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Hydrophysical characteristics of a sandy loam soil under bed planted maize (*Zea mays*)

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ABSTRACT

A field experiment was conducted for two years on sandy loam soil for maize (*Zea mays* L.) cultivation on beds. An index called least limiting water range (LLWR) was computed to compare hydrophysical characteristics of soil under bed planted maize with those under conventionally flat planted maize. Among all four parameters of LLWR, soil water content at field capacity (fc) and wilting point (q_{pwp}) did not change much, whereas soil water content at 10% aeration porosity (q_{ap}) reduced significantly and soil water content at 2MPa soil strength (q_{2MPa}) increased appreciably with increase in bulk density (BD). It was further observed that available water retention capacity (AWRC) did not vary appreciably with BD, whereas LLWR decreased with increase in BD, which indicated that LLWR was a true indicator of soil structural condition. Again, lower water stress period was obtained under bed as compared to conventional planting system. Field saturated hydraulic conductivity at 10 cm soil depth was 3 times of its value of 0.36 cm/hr under conventional planting. Root length density was also more in upper 45 cm in beds due to porous soil environment. These results thus indicated that bed-planting system is superior to conventional planting as it had wider LLWR indicating better water availability and improved soil structural conditions which led to enhanced root growth, and higher maize yield. The above study also confirmed that LLWR could be used as a tool for assessing the suitability of a given soil management practices in improving soil productivity.

Key words: Bed planting, Least limiting water range, Soil hydraulic characteristics

The least limiting water range (LLWR) has been proposed as an index of the structural quality of soils for crop growth (da Silva *et al*. 1994) and is based on the concept introduced by Letey (1985). The LLWR is defined as the range of soil water content within which limitations to plant growth associated with water potential, aeration and mechanical impedance are minimal. The upper limit of this range is defined by water content at field capacity or water content at which aeration become limiting, whichever is smaller. The lower limit is defined by water content at the permanent wilting point or water content at which penetration resistance become limiting, which ever is higher. Within the context of the LLWR, the impact of changes in soil structure on plant growth is strongly influenced by water content (Topp *et al*. 1994, da Silva and Kay 1997 and Ram *et al*. 2005). For instance, water contents associated with cone penetration resistance (PR) values >2MPa (Bengough and Mullins 1990, Greacen 1986), and more conservatively >3MPa (Horn and Baumgartl 2000), are generally accepted to limit root growth. A critical aeration limit is often assumed to occur at an air-filled porosity (AFP) of approximately 10% (v/v) for most agricultural crops. For AFPs <25% (v/v) aeration may be significantly deficient under some conditions (Glinski and Stepniewski 1985). Intrinsic accountability of these important water limiting criteria makes the LLWR a potentially useful soil quality indicator of cropping system impact on soil physical conditions and crop yield (da Silva and Kay 1997, Betz *et al*. 1998, McKenzie and McBratney 2001).

Quite a few studies in past compared the magnitude of LLWR under different tillage and management treatments to predict their impact on surface soil physical conditions under contrast growing seasons (Carter 1988, da Silva and Kay 1996, Betz *et al*. 1998, Lapen *et al*. 2004). Verma and Sharma (2008) evaluated the long-term effects of organics, fertilizers and cropping systems on soil physical productivity using a single value index – nonlimiting water range (NLWR) which was linearly, significantly and positively correlated with wheat grain yield.

Furrow irrigated reduced tillage bed planting system got wider adaptability in Indo Gangetic plains (IGP) of India, Bangladesh and Pakistan and parts of China, central Australia

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(Hobbs and Gupta 2003, Timsina and Connor 2001). In this mechanized system of bed planting, both bed making and seeding of crops are done in single operation. For the next season, the same bed is renovated/reshaped. Aggarwal and Goswami (2003), Zhang *et al.*(2007) and Singh *et al.*(2010) found lower water consumption and higher wheat yield under furrow irrigated raised bed-planting (FIRB) than under conventional flat planting due to decrease in irrigation amount. Bed planting also created better soil physical environment all throughout the crop growth, which led to higher crop productivity (Aggarwal and Goswami 2003, Sharma and Bhushan 2001).

Research trials at Delhi showed that beds were most suited for growing wheat, soybean and maize as they significantly decreased water use (Aggarwal and Goswami 2003). Hence an attempt was made to evaluate the suitability of bed planting technology, by monitoring changes in LLWR, rooting characteristics and water use under bed planting as compared to conventional for showing its effect in improving or deteriorating the soil physical environment and crop yield.

MATERIALS AND METHODS

The study was conducted during maize growth from mid June to end of September in 2007 and 2008 at IARI. The mean monthly maximum and minimum temperatures during the year ranged from 21.3°C to 40.5°C and 7.3°C to 28.7°C respectively. The average annual rainfall was 708.6 mm of which on an average 597 mm (84%) was received from June to September The soil was sandy loam (Typic Haplustept) with 71.95% sand and 19.2% clay. Main treatments included two methods of planting: Bed planting system (Sowing of one row of maize on 37.5 cm wide beds alternating with 30 cm wide furrows by using a tractor drawn bed planter) and conventional planting (line sowing on flat land at 67.5 cm row-to-row spacing using Dibbling method).

Soil bulk density (BD) was determined by core method (Blake and Hartge 1986) at 10, 30 and 60 DAS . Rings with undisturbed soil were used for determination of soil water contents (θ) at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}) by pressure plate apparatus (Richards and Fireman 1943). Soil water content at saturation (θ_{sat}) was determined gravimetrically. Soil water content at 10% aeration porosity (θ_{ap}) was determined by using formula: $\theta_{ap} = \theta_{sat} - 0.1$ (Da Silva *et al*. 1994).

Soil penetration resistance (PR) was measured by Rimik cone penetrometer (model no. CP20). Soil penetration resistance was measured in both bed-furrow and conventional planted system at 2-3 days interval during drying cycle after each irrigation /rainfall. Soil moisture content (θ of 0-15, 15-30 and 30-45 cm soil layer) was determined by gravimetric method along with soil penetration measurement. In order to calculate soil water content at 2 Mpa soil penetration resistance (θ_{2MPa}), a regression model was developed (Using 'STASTICA 6.0' software package) which related PR to BD and θ_w.

A root auger (0.15 m high and 0. 05 m in diameter) was used to collect the root samples in the 0-45 cm soil profile at 15 cm depth interval at flowering stage of the crop . A gap of 2.5 cm was left between two successive samples as shown in Fig 1. Root samples were washed (Aggarwal *et al.* 2006) and various rooting characteristics were determined by using root length scanner. Winrhizo software was used for the analysis of the scanned root image and determination of root length density (RLD).

Calculation of LLWR (% M^3 m^{-3}) and available water retention capacity of soil (AWRC) (% m^3 m^{-3})

Upper limit of LLWR = θ_{fc} or θ_{ap} whichever is lower

Lower limit of LLWR = θ_{wp} or θ_{2MPa} whichever is higher

Magnitude of LLWR = soil water content between the upper and lower limit of LLWR.

Magnitude of AWRC = $\theta_{fc} - \theta_{wp}$

The field saturated hydraulic conductivity was measured by Guelph permeameter (GP). A single depth of ponding (10 cm) was used and single height analysis procedure was be applied to evaluate Kfs (Reynolds 1993). Other hydraulic parameter measured by GP were matric flux potential (Φm), alpha parameter (α) and unsaturated hydraulic conductivity K (Ψ) which were defined as

$$\Phi m = \int_{\psi i}^{0} K(\Psi)$$

where Ψi was the initial soil matric suction

$\alpha = K_{fs}/\Phi m$

RESULTS AND DISCUSSION

Temporal variation of LLWR and AWRC

Studies on temporal variation of average BD of 0-30 cm sandy loam soil under bed-furrow and conventionally planted maize revealed that BD measured on 10 DAS at center of bed was lower by 9% than BD of 1.48 Mg/m^3 under conventional system. The trend continued during the later stages of crop growth but the differences among the treatments

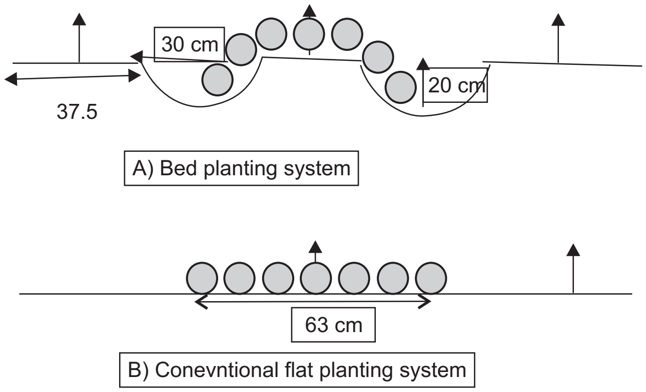

Fig 1 Root sampling scheme of bed and conventional planting system for maize

Table 1 Multiple regression model for prediction of PR as a function of BD and q_w under bed and conventional systems

System	Parameter	Coefficient	Std. error	t Stat	R^2
Bed	Intercept	–571.94	829.52	-0.68	0.93
	q_w	2175.96	553.52	3.93	
	BD	–144.17	11.58	–12.43	
Conventional	Intercept	903.33	619.99	1.45	0.96
	q_w	–182.24	9.06	–20.11	
	BD	1845.55	393.83	4.68	

narrowed down.

Multiple regression model developed for Prediction of PR as a function of BD and θ_w clearly indicated that BD was positively correlated, whereas θ_w was negatively correlated with PR (Table 1). The computed t-Stat of BD and θ_w values in multi regression model developed for prediction of PR were more than 2 which indicated significant correlation of PR with both BD and θ_w. Bulk density along with θ_w accounted for 93-96 % variation in PR in both methods of planting.

For both methods of planting, four soil water constants, i e θ_{fc}, θ_{pwp}, θ_{ap} and θ_{2MPa} on common y-axis and BD on x-axis were plotted to determine the limits of LLWR (Fig 2). For both systems it was observed that θ_{ap} decreased with increase in BD, whereas θ_{2MPa} increased appreciably with increase in BD. On the other hand $\theta_{fc,}$ and θ_{pwp} did not change much with increase in BD. It was further observed that all throughout the crop growth, for both bed and conventional planting systems, θ_{fc} was the upper limit and θ_{2MPa} was the lower limit of LLWR except in conventional planting where at higher BD (1.72 Mg/m^3) θ_{ap} was the upper limit.

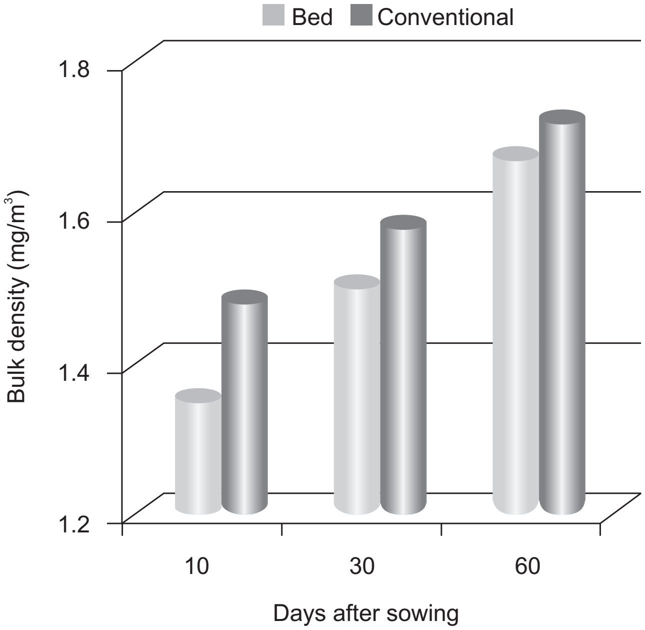

Fig 2 Temporal variation of soil bulk density under bed and conventional system

Magnitude of LLWR (Fig 3), which was the difference in magnitudes of upper and lower limit appeared to be higher at initial crop stages and declined sharply at harvest. It varied between 15.33% (m^3/m^3) at BD of 1.35 Mg/m^3(on 10 DAS) to 11.44% (m^3/m^3) at 1.67 Mg/m^3 (on 60 DAS) for bed system and between 12.39% (m^3/m^3) at 1.48 Mg/m^3 (on 10 DAS) to 5.49% (m^3/m^3) at 1.72 Mg m^3 (on 60 DAS) during same time period for conventional system. Results thus showed that decline was sharper in conventional system than in bed planting system indicating that LLWR remained wider in bed than in conventional all throughout the crop growth. Wider LLWR in bed indicated better structural quality, more water availability and lesser mechanical impedance to growing roots than in conventional system. Similar trends were reported earlier (da Silva *et al.* 1994, Betz *et al.* 1998,

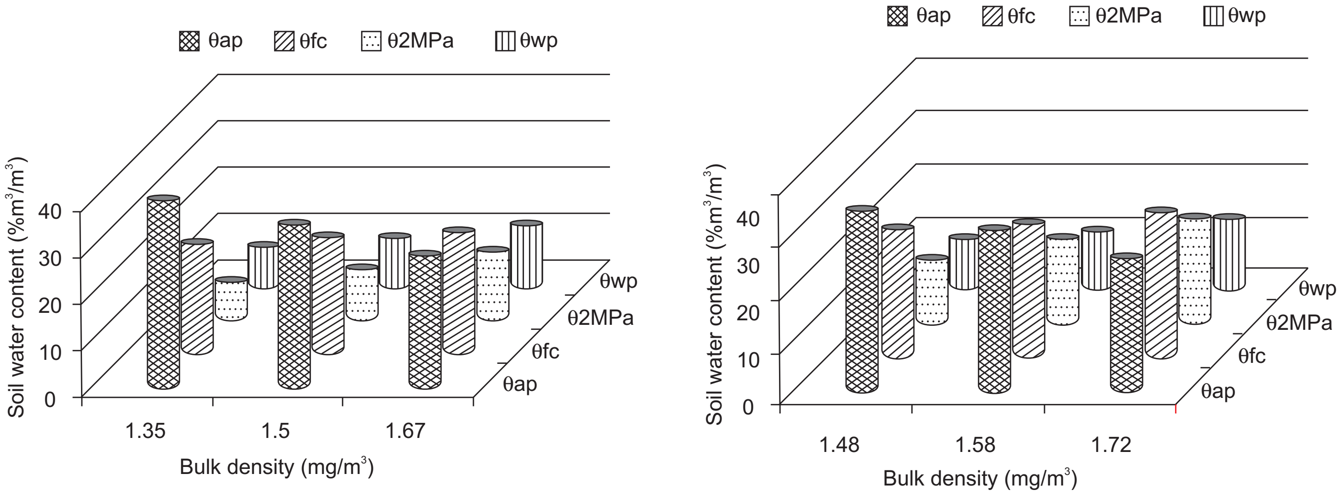

Fig 3 Variation of soil water content at 10% aeration porosity (θ_{ap}), field capacity (θ_{fc}), 2MPa soil strength (θ_{2MPa}) and wilting point (θ_{wp}) under bed and conventional planting

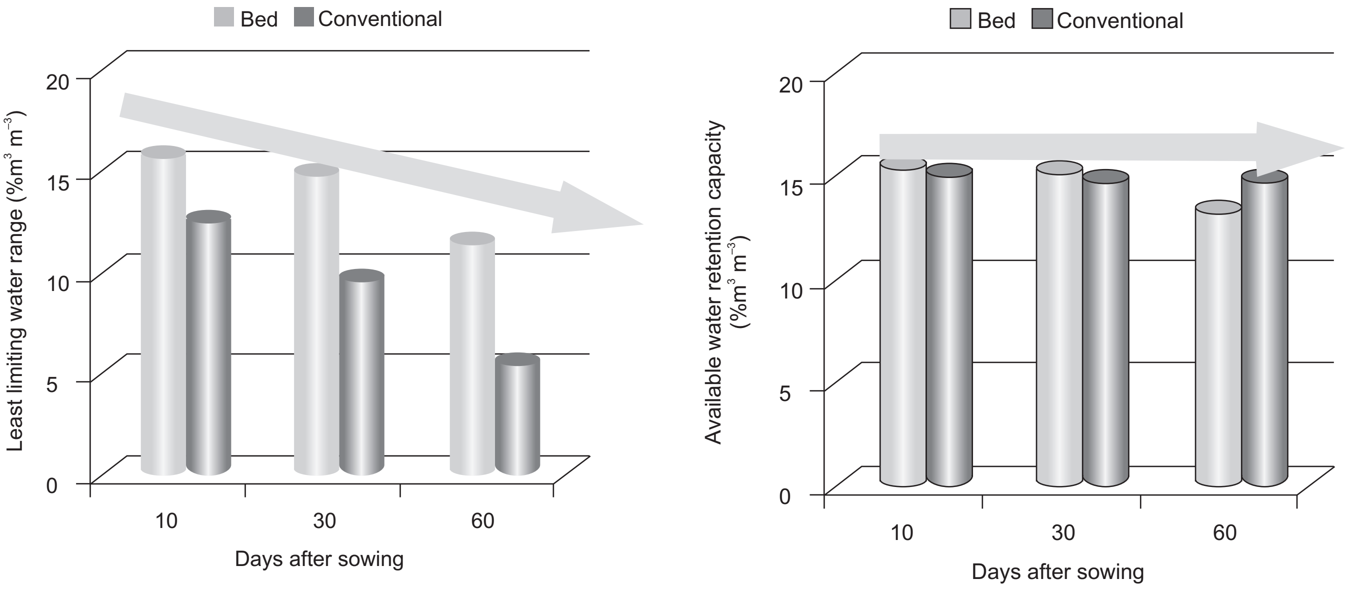

Fig 4 Temporal variation of least limiting water range and available water retention capacity during maize growth

Lapen *et al*. 2004).

On the other hand, AWRC did not show any much variation with increase in BD. The reduction in range of available water due to deterioration of soil structure with time was best reflected in decline in LLWR, whereas AWRC did not show significant temporal changes. The above results thus indicated LLWR is a better indicator of soil structure quality and water availability than AWRC**.**

The plant water stress period was computed as the number of days water content of soil was outside LLWR or AWRC during various growth periods. It was observed that when stress period was calculated by using LLWR as index of water availability, lower water stress period was obtained under BD as compared to conventional (Fig 4). Whereas no significant variation in stress was observed among the treatments when stress period was calculated by using AWRC as index of water availability. The above results thus indicated that LLWR seems to be a better indicator of soil water stress than AWRC. Hence it could be suggested that in order to avoid stress, irrigation should be given as soon as SWC reaches lower limit of LLWR, i e θ_{2MPa} and not lower limit of AWRC, i e θ_{pwp}.

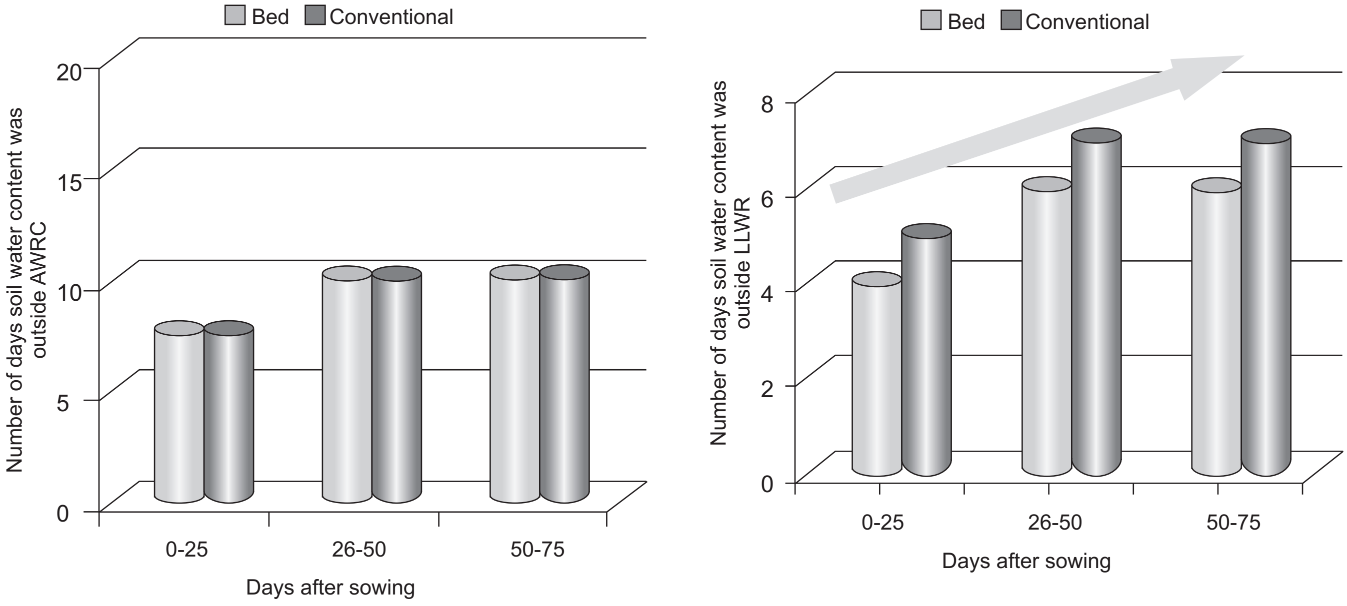

Fig 5 Temporal variation of LLWR and AWRC during maize growth

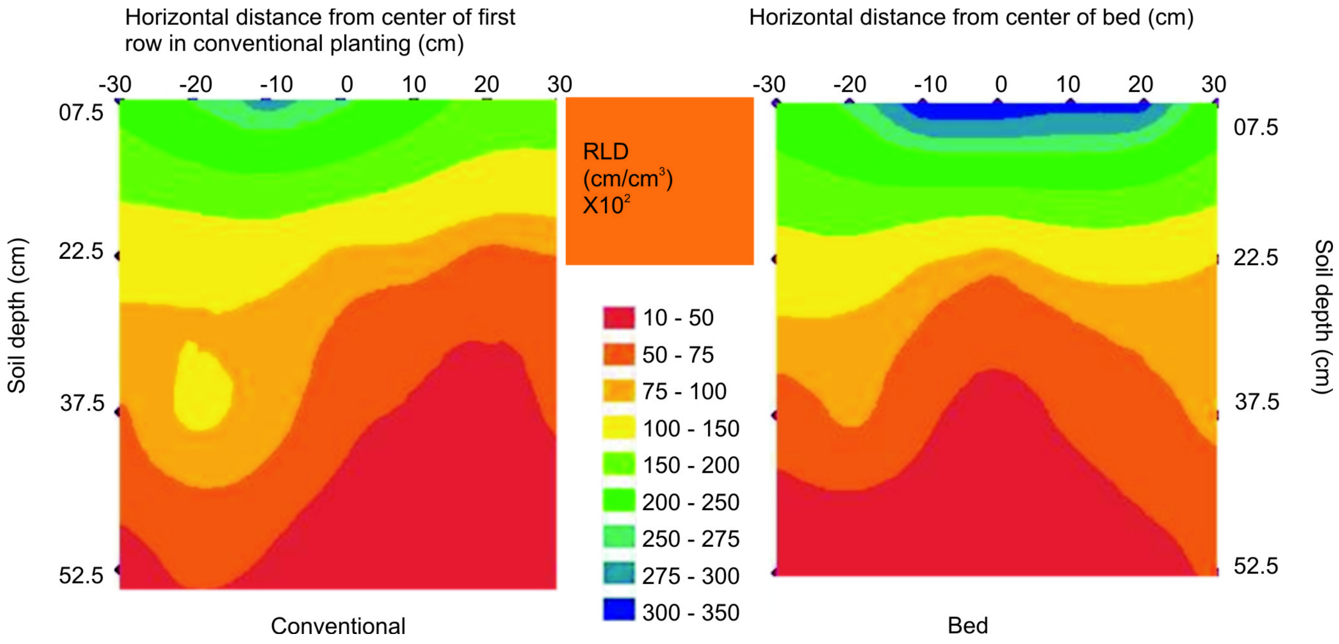

Fig 6 Root length density distribution of maize under bed and conventional systems

Table 2 Soil hydraulic parameters measured by Guelph permeameter under bed and conventional systems at 10cm soil depth on 65DAS

Hydraulic parameters	Bed	Flat
Ks (cm/hr)	1.08	0.36
Φm(cm^2/hr)	10.8	11.52
α (cm^{-1})	0.0928	0.0438

Table 3 Water use and grain yield of bed and conventionally planted wheat

Treatment	Water use (cm)	Grain yield (q/ha)
Bed	22.4	29.3
Conventional	26.3	18.4
t test	S	S

Rooting characteristics

It was observed that for both methods of planting nearly 80-85 % of maize roots were confined in upper 0-15 cm and 15-30 cm soil layers (Fig 5). Horizontal and vertical root lengths densities (RLD) (30 cm horizontally on either side of row of the crop and vertically upto 60 cm at 15 cm interval) were also more under bed than under flat planting system, which were again because of more porous environment of bed planting system. Similar results were reported by Aggarwal *et al.* (2006) and Kay *et al.*(2006).

Field saturated hydraulic conductivity

Results revealed that saturated hydraulic conductivity (Ks) under bed was 3 times of its value of 0.36 cm/hr under conventional planting (Table 2) because of more total porosity under bed.

Water use and yield

Statistical analysis of maize grain yield data (Table 3) showed that average yield under bed planting system was higher by nearly 50% over the average grain yield of 19.4 q/ha under conventional system. Total water used by crop during the whole season was also less by 3.9 cm in bed over conventional planting. These results are in agreement with those reported by others (Lapen *et al.* 2004, Fahong *et al.* 2004, Sayre and Hobbs 2004, Zhang *et al.* 2007, Singh *et al.* 2010)

In brief, it could be concluded that bed-planting system is superior to conventional planting as it had wider LLWR which indicated better soil structural condition leading to more water availability to plant, i e less water stress period for plant, higher root growth and significantly higher maize yield. it could also be suggested that in order to avoid plant water stress, irrigation should be given as soon as SWC reaches lower limit of LLWR, i e θ_{2MPa} and not lower limit of AWRC, i e θ_{pwp}. The above study also confirmed that LLWR could be used as a tool for assessing the suitability of a given soil management practices in improving soil productivity.

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