Permanent raised bed configurations and renovation methods affect crop performance

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Abstract
Permanent raised bed (PRB) configurations and renovation methods vary throughout the world depending on soil type, cropping pattern, farmer preferences, available machinery and local expertise. An increase in the bed width generally increases land use efficiency due to a smaller cropped land loss due to furrows. However, PRB configuration and seasonal pre-sowing renovation need careful selection due to their influence on crop production. Two experiments investigating PRB systems used for wheat-maize rotations were conducted over a ten year period on a silty clay loam in Pakistan. The use of PRBs generally resulted in higher yield, lower water application and higher Gross Production Water Use Indices (I_{GP}) compared to traditional flat basin systems. Wide (180 cm) beds produced higher wheat (15%) and maize (26%) yields than the flat basin treatment during the first experiment. Maize yields were 10% higher than the basin treatment in the second experiment involving narrow (65 cm) and medium (130 cm) width beds while wheat yields were only marginally (<5%) higher. The lower water application in the PRB compared to basin treatments was found to be closely related to bed width. The narrow beds used 3-7% less water than the basins while the medium and wide beds used 16-17% and 18-22% less, respectively. The difference in I_{GP} between the basin and PRB treatments was also found to be closely related to bed width with the I_{GP} ranging from 13-18%, 30-31% and 43-70% higher for the narrow, medium and wide beds, respectively. Substantial differences in both bulk density and hydraulic conductivity were also found between the basin and bed treatments. Within the PRB treatments, the soil bulk density was lower and hydraulic conductivity higher when machinery track widths were matched to furrow spacing and bed renovation was conducted using horizontal blades which minimised bed disturbance and soil inversion.

Key Words
Irrigation performance, lateral wetting, land preparation, zero till bed planter.

Introduction
The agriculture sector is under increasing pressure to sustainably produce higher yields with less inputs due to declining land and water productivity potential (McGarry 2001), increasing cost of production (Tullberg and Murray 1988), variable market conditions and increasing world population. Permanent raised bed (PRB) farming systems combine most of the elements of conservation agriculture and have produced encouraging production results under various environmental conditions. PRBs offer the opportunity of reducing field compaction and restoring physically degraded soil structure (McHugh et al. 2009) as well as the potential to reduce irrigation water and increase crop yield (Akbar et al. 2007) while reducing the risk of waterlogging (Hamilton et al. 2005). PRBs also have lower land preparation costs (Ortega et al. 2006) by reducing field operation time, facilitate crop residue management (Talukder et al. 2002) by minimum tillage and mitigate weed infestation (Hulugalle and Daniells 2005) through better mid-season field access. Different PRB configurations are used throughout the world depending on soil type, available machinery, farmer preference and expertise. In general, increasing the width of the bed reduces total water used and increases land use efficiency and yield by reducing the uncropped furrow area (Jin et al. 2007). In Australia, bed widths of 2 to 3 m are common while 0.6 to 1.5 m widths are common in China, Pakistan, India and Bangladesh (Sayre et al. 2005). However, there are a number of factors which affect optimal bed widths including the potential for bed compaction by mismatched machinery operation, inadequate lateral movement of water into the centre of furrow irrigated bed, soil subsidence due to rainfall hammering and bed renovation practices. This paper reports on a ten year program in Pakistan to evaluate the effect of bed configuration and renovation on crop performance.

Methods
The experimental site was located on a uniform clay loam soil in Mardan, north-west Pakistan. This area is semi-arid with a mean seasonal rainfall of 250 mm during the Kharif (summer) and 300 mm during the Rabi (winter) seasons. The mean maximum temperature ranges from 27-30°C during June while the mean minimum temperature ranges from 5-8°C during January. A wheat-maize cropping rotation was grown from 2000 to 2009 over two experimental periods. During the first experimental period (2000 to 2004) four wheat and five maize crops were grown using flat basin (control) and wide beds (180 cm between furrow centres) treatments. During the second experimental period (2005 to 2009) four wheat and maize crops were grown using flat basin (control), narrow bed (65 cm centres) and medium bed (130 cm centres) treatments. The furrow top width was approximately 50 cm for all bed treatments. A local maize variety was used during the first experimental period and Pioneer 3025 Hybrid seed in the second experiment. Similar quantities of fertilizers and herbicides were applied to all treatments. A completely randomized block design was used with three replicates of each treatment.

The flat basin treatment was prepared using a cultivator followed by rotary hoeing and seed broadcasting. A seed drill was used for the flat basin treatment during the second experimental period. Only minor renovation and reshaping of the beds were conducted before each crop planting. A zero till bed planter was used for sowing the maize and wheat crops on the PRBs. The first experiment involved the use of machinery with mismatched track widths and involved shallow rotary hoeing of the beds to remove weeds. The second experiment used matched track width machinery and there was no rotary hoeing of the beds. Renovation of the beds during the second experiment was conducted using a horizontal blade plough that cut the beds at the base of furrows without inverting the soil. Soil hydraulic conductivities were measured using a double ring infiltrometer at harvest and bulk density was measured using core sampling both prior to sowing and harvest of each crop.

Results
Effect of PRB configuration
The use of PRBs generally resulted in a higher yield and lower water application compared to traditional flat basin systems (Table 1). The wide beds produced higher wheat (15%) and maize (26%) yields than the flat basin treatment during the first experiment. However, average wheat yields during the second experiment were only slightly (<5%) higher on the narrow and medium beds compared to the basin. In this experiment, the maize yields were approximately 10% higher on the beds compared to the basin treatments. The reduction in applied water was found to be closely related to bed width confirming that this is related to hydraulics of the surface irrigation application. The narrow beds used 3-7% less water than the basins while the medium and wide beds used 16-17% and 18-22% less, respectively. The Gross Production Water Use Index (I_{GP}) was substantially higher for all PRB configurations compared to the basin treatments. The difference in I_{GP} between the basin and PRB treatments was also found to be closely related to bed width with the wheat I_{GP} being 13%, 31% and 43% higher for the narrow, medium and wide beds, respectively. Similarly, the maize I_{GP} was 18%, 30% and 71% higher than the basin I_{GP} for the narrow, medium and wide beds, respectively.

In the second experiment, the high water demanding maize crop produced a marginally lower (~2%) yield on the medium bed than on the narrow bed. Anecdotal observations suggest that this may have been due to problems with lateral water movement (subbing) across the beds and lower soil moisture storage in the crop root zone as the bed width increases. This is likely to be a more significant problem for crops with high water demands grown during the hot summer season. The wheat yield on wide beds may have been less affected by subbing problems because of the lower evapotranspiration demand and the presence of sufficient in-season rainfall to reduce the reliance on the irrigation applications. Alternatively the increase in wheat cropping area with increases in bed width may have masked any yield reductions due to subbing. However, it should be noted that the furrows fitted within the normal maize crop rows so in this case there was no impact of bed width on cropped area.

Table 1: Effect of bed configuration on yield and water use for a wheat-maize rotation on a clay loam soil (Mardan, Pakistan). Means with range shown in brackets.

	Crop	Experiment 1(2000 to 2004)		Experiment 2 (2005 to 2009)		
		Flat Basin	180cm Bed	Flat Basin	65cm Bed	130cm Bed
Yield (t/ha)	Wheat	3.9 (3.8-4.0)	4.5 (3.9-4.9)	4.4 (2.9-4.4)	4.5 (3.1-5.3)	4.6 (3.2-4.8)
	Maize	3.4 (1.7-6.4)	4.3 (2.7-8.0)	7.7 (6.9-8.4)	8.7 (7.3-10.0)	8.5 (7.4-10.0)
Water Applied (mm)	Wheat	448 (353-575)	348 (317-508)	523 (326-666)	508 (320-663)	434 (262-589)
	Maize	627 (220-767)	517 (198-575)	841 (666-953)	785 (663-884)	707 (587-807)
Gross Production Water Use Index (kg/ha/mm)	Wheat	8.3 (6.7-11.5)	11.9 (7.6-14.1)	8.4 (5.7-13.1)	9.5 (6.1-13.9)	11.0 (6.9-17.2)
	Maize	6.1 (4.2-9.4)	10.4 (5.7-17.1)	9.3 (7.5-10.5)	11.0 (7.5-12.9)	12.1 (9.9-13.5)

Effect of PRB renovation method

The hydraulic conductivity of the beds (Figure 1) were 62% higher than the basin treatments in the first experiment and more than 100% higher during the second experiment. The average bulk densities were also 7%, 13% and 6% lower for wide, medium and narrow PRBs respectively than flat basin in their respective experiments. The lower bulk density and higher hydraulic conductivity suggests that the beds have much improved soil structural properties including a larger macropore volume and better pore connectivity leading to improved infiltration and internal drainage. The improved soil structure also facilitates the development of root mass, accelerates biological activities and increased soil aeration. These benefits are likely to have contributed to the higher crop yields observed on the PRB compared to flat basin treatments (Table 1). The lower bulk density and higher hydraulic conductivities observed on the beds in the second experiment compared to the first experiment are most likely associated with the better matching of machinery track widths and the implementation of horizontal renovation blades which reduced bed disturbance and inversion. This renovation practice was observed to leave crop residues in place, maintain root channels and presumably also caused minimal disturbance to microorganisms within the root zone.

Conclusions

Permanent raised beds have been shown to produce higher yields, require less water and have higher gross production water use indices than traditional flat basin systems in north-west Pakistan. The volume of irrigation water applied was found to be a function of the bed width with wider beds typically having smaller water application volumes. However, the yield achieved on the beds was less affected by bed width. Anecdotal evidence suggested that wider beds experienced difficulty with lateral water movement from the furrows but wider beds also typically had a larger infield cropped area due to fewer furrows. Investigations of soil structural properties in the beds indicated that matching the machinery track width to the furrow spacing and using horizontal blades for renovating beds without soil inversion resulted in lower soil bulk densities and higher hydraulic conductivities within the root zone.
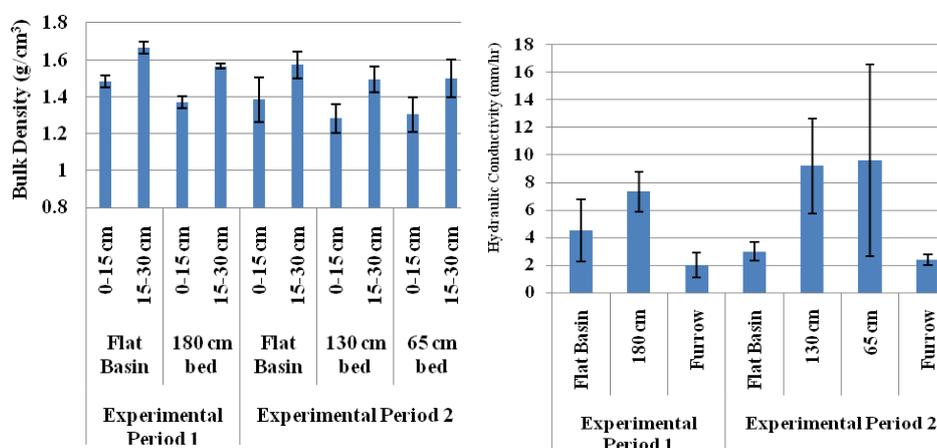

Figure 1. Effect of bed configuration and renovation on hydraulic conductivity and bulk density of a clay loam soil (Mardan, Pakistan). Bars show +/- standard deviation.

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