2010 (Table 3). DT at Hebi and Luohe had 41.4% and 29.6%, respectively, higher root length density than CT, which was consistent with the findings of Ball-Coelho et al. (1998). During the growth period of maize, DT had significantly higher root length density than CT, except for R6 stage in 2010 and V6 stage in 2011 on loam (Figure 5).

Moreover, the root length density of DT was significantly higher than CT at each soil layer at VT stage on loam (Figure 6). The root length density of DT at 0–10, 10–20, 20–30 and 30–40 cm depths were higher by 28.7, 50.0, 52.5 and 64.0%, respectively, than CT. On clay at Luohe, the root length density of DT was significantly higher than CT at 0–10 cm depth at VT stage, while there was no significant difference in root length density at 30–40 cm depth. The root length density of DT at 0–10, 10–20, 20–30 and 30–40 cm depths were higher by 32.0, 41.5, 43.5 and 26.2%, respectively, than CT. This suggests that deep tillage mainly increased the root growth from 10–40 cm depth on loam, while increased the root growth at 0–30 cm on clay. Previous studies also proved that deep tillage not only increased root proliferation and the depth to which roots penetrated (Shirani et al. 2002), but also increased the biomass of deeper root (Varsa et al. 1997), but soil texture may have been the essential reason for the differences in root growth between sites (Ball-Coelho et al. 1998).

Soil compaction was positively correlated with bulk density or penetration resistance. In the study, DT reduced soil compaction, promoted growth of maize, increased yield and nutrient uptake. The increase in dry mass and yield of maize due to DT was 4.8–6.2%, and 4.9–6.5%, respectively. The increase in nutrient uptake by maize due to DT was 4.4–13.9% for N, 9.9–10.8% for P and up to 14.1–27.0% for K. Similar results were found by Ishaq et al. (2001). However, the size of the increase in profit is shown to depend on the size of yield increases from deep tillage and the appropriate selection of rotations, frequency and timing of deep tillage and the type and size of deep tillage machinery. If the expected yield response to deep tillage is at least 300 t/ha, adoption of deep tillage is profitable (Ghadim et al. 1991). Furthermore, the effects of tillage on soil physical characters and root growth were affected by soil texture. According to the findings of Håkansson et al. (1998), it may be profitable to plough sandy soils annually as deep as 30 cm, but in clay and clay loam soils, ploughing deeper than 20–25 cm generally cannot be recommended.

Therefore, we conclude that deep tillage improved the soil physical characters and increased the root growth of maize, and deep tillage on the loam is more suitable for the root growth of summer maize.

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