Vol. 14, No. 2, pp. 194-200 (2014)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Immediate and Residual Effect of Chiseling on Soil Hydro-Mechanical Behaviour and Root Growth in a Soybean-Wheat Rotation

MUKHTAR AHMED, PRAMILA AGGARWAL*, DEBASHIS CHAKRABORTY, SHEORAJ SINGH AND R.N. GARG

Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi-110 012

ABSTRACT

A field experiment was conducted in the experimental farm of the ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of immediate and residual effects of chiseling on soil hydro-mechanical behaviour and root growth in a soybean-wheat rotation. The treatments were: RS; Residual chisel (Chiseling on June, 2011), RC; Repeated chisel (Chiseling on May 2011 and again on May 2013), FC; Fresh chisel (Chiseling once in May 2013) and NC; No chisel (Control). Soil bulk density (r_b), penetration resistance (Q), field-saturated hydraulic conductivity (K_{fs}), and steady state infiltration rate (i) were recorded initially, and at harvest of wheat crops. Root length density (RLD), root surface area (RSA), root volume density (RVA) and average diameter (RAD) of roots were also recorded at peak flowering stages of the crops. A very high rainfall (1182 mm against normal *kharif* rain of 582 mm) immediately following the chiseling operation counteracted the benefits of loosening the sub-surface layers, and no chiseling effect was realized in the FC plots. The residual effect (RS and RC) however was apparent, and in soybean, 3-5 % lower soil bulk density was observed in RS and RC plots as compared to NC, particularly at 15-30 cm soil layer. The RC and RS reduced Q by 35 and 15% lower in soybean as compared to NC at 15-30 cm soil layer. However, the effect of chiseling reduced thereafter and the residual effect on r_b and Q reduced was marginal at harvest of the wheat crop. Initially, the K_{fs} at 15-30 cm soil layer in NC was significantly higher (25-30%) than that in FC, RS and RC plots, although the effect did not continue, and marginal differences could be recorded in wheat among the chisel treatments. Similarly, i also recorded 30-36 % higher values in NC initially, and then differences became non-significant. Chiseling improved RLD and RSA at 15-30 cm layer in both the crops. Significantly higher yields of soybean were obtained in RS and RC, but the yield difference was only marginally higher in case of following wheat crop. Results indicated that the effect of chiseling could be short-lived in sandy loam to sandy clay loam soils, while high rainfall immediately after chiseling negates the benefits, which could otherwise be realized for a longer period.

Key words: Chiseling, Bulk density, Penetration resistance, Hydraulic conductivity, Infiltration, Soybean, Wheat

Introduction

In intensive agricultural land use, soil compaction caused by wheel traffic and natural forces affects soil physical properties and the crop performance. Soil compaction leads to soil structure degradation, increase in bulk density and soil penetration resistance which adversely affect the plant root growth and crop yields. A compact zone just below the plough layer prevents root

*Corresponding author,
Email: pramila.iari@gmail.com

development and could be most damaging to the crop in rainfed areas. Chisel ploughing is one of the most commonly used mechanical methods to break the compact subsoil layer. It involves deep ripping of a dry soil to 30-45 cm depth at 50-120 cm intervals depending upon the location of impedance layers and row to row spacing of the plants. A chisel, generally mounted in the place of a plough, is used to break the sub-surface soil layer. This loosens the compact layers and cause root proliferation to deeper downs the profile. Chiseling is likely to increase infiltration, and thus increase the water storage in the sub-surface, and improves aeration in the root zone of temporarily water logged soil. However, chiseling effects could be short lived (Busscher *et al*., 2002) and the increase in total porosity may not ensure greater root growth because it also destroys macro-pore continuity.

Studies on the effect of chisel have shown inconsistent results on soil physical and hydraulic properties due to the transitory nature of soil structure after tillage, site history, initial and final water contents, time of sampling and the extent of soil disturbances (Arshad *et al.*, 1999). Studies have used soil penetration resistance to screen for spatial changes in soil properties (Hartge *et al.,* 1985; Carter and White, 1986), to quantify the depth and intensity of soil compaction and to estimate the extent of the potential rooting depth and degree of soil structure regeneration. Penetration resistance was also used to correlate soil strength with plant growth and establishment, especially in obtaining the limiting resistance for optimum root growth (Ehlers *et al*., 1983; Busscher *et al*., 1987) or shoot emergence. Chisel plough resulted in a higher soil moisture content compared to ridger and disk plough (Makki and Mohamed, 2008). Type of chiseling had consistent effect on moisture content but was inconsistent on bulk density and porosity (Carman, 1997). Field prepared by chisel plough in combination with cultivator and mouldboard plough lead to higher moisture content, lower bulk density and soil strength as compared to shallow or no tillage on a sandy loam soil in wheat under rainfed condition (Khan *et al.,* 2006). Chiseling alters soil pore size distribution. The rate of infiltration is controlled by the pore sizes and their continuity (Kutilek, 2004), while macropores are important for root growth and solute movement (Wang *et al*., 1986).

Although the benefits of chiseling have been well-documented, the operation involves draft and is therefore costly. Cost of a chiseller is Rs. 8000-10000 and operation charges in the field could be as high as Rs. 4000 ha^{-1}. Unfortunately, benefits of chiseling are only temporary and as the fine soil particles fill the pore spaces after subsequent rainfall events leading to gradual soil settlement and reconsolidation at sub-surface, and the soil approaches to its previous condition (Rao *et al*., 1998b; Allen and Musick, 2001).

Farmers may be suggested to go for chiseling once in every year when annual rainfall is greater than 100 cm and once every 2-3 years when rainfall is less than 100 cm (Fouss *et al*., 1987), although the soil type is the most dominating factor. Currently there is insufficient information available to advise the farmers how often to chisel their farm fields to maximize the benefits of chiseling. Considering that chiseling effect could be short-lived in soils of sandy loam in texture, but the benefits could be realized for a longer period, we studied the effect of immediate and residual effects of chiseling on soil hydro-mechanical behaviour and root growth in a soybean-wheat rotation.

Materials and Methods

A field experiment was conducted in the experimental farm of the Indian Agricultural Research Institute, New Delhi (28°38′23″ N latitude and 77°09′27″ E longitude with altitude of 228.6 m above the mean sea level). The soil belongs to the major soil group of Typic Haplustept, is sandy loam in texture at surface (0-15 cm) and sandy clay loam in sub-surface layers, pH (7.8-8.1), low in soluble salt content and low to medium in organic carbon contents (0.53% at 0-15 cm and 0.41% at 15-30 cm layers) (S. Pradhan, Personal Communication).

The chisel plough (one tyne) was set to run up to a depth of 30 to 40 cm at 50-120 cm intervals. Chiseling operations were carried out in criss cross fashion by a high draft tractor (>50-60 horsepower per shank). The experimental design was a complete randomized block with 4 treatments [RS; Residual chisel (Chiseling on May, 2011), RC; Repeated chisel (Chiseling on May 2011 and again on May 2013), FC; Fresh chisel (Chiseling once in May 2013) and NC; No chisel (Control), each with six replicates. The cropping system was soybean-wheat rotation. Soybean crop (variety Pusa 9814) was sown on July 9, 2013 with fertilizer dose of 20 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1}, respectively. The crop was grown under rainfed conditions and harvested on November 2, 2013. The wheat crop (variety PBW-502) was sown on November 26, 2013 with fertilizer doses of 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1}, respectively. The crop was grown under irrigated conditions with a total of 4 irrigations at CRI, late tillering, booting and dough stages. The crop was harvested on April 16, 2014.

The hydro-mechanical properties *viz.,* soil bulk density (r_b), penetration resistance (Q), steady-state infiltration rate (i) and field-saturated hydraulic conductivity (K_{fs}) were recorded at harvest of both the crops. A core sampler was used to collect undisturbed soil cores from 0-15, 15-30, 30-45 cm layers to determine soil bulk densities. Soil penetration resistance (Q) was measured by using Rimik cone penetrometer (model no. CP20) up to a depth of 45 cm, and the data was retrieved on a PC by using CP20V2 software at depth interval of 15 mm.

Double ring infiltrometer was used to measure the infiltration rate of the soil. When the rate became stable, last 3-4 readings were averaged to obtain the steady state infiltration rate. The K_{fs} was measured by Guelph permeameter (a constant head well permeameter; Reynolds, 1993) at 7.5, 22.5, 37.5 cm depths (representing 0-15, 15-30 and 30-45 cm layers). The steady-state rate of water recharge into the soil was measured and the K_{fs} for each layer was computed.

Root sampling was done at peak flowering (70-85 days after sowing) to study growth parameters (RLD, RSA, RVD and RAD). A root auger (0.14 m high and 0.10 m in diameter) was used to collect root samples at 0-15, 15-30, 30-45 and 45-60 cm soil layers, and the parameters were analyzed by using a root scanner and software (WINRHIZO system, Regent Instruments Inc).

Results and Discussion

Bulk density and soil penetration resistance

No significant changes in soil bulk density were observed between the treatments at 0-15 cm soil layer in both the crops (Table 1). Values were marginally higher in NC at 15-30 and 30-45 cm depths in soybean (3-5% lower bulk density in RS and RC plots). Irrespective of treatments, maximum compaction was located at 10-20 cm depths (Fig. 1), and the Q was significantly higher in NC (3309 kPa) compared to RS (2804 kPa) and RC (2881 kPa) at 15-30 cm, and 2711 kPa in NC compared to 2217 kPa (RS) and 2243 kPa (RC) at 30-45 cm layer. The *kharif* season 2013 recorded a very high rainfall of 1196 mm (*kharif* normal rainfall is 582 mm; Agromet observatory, Division of Agricultural Physics, IARI) of which 730.4 mm occurred in the period between date of chiseling and the first sampling date in soybean. This high rainfall nullified the effect of chiseling in June 2013), where the FC plots had the r_b and Q values at 15-30 (1.75 Mg m^{-3} and 3424 kPa)

Table 1. Bulk density (Mg m^{-3}) in soybean and wheat crop under different chiseling treatments

Depth	Soybean				Wheat			
(cm)	RS	RC	NC	FC	RS	RC	NC	FC
0-15	1.54±0.02	1.55±0.02	1.56±0.01	1.55±0.03	1.61±0.01	1.62±0.02	1.60±0.03	1.61±0.03
15-30	1.61±0.02	1.60±0.02	1.66±0.02	1.68±0.01	1.65±0.04	1.65±0.02	1.59±0.04	1.64±0.03
30-45	1.63±0.02	1.64±0.01	1.64±0.02	1.71±0.03	1.64±0.03	1.58±0.02	1.65±0.03	1.68±0.01

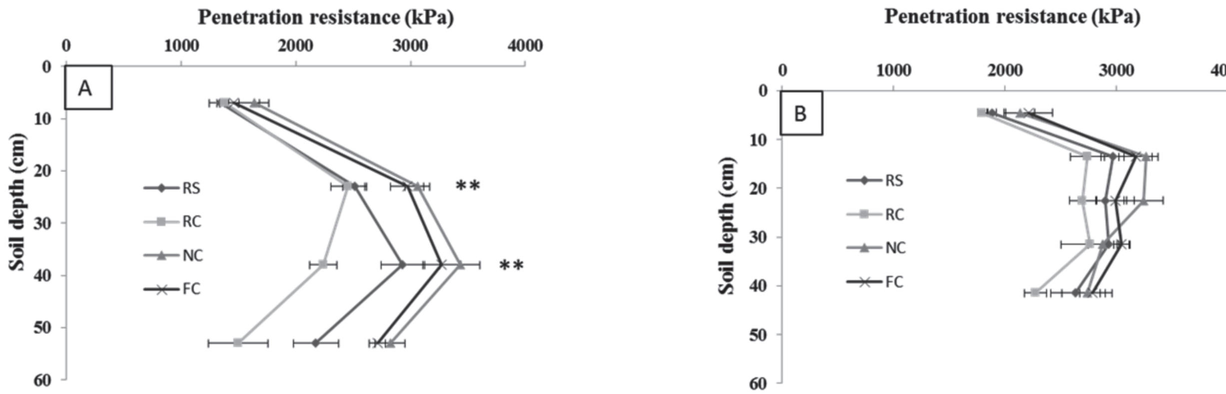


Fig. 1. Penetration resistance (kPa) in (A) soybean and (B) wheat under different chiseling treatments

Table 2. Field saturated hydraulic conductivity (K_s) (cm d^{-1}) in soybean and wheat under different chiseling treatments

Depth	Soybean				Wheat			
(cm)	RS	RC	NC	FC	RS	RC	NC	FC
7.5	20.16±1.1	21.94±4.7	22.47±4.4	22.31±0.9	15.05±4.2	17.33±2.4	14.11±2.9	18.72±0.8
22.5	21.07±5.8	20.35±3.7	29.95±2.9	25.20±4.5	19.98±2.4	18.93±4.9	22.04±0.9	17.27±2.2
37.5	14.98±2.0	21.35±1.1	16.88±3.2	22.47±4.08	14.56±0.5	15.03±0.2	14.60±0.4	19.02±1.0

and 30-45 cm (1.78 Mg m^{-3} and 2822 kPa) layers similar to NC and significantly higher than the RS and RC. The high rainfall intensifies soil reconsolidation and moderates the chiseling effects, which may explain the increase in BD immediately after chiseling. Intensification of soil reconsolidation and reduction of the chiseling effects after high and intense rainfall have been reported earlier in a Hapludalf (Reichert *et al*., 2009). All benefits of chiseling were lost after 115 cm rainfall since its operation (Moriasi, 2004). It was reported that the amount and duration of rainfall following chiseling and till the crop was sown, farmers may lose 60% or more of the maximum benefits of chiseling (Moriasi, 2004). At succeeding wheat crop, differences in r_b further reduced. At 15-30 cm layer, the Q value was significantly lower in RS and RC (2516 and 2617 kPa, respectively) compared to NC (3156 kPa), even though the r_b was similar among treatments, possibly due to marginally higher (1-2%) moisture content in RS and RC. At 30-45 cm, however, neither the r_b nor Q was different among treatments. The r_b and Q in FC plots were similar to those in NC. Lower soil bulk density and resistance to penetration after chiseling have been widely reported (Khan *et al.,* 2006). However, the chisel effect could be temporary (Silva *et al*., 2012), as also documented in our study.

Field saturated hydraulic conductivity and soil infiltration rate

The field saturated hydraulic conductivity (K_{fs}) was significantly higher by 30 and 18% in NC plots at 15-30 cm soil layer in soybean and wheat crop, respectively (Table 2). At 0-15 and 30-45 cm soil layers, no differences between the treatments were recorded. The steady-state infiltration rate was also higher in NC by 30-36 % over other treatments in soybean crop, although the difference was marginal at harvest of wheat with NC showing higher values (Table 3). Our results are in contradictory to previous studies which showed higher infiltration in chiselled plots (Mohanty *et al.*, 2007). Normally, chisel ploughing and disking creates pores and voids in the soil that increase the pathways for water movement and increase infiltration. The higher infiltration rate in NC in our study could be due to prevalence of macro- and meso-pores and their

Table 3. Infiltration rate (cm h^{-1}) in soybean and wheat fields under different chiseling treatments

Treatment	Soybean	Wheat
RS	1.34^{B}	1.14^{A}
RC	1.15^{B}	0.88^{B}
NC	1.48^{A}	1.08^{A}
FC	1.32^{AB}	1.04^{A}

Means with at least one letter common are not statistically significant using DUNCAN's Multiple Range Test [RS: Residual chisel; RC: Repeated chisel; FC: Fresh chisel; NC: No chisel]

continuity, as the sub-surface layer has not been disturbed. The rate of downward movement of water is controlled by pore size distribution and continuity of pores (Kutilek, 2004), and the role of macropores have been emphasized (Lin *et al.*, 1996; Lipiec *et al.*, 2006). The larger flow-active pores in NC facilitated faster movement of water down the soil profile, which may eventually become unavailable to the crop. High rainfall that occurred after the chisel ploughing contributed to the settling process in FC plots, and reduced infiltration rates. However, the field saturated hydraulic conductivity and the infiltration rates reduced in NC over the time, and differences become non-significant at the wheat harvest, indicating effect is getting minimized within a year of chisel ploughing.

Root growth parameters

All the root growth parameters were higher at 0-15 cm, and gradually decreased downward. The average RLD at 0-15 cm layer was 0.32 and 0.78 cm cm^{-3} in soybean and wheat, respectively (Fig. 2). The RLD is greater in RS and RC treatments compared to NC at 15-30 cm layer, and the treatment difference was non-significant in other layers. The RSA is higher in RS and RC (Fig. 3); along with higher RLD, this indicates greater root proliferation and generation of more lateral roots,

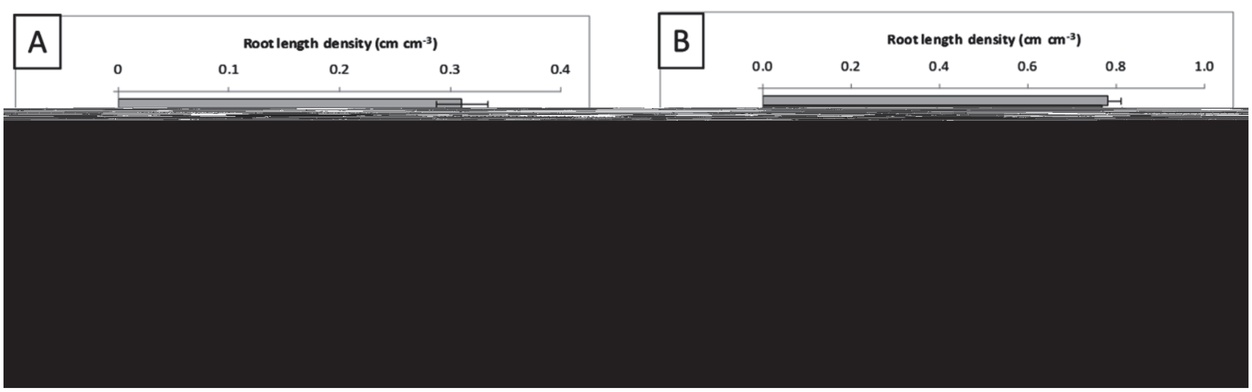
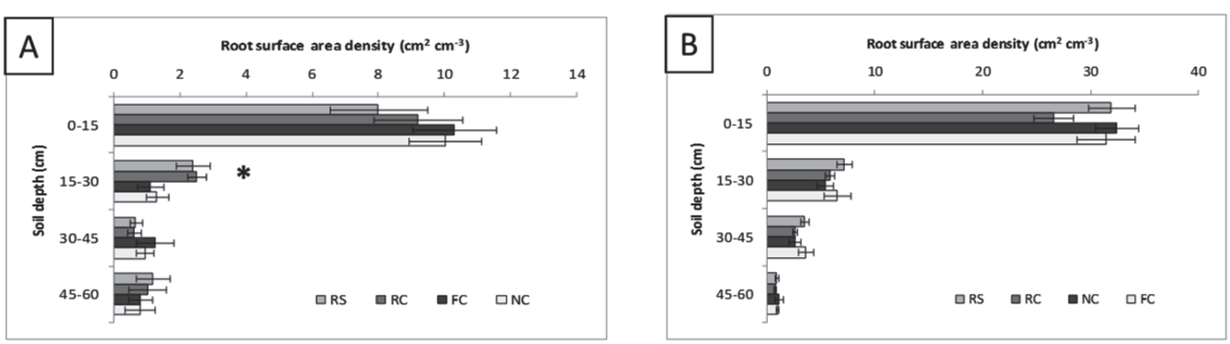


Fig. 2. Root length density (cm cm^{-3}) in (A) soybean and (B) wheat under different chiseling treatments



** - Significant at 1%, * - Significant at 5%, NS - Non Significant

Fig. 3. Root surface area density (cm^2 cm^{-3}) in (A) soybean and (B) wheat under different chiseling treatments

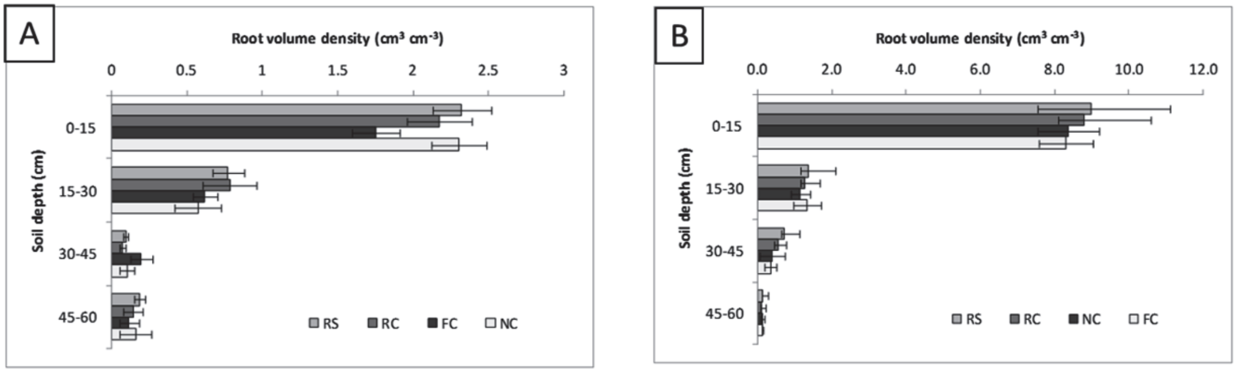
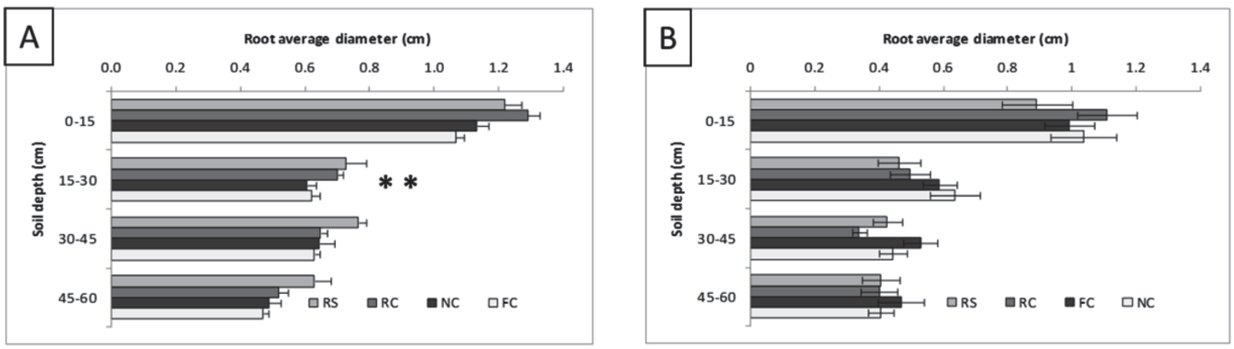


Fig. 4. Root volume density ($cm^3\ cm^{-3}$) in (A) soybean and (B) wheat under different chiseling treatments



** - Significant at 1%, * - Significant at 5%, NS - Non Significant

Fig. 5. Root average diameter (mm) in (A) soybean and (B) wheat under different chiseling treatments

which provides scope of utilizing soil water. The RVD did not show any appreciable changes due to chisel ploughing (Fig. 4), however, the average root diameter (RAD) was higher in NC in soybean, an indication of larger presence of biopores (Fig. 5). However, this effect was not distinguished at harvest of wheat.

Root length density (RLD) varied from depth to depth within the tillage treatments, but the average values for four depths with regard to tillage systems were more consistent. The reason for higher RLD and RSA area due to chiseling in sub-surface layer could be the loosening the soil and consequently root proliferation and lateral growth was enhanced. Lower RLD and RSA in FC was due to effect of heavy rainfall and subsequent soil reconsolidation and settling of soil pores with finer soil particles. Oussible *et al.* (1992) reported that root weight density of wheat was not affected by compacted soil, but length density was significantly reduced. Root fineness decreases with increase in root diameter, a higher value of RAD denoting a thinner root. High penetration resistance promotes root thickness and decrease root length, which has been demonstrated in wheat (Merotto and Mundstock, 1999) and maize (Lipiec *et al*., 2012), among others. Root surface area, a component proportional to root length and diameter, is the most important morphological characteristic influencing plant water and nutrient uptake (Barber, 1984).

Conclusion

Chiseling reduced sub-surface compaction, although the effect had been temporary. The effect on pore size distribution continues for a longer period, mediating the water retention in soil profile. High rainfall followed by chiseling negates its effect, and the soil behaves similarly to no-chiseling. However, marginal improvement in soil mechanical resistance could be favourable for root growth, and the effect of chiseling could be appreciated for a longer time.

References

Allen, R.R and Musick, J.T. 2001. Deep ripping and blocked furrow effects on lower 1/3 furrow irrigation infiltration. *Appl. Engg. Agric.* **17**(1):41-48.

Arshad, M.A., Franzluebbers, A.J. and Azooz, R.H. 1999. Components of surface soil structure under conventional and no-tillage in north-western Canada. *Soil Till. Res.* **53**: 41–47.

Barber, S.A. 1984. Soil Nutrition Bioavailability: A Mechanistic Approach. John Wiley and Sons In., New York.

Busscher, L.D., Spivey, Jr. and Campbell, R.B. 1987. Estimation of soil strength properties for critical rooting conditions. *Soil Till. Res.* **9**: 377-386.

Busscher, W.J., Bauer, P.J. and Frederick, J.R. 2002. Recompaction of a coastal loamy sand after deep tillage as a function of subsequent cumulative rainfall. *Soil Till. Res.* **68**: 49-57.

Carman, K. 1997. Effect of different tillage systems on soil properties and wheat yield in Middle Anatoliarc. *Soil Till. Res.* **40**: 201–207.

Carter, M.R. and White, R.P. 1986. Determination of variability in soil physical properties and microbial biomass under continuous direct-planted corn. *Canadian J. Soil Sci.* **66**: 747-750.

Ehlers, W., Kiipke, Y., Hesse, F. and Biihm, W. 1983. Penetration resistance and root growth of oats in tilled and untilled loess soil. *Soil Till. Res.* **3**: 261-275.

Fouss, S.C., Bengston, R.L. and Carter, C.E. 1987. Simulating surface drainage in the Lower Mississippi Valley with DRAINMOD. *Trans. ASAE* **30**(6): 1679-1688.

Hartge, K.H., Bohne, H., Schrey, H.P. and Extra, H. 1985. Penetrometer measurements for screening soil physical variability. *Soil Till. Res.* **5**: 343-350.

Khan, M.J., Khattak, M.K. and Wahab, S. 2006. Influence of various tillage practices on selected physical properties of sandy loam soil under rainfed area. *Sarhad J. Agric.* **22**: 71-80.

Kutilek, M. 2004. Soil hydraulic properties as related to soil structure. *Soil Till. Res.* **79**: 175-184.

Lipiec, J., Kuś, J., Slowińska-Jurkiewicz, A. and Nosalewicz, A. 2006. Soil porosity and water infiltration as influenced by tillage methods. *Soil Till. Res.* **89**: 210-220.

Lipiec, J., Horn, R., Pietrusiewicz, J. and Siczek, A. 2012. Effects of soil compaction on root elongation and anatomy of different cereal plant species. *Soil Till. Res.* **121**: 74-81.

Lin, H.S., McInnes, K.J., Wilding, L.P. and Hallmark, C.T. 1996. Effective porosity and flow rate with infiltration at low tensions in a well-structured subsoil. *Trans. ASAE* **39**: 131-133.

Makki, E.K. and Mohamed. A.E. 2008. Tillage implements performance and effect on some soil physical properties. *Agric. Mech. Asia* **39**: 9-13.

Mohanty. M., Bandyopadhyay, K.K., Painuli, D.K., Ghosh, P.K., Misra, A.K. and Hati, K.M. 2007. Water transmission characteristics of a Vertisol and water use efficiency of rainfed soybean (*Glycine max* L. Merr.) under subsoiling and manuring. *Soil Till. Res.* **93**: 420-428.

Moriasi, D.N. 2004. Modeling the effects of rainfall intensity and deep chiseling on infiltration and runoff within DRAINMOD for alluvial soils. Ph.D. Dissertation, Louisiana State University, US, URN: etd-11092004-005103.

Merotto A. Jr. and Mundstock, C.M. 1999. Wheat root growth as affected by soil strength. *Braz. J. Soil Sci.*, **23**: 197–202.

Oussible, M., Crookston, R.K. and Larson, W.E. 1992. Subsurface compaction reduces the root and shoot growth and grain yield of wheat. *Agron. J.* **84**: 34-38.

Rao, K.P.C., Steenhuis, T.S., Cogle, A.L., Srinivasan, S.T., Yule, D.F. and Smith, G.D. 1998b. Rainfall infiltration and runoff from an Alfisol in semi-arid tropical India. II. Tilled systems. *Soil Till. Res.* **48**(1/2): 61-69.

Reichert, J.M., Kaiser, D.R., Reinert, D.J. and Riquelme, U.F.B. 2009. Variação temporal de propriedades físicas do solo e crescimento radicular de feijoeiro em quatro sistemas de manejo. *Pesq. Agropec. Bras.*, **44**: 310-319 (Original not seen; Only abstract in English).

Reynolds, W.D. 1993. Saturated hydraulic conductivity: Field measurement, pp. 599-613. (In) M.R. Carter (ed.) *Soil sampling and methods of analysis*. Lewis Publ., Boca Raton, FL.

Wang, J., Hesketh, J.D. and Woolley, J.T. 1986. Preexisting channels and soybean rooting patterns. *Soil Sci.* **141**: 432-437.

Received: 28 June 2014; Accepted: 13 October 2014