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Determination of Least Limiting Water Range of a Sandy Loam Soil Under Bed and Conventionally Planted Wheat

PRAMILA AGGARWAL, ANIL KUMAR SINGH,* USHA KIRAN CHOPRA, ROJALIN TRIPATHY* AND KARUN KUMAR CHOUDHARY

Division of Agricultural Physics, IARI, New Delhi
**Water Technology Centre, IARI, New Delhi*

ABSTRACT

The least limiting water range (LLWR) concept characterizes a single range of soil water content beyond which available water, soil aeration and mechanical resistance impose a serious limitation to root growth. Since the concept of LLWR has integrated above three factors associated with plant growth into a single variable, hence, it could be regarded as a useful soil structural quality index for crop production. The present field study was conducted to quantify the upper as well as lower limit of LLWR of a sandy loam soil under bed and conventional tillage during wheat growth.

In order to quantify the limits of LLWR of 0-45 cm layer, soil penetration resistance data (PR) and soil moisture (MC) were recorded at 4-6 days interval during drying cycle after each irrigation along with bulk density determination done only once during that drying cycle. The above observations were used to develop multiple regression equations, which could be used to predict PR as a function of bulk density (BD), soil moisture (MC) and Depth (DEP). The above relationship was used to determine volumetric soil moisture corresponding to soil penetration resistance of 2MPa (MC_{2MPa}) for a given drying cycle. Similarly for each drying cycle, water contents at 10% aeration pore space (MC_{ap}), 0.1bar (MC_{fc}) and 15bar (MC_{wp}) were also determined once. Finally four curves with bulk density on x-axis and MC_{ap}, MC_{wp}, MC_{fc} and MC_{2MPa} on y-axis were drawn to determine the limits of LLWR as a function of bulk density.

The results demonstrated that all throughout the crop growth it was MC_{fc}, which determined the upper limit of LLWR for both bed and conventional system, the lower limit was represented initially by MC_{wp} but at later stage when bulk density exceeded nearly 1.36 Mg m^{-3}, it was represented by MC_{2MPa}. Further, it was observed that under bed system the LLWR range was wider than conventional system, which indicated better structural environment in the former.

Keywords: Least limiting water range; Sandy loam; Wheat; Bed planting; Conventional planting

Introduction

The least limiting water range (LLWR) concept characterizes a single range of soil water content beyond which available water, soil aeration and mechanical resistance impose significant limitations to root growth. The concept of LLWR introduced by Silva *et al.* (1994) integrated three factors i.e. soil water, soil aeration and mechanical impedance into a single variable LLWR which was found to be more sensitive to soil structural changes than available water. Upper limit of LLWR is either soil water content at 10% aeration porosity (MC_{ap}) (according to Silva *et al.* 1994, for most of the crops growing on soils with aeration pores space less than 10% of the total pore space will experience aeration stress which may cause drastic reduction in their yields) or soil water content at field capacity (MC_{fc}) which ever is lower and lower limit is either soil water content corresponding to 2MPa soil strength (MC_{2MPa}) or soil water content at wilting point (MC_{wp}) whichever is higher. Temporal variation of LLWR with bulk density (BD) was different for soil of different textures but the differences diminished when the densities were expressed as relative bulk densities (BD_{rel}).

Jo *et al.* (1997) also made similar observations. Silva and Kay (1997) evaluated the influence of soil properties and tillage on LLWR. It was observed that LLWR was negatively correlated to bulk density and clay, and positively correlated to organic carbon (OC). All soil management practices that reduced BD and increased organic matter status (incorporation of crop residue/FYM/GM into soil) widened LLWR and hence, improved soil structural condition.

Betz *et al.* (1998) used LLWR concept to evaluate the impact of tillage and tracking on root and hydrological environment of poorly drained clay loam. The result revealed that the influence of tracking in reduction of LLWR was more pronounced in no tillage treatment than in conventional tillage. At the lower limit of LLWR, penetration was more limiting than wilting point and at the upper limit, aeration was limiting than field capacity in no tillage treatment and treatment with plow pan at 20 cm depth. Sharma and Bhusan (2001) suggested that the ratio of non limiting water range (difference in soil water at 10% aeration porosity and soil water at 2MPa soil impedance) and available water range (difference in soil water at 1/3 and 15 bar) could be used as an index to characterize soil physical environment under different soil management practices. Higher ratio indicated better soil structural condition.

In a study by Tormena *et al.* (1999), LLWR was evaluated for a Brazilian clay Oxisol cropped with maize under no-tillage and conventional tillage. The results demonstrated that LLWR was higher in conventional tillage than in no-tillage and was negatively correlated with bulk density for values above 1.02 Mg m^{-3}. It was further observed that the soil resistance to root penetration determined the lower limit of LLWR in no-tillage. Benjamin *et al.* (2003) in a study in Colorado, USA concluded that the LLWR could be a useful index for assessing management effects on soil potential productivity. Soil management practices that maximized the LLWR could maximize the potential of a soil for crop production. Knowledge of the LLWR for a soil could help the farm manager optimize growing conditions by helping schedule irrigation and for making tillage decisions. In a field study on assessing the usefulness of bed planting system, it was observed that sowing of three rows of wheat on 37.5 cm wide beds in alluvial sandy loam soil (Typic ustochrept) resulted in lower bulk density, higher infiltration rate, lower penetration resistance, increased root length density, reduced irrigation requirement, significantly higher grain yield and increased water use efficiency as compared to conventional flat planting (Aggarwal and Goswami, 2003).

Keeping in view of the results of above studies, a necessity was felt for determining LLWR for assessing the productivity of sandy loam soil of IARI farm under wheat cultivation. In order to quantify LLWR, there was a need to determine the values of MC_{ap} , MC_{fc} , MC_{wp} and MC_{2MPa} at different bulk densities for IARI soils. In addition to the above information, it was desirable to study the influence soil management practices such as use of bed-furrow system for growing wheat in improving the LLWR and hence the soil structural quality.

In the light of the above background, a study was proposed with the following objectives -

- To determine the temporal variation of MC_{ap}, MC_{fc}, MC_{wp} and MC_{2MPa} along with bulk density.
- To determine and compare the variation of LLWR with bulk density under bed planting and conventional planting systems.

Material and Methods

A field study was conducted on sandy loam soil of IARI farm under wheat (HD2687) cultivation during 2002-2003 and 2003-2004. The treatment consisted of sowing of three rows of wheat on 37.5 cm wide bed (bed planting system) and flat sowing of wheat at 22.5 cm row-to-row spacing (conventional planting). Each treatment was replicated eight times. Three representative undisturbed core samples were taken from 0-15, 15-30 cm and 30-45 cm soil layers in each treatment to determine the average values of BD (core method) along with determination of moisture content at 0.1 bar (MC_{fc}) and at 15 bar (MC_{wp}) (using pressure plate method). Moisture content at 10% aeration porosity (MC_{ap}) was calculated as follows:

$$MC_{ap} = MC_{sat} - 10\%$$

Where, MC_{sat} is maximum water holding capacity i.e. total pore space of soil (% v/v) and determined once during the period from sowing to Ist irrigation and thereafter at the middle of each drying cycle after irrigation. Soil penetration resistance data of 0-45 cm layer was recorded (using Rimik CP20 cone penetrometer) along with soil moisture (by gravimetric method) at 4-6 days interval during the period from sowing to Ist irrigation and also during the drying cycle after each irrigation. The above observations were used to develop a multiple regression equation relating soil penetration to soil moisture, bulk density and soil depth, which was required to determine MC_{2MPa} for a given BD for that drying cycle.

Finally four curves with bulk density on x-axis and MC_{ap}, MC_{wp} , MC_{fc} and MC_{2MPa} on y-axis were drawn on the same scale to determine the limits of LLWR as a function of bulk density. The lower limit was the magnitude of either MC_{wp} or MC_{2MPa} whichever was higher and the upper limit was magnitude of either MC_{ap} or MC_{fc}, which ever was lower.

Results and Discussion

Table 1 shows temporal variation of bulk density of surface soil under bed and conventional system. Bulk density of surface 0-15 cm increased gradually from sowing to harvest. Increase in bulk density with time indicated increase in soil compaction with time, which could be due to settling of soil after tillage or breaking up of the aggregates under the influence of irrigation or rainfall. Bulk density of soil under bed system for 0-15 cm was significantly less than conventional system throughout the crop growth as the 20 cm high beds were formed initially by flattening the loose heap of soil formed by removing the soil from furrow. The differences, which were highly significant initially, became less significant at later crop stages and nonsignificant at harvest. For 15-30 and 30-45 cm depths also, the difference between both systems were significant initially, but as crop growth advanced they became nonsignifcant. The

Table 1. Temporal variation of bulk density in bed and conventional planting systems

Soil depth (cm)	Days after sowing (DAS)	Bulk density (Mg m^{-3})		T test
		Bed planting	Conventional planting	
0-15	0	1.20	1.32	**
	15	1.27	1.36	**
	30	1.36	1.42	*
	60	1.40	1.46	*
	90	1.48	1.51	NS
	105	1.53	1.51	NS
15-30	0	1.47	1.54	*
	15	1.50	1.58	*
	30	1.55	1.59	*
	60	1.58	1.58	NS
	90	1.56	1.56	NS
	105	1.57	1.58	NS
30-45	0	1.45	1.58	**
	15	1.53	1.60	**
	30	1.55	1.61	*
	60	1.56	1.56	NS
	90	1.56	1.55	NS
	105	1.56	1.56	NS

** Highly significant; * Significant; NS Nonsignificant.

nonsignificant bulk density differences between both systems at maturity were due to flattening of beds (shift in height of bed from 20 cm at sowing to just 4 cm at harvest) because of the movement and settling of soil from beds in furrows after each irrigation and rain.

Stepwise multiple regression analysis of 16 data set of penetration resistance and soil moisture content (4 data set for each drying cycle) for each soil layer along with 4 bulk density data (one for initial period before irrigation, one each during drying phases of first, second and third irrigation) revealed that for both systems, moisture alone contributed to 59-65%, whereas both moisture and bulk density contributed 93-96% towards the variation of penetration resistance (Table 2). Inclusion of depth did not improve the correlation.

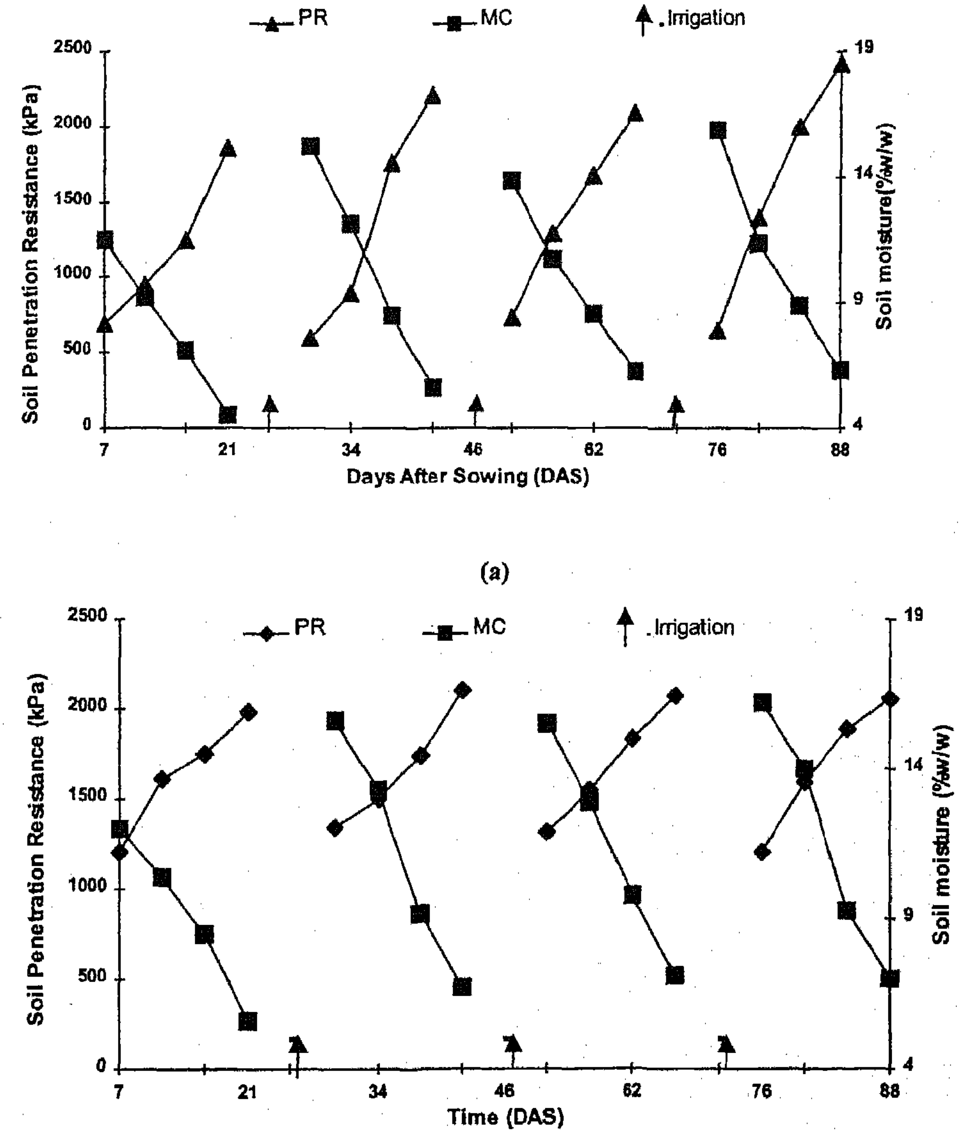
Temporal variation of PR with MC for 0-15 cm soil during drying phase after each irrigation was studied for both systems of planting. Results showed that PR increased with decrease in MC (Figure 1(a) and1(b)). All throughout the crop growth PR was higher in conventional than under bed. The results thus indicated that with reduction in moisture, soil impedance was more under conventional than under bed planting system. Again for a given value of soil penetration, MC was higher for conventional than bed planting.

Since 2MPa is considered as critical limit of soil penetration resistance and corresponding moisture is MC_{2MPa}. Soil moisture lower than MC_{2MPa} will adversely affect the root growth. Predicted soil moisture corresponding to 2MPa soil penetration resistance on various days after sowing (DAS), for all three layers showed lower values in bed planting as compared to conventional system (Table 3). In other words, the critical soil penetration resistance of 2MPa was obtained at relatively higher soil wetness in conventional planting as compared to bed planting.

For both methods of planting, four curves with BD on x-axis and MC_{ap}, MC_{fc}, MC_{wp} and MC_{2MPa} on common y-axis were plotted to determine the limits of LLWR (Figs. 2 and 3). For both systems it was observed that MC_{ap} decreased with increase in BD, whereas MC_{fc} and MC_{wp} decreased slightly with increase in BD. In contrast, MC_{2MPa} increased apreciably with

Table 2. Stepwise statistics of multiple regression model

Method/no of step	Parameter	Intercept	BD	MC	DEP	R^2
			Bed planting			
Forward stepwise/1	Coefficient	3024.75	-	-138.34	-	0.589
	T_{static}	13.64	-	-6.99	-	
Forward stepwise/final	Coefficient	-1155.50	3137.25	-176.58	-	0.963
	T_{static}	-4.84	18.23	-27.61	-	
Standard	Coefficient	-1005.16	3012.12	-177.59	1.94	0.964
	T_{static}	-3.55	14.16	-27.44	0.99	
			Conventional planting			
Forward stepwise/1	Coefficient	2650.73	-	-76.28	-	0.647
	T_{static}	23.34	-	-7.9	-	
Forward stepwise/final	Coefficient	192.75	1724.22	-90.39	-	0.935
	T_{static}	0.96	12.54	-21.35	-	
Standard	Coefficient	99.79	1794.40	-90.28	-0.66	0.939
	T_{static}	0.33	8.43	-21.02	-0.44	



(b)

Fig. 1. Temporal variation of penetration resistance (PR) and moisture (MC) of 0-15 cm soil during wheat growth in (a) bed planting (b) conventional planting

increase in BD. It was further observed that MC_{fc} determined the upper limit throughout the crop growth for both bed and conventional system, but lower limit was represented initially by MC_{wp} but at later stage when bulk density exceeded nearly 1.36 Mg m^{-3}, lower limit of LLWR was represented by MC_{2MPa}.

Magnitude of LLWR (Fig. 4), which was the difference in magnitudes of upper and lower limit appeared to higher at initial crop stages and declined sharply at the harvest. The decline appeared to be 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. Thus, bed planting was found to be superior to conventional planting in improving the soil physical environment and hence the soil productivity.

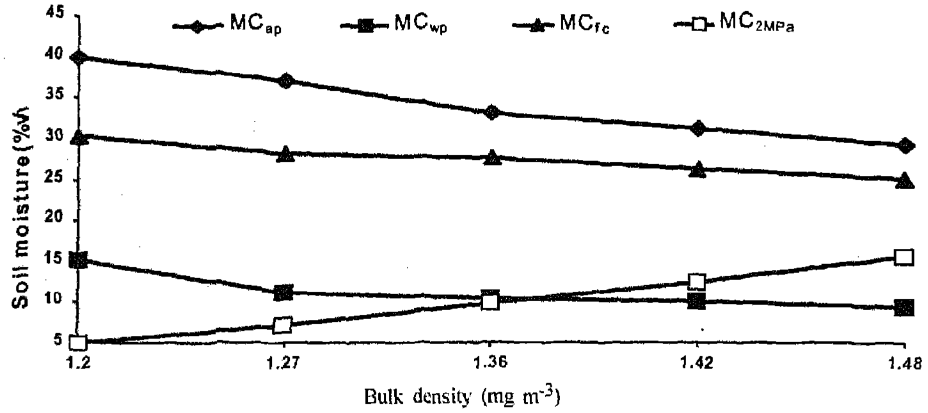


Fig. 2. Temporal variation of moisture content of 0-15 cm soil at 10% aeration capacity (MC_{ap}) , 0.1 bar (MC_{fc}), 15 bar (MC_{wp}) and at 2 MPa soil penetration resistance (MC_{2MPa}) for bed planting system

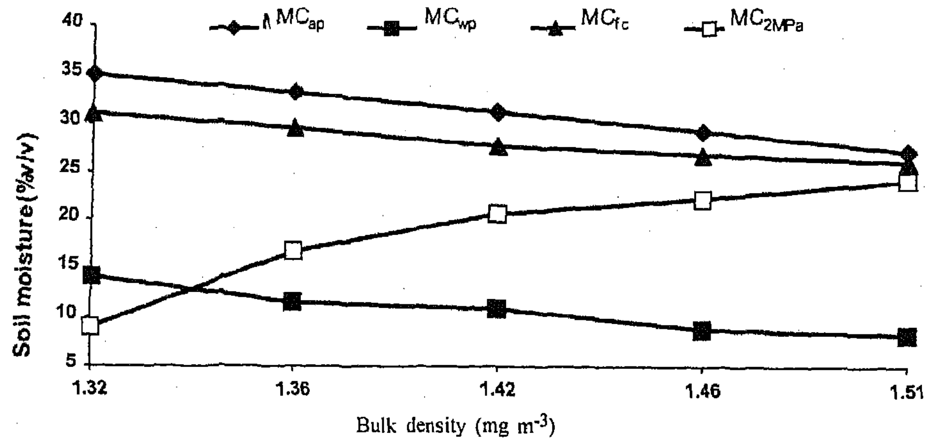


Fig. 3. Temporal variation of moisture content of 0-15 cm soil at 10% aeration capacity (MC_{ap}) , 0.1 bar (MC_{fc}), 15 bar (MC_{wp}) and at 2 MPa soil penetration resistance (MC_{2MPa}) for conventional system

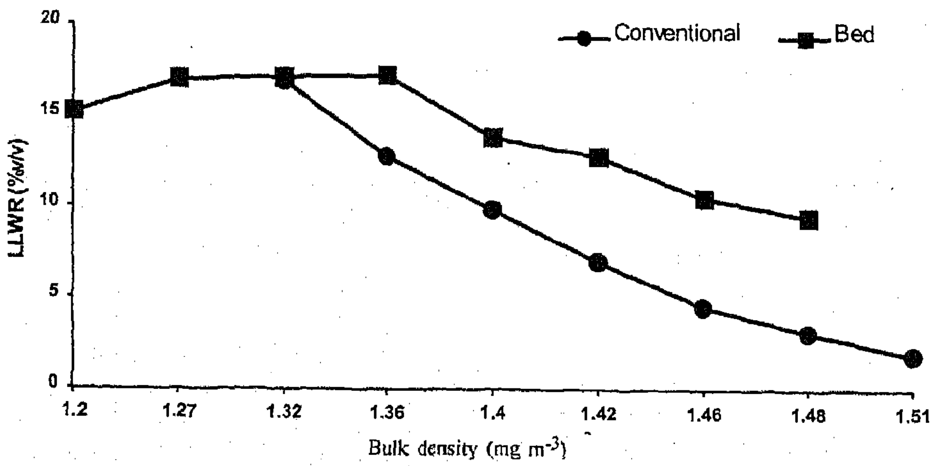


Fig. 4. Variation of LLWR with bulk density under bed and conventional planting

Table 3. Predicted soil moisture at 2MPa soil penetration resistance in bed and conventionally planted systems

Days after sowing (DAS)	Soil depth (cm) (DEP)	Bulk density ($Mg\ m^{-3}$) (BD)	Predicted* Soil moisture (%w/w) at 2 Mpa (MC_{2MPa})
	Bed planting		
0	0-15	1.20	3.35
	15-30	1.36	6.06
	30-45	1.48	8.01
30	0-15	1.40	6.58
	15-30	1.55	9.12
	30-45	1.56	9.29
90	0-15	1.45	7.26
	15-30	1.55	8.96
	30-45	1.56	9.13
	Conventional planting		
0	0-15	1.32	5.13
	15-30	1.42	7.12
	30-45	1.50	8.71
30	0-15	1.54	9.40
	15-30	1.59	10.39
	30-45	1.56	9.79
90	0-15	1.58	10.08
	15-30	1.61	10.68
	30-45	1.55	9.48

* Prediction equation for -

a) Bed planting: PR= -1005.16 + 3012.118*BD - 177.589*MC + 1.941723*DEP

b) Conventional planting: PR = 99.7891 + 1794.403*BD - 90.2803*MC - 0.66305*DEP

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