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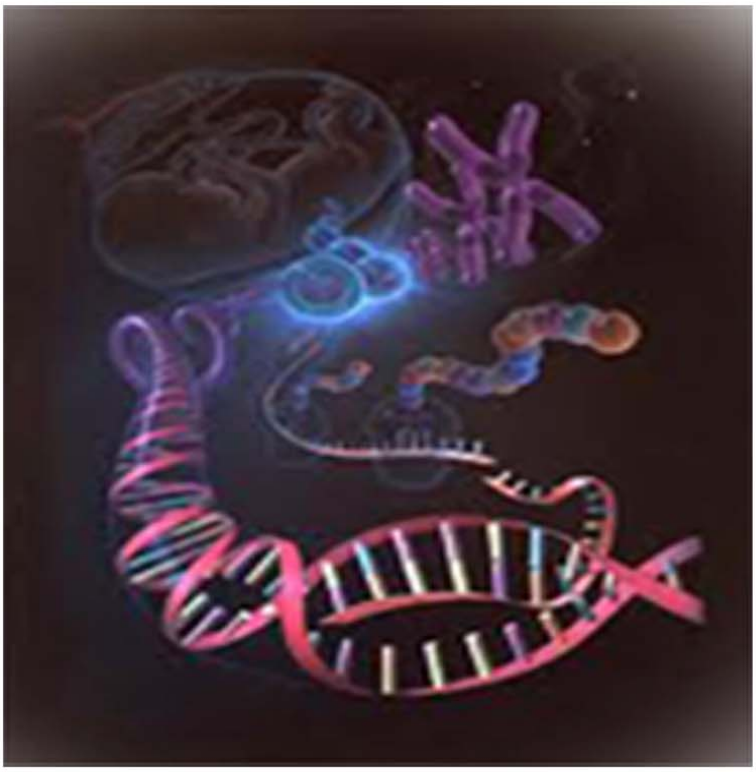

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Research Paper

EFFECT OF MULCHING AND CROP ESTABLISHMENT METHOD ON YIELD,WATER BALANCE AND SOIL WATER DYNAMICS OF PERMANENT BEDS ON WHEAT CROP IN WESTERN UTTAR PRADESH

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Permanent beds with crop residue retention have been proposed as a means of reducing irrigation water use, improving soil properties and reducing the cost of crop establishment. A field experiment was conducted over 3 years in Western Uttar Pradesh, to compare conventional and permanent bed wheat crop, with and without retention of crop residues, in terms of crop performance and components of the water balance and soil water dynamics. Results of this study showed that total irrigation amounts for wheat (239-446 mm) were about one-eighth of those for rice. The amount of water applied at each irrigation was usually less on the beds than on the flats. In 2001-02 a long-term trial was initiated to compare the farmer practice of tilling to destroy the beds after the harvest of each crop with a new approach. In this alternative method new raised beds were made following a final cycle of tillage, after which these beds were maintained permanently with only occasional reshaping as needed after harvest and before planting the next crop. By the 2008-09 winter crop season, 3 wheat crops have been successfully produced in this long-term trial, including treatments where no tillage or no crop residue removal has been practised. Significant yield differences between the tillage/ residue management treatments have been observed for wheat, with major differences starting with the second wheat crop. More stable, higher wheat yields have been obtained with permanent beds combined with residue retention.

Keywords: Crop residue, zero-tillage, water productivity, Permanent raised beds, Soil quality

INTRODUCTION

Traditionally, wheat in the western Uttar Pradesh was planted in flat basins which were flooded for irrigation. During the 2000s the technique of planting on raised beds with irrigation water confined to furrows between the beds (FIRB). A

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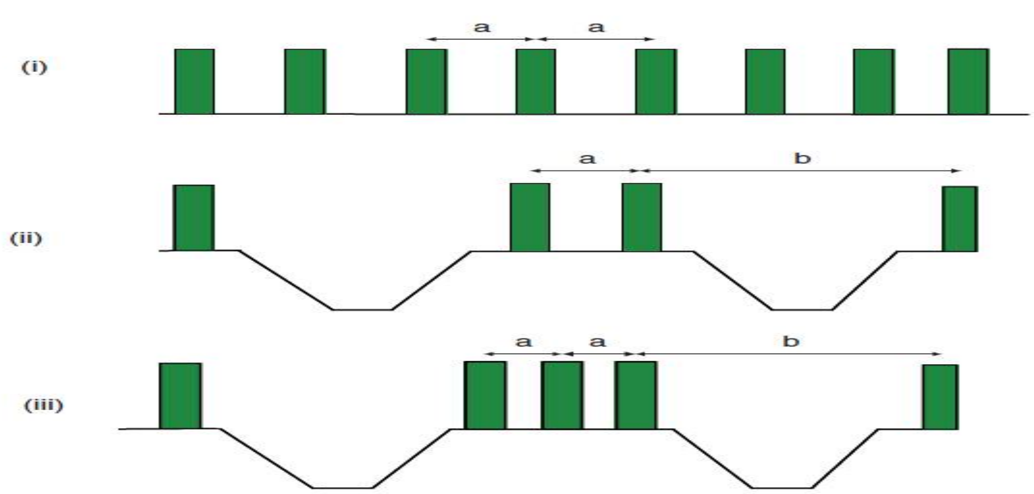
feature of the bed planting system which initially always arouses concern from farmers and researchers alike is the apparent waste of resources represented by the unplanted space, known here as the gap, between the beds. The gap comprises the unplanted shoulder of a bed, the furrow itself and the shoulder of the adjacent bed. Depending on tractor wheel widths and bed planter configurations, the gap can be between 40 and 45 cm wide, i.e., from the last row of plants on one bed to the first row on the adjacent bed (dimension 'b' in Figure 1) and cumulatively can appear to occupy half of the land area. In some instances farmers' perceptions about yield loss due to such wide gaps are a key impediment to the uptake of raised bed technology. The wheat plants in the outside rows on the beds normally tiller well and appear to spread into the gap.

Over the past 10 years there has been a substantial reduction in tillage operations when compared to the previous widespread practice of deep subsoiling on a regular basis combined with disc ploughing, followed by several passes of the disc harrow and then superficial levelling before each crop cycle. Now, few farmers are using the plough and the number of passes with the disc harrow has been markedly reduced. Similarly, there has been a marked reduction in the removal of crop residues,with more farmers chopping residues either with tractor-drawn field choppers. Very few farmers, however, have adopted permanent bed planting, although some have taken the first true step towards use of permanent beds, especially in the main cropping systems that involve wheat in the autumn/winter cycle followed by maize, vegetables or rice in spring/summer cycle. Land is still tilled and new beds made for the autumn-sown wheat, but these same beds are reshaped if needed and reused for the succeeding summer crop of maize, vegetables or rice. Because of the lack of appropriate planters to seed summer crops on untilled beds with retention of the residue/straw

Figure 1: Diagram Showing the Key Dimensions for Plantings: (I) Flat Planting Row Spacing of a cm; Designated 'a, a'; (II) Bed Planting with Two Rows on Bed Spaced a cm Apart, Furrow Gap b cm; Designated 'a, b' (III) Bed Planting with Three Rows on Beds Spaced a cm Apart, Furrow Gap b cm; Designated 'a, a, b'



on the soil surface, most farmers tend to either burn the straw, or cut the stubble close to the ground before planting the summer crop. In the autumn after harvesting the summer crops, the beds are destroyed by tillage and new beds re-established for the following small grain crop. Thus, the principal reason that farmers use this ‘hybrid tillage system’is the lack of suitable small grain seeders that can readily and reliably plant 2-3 rows of wheat on the untilled top of the permanent beds,especially in the presence of high levels of surface retained rice residue. Similarly, almost no technical advice has been made available to farmers about how to manage weeds, fertiliser and irrigation for the new permanent bed planting practice since little or no formal research effort to generate this information has been carried out in western Uttar Pradesh. The realisation of this knowledge gap, combined with a firm belief that permanent bed planting offers the best alternative for ensuring farmer adoption of sound, sustainable CA technologies for surface irrigated cropping systems, has provided a foundation for SVPUA&T, Meerut to initiate research in,and extension of, permanent bed planting systems. Given the absence of knowledge and lack of experience in managing permanent beds with retention of surface crop residues in irrigated systems, both world wide and especially in western Uttar Pradesh 10 years ago.

Crop residue management strategy for permanent beds has been to ensure that the implements and other management features can handle seeding with full or partial residue retention. This can be achieved by removing the cut, loose residue and leaving the standing stubble, especially with crops like wheat; or, alternatively, by rotational removal of residues. A clear understanding of how to achieve rational implementation of strategies that allow adequate, partial residue retention will be crucial in those (most) developing countries where the use of residues for fodder in mixed crop/livestock enterprises is of great importance or where residues are used for other purposes. Otherwise, opportunities for implementation of new technologies like permanent bed planting will be markedly diminished. For irrigation of wheat and other crops when 2 or more rows are planted on top of the beds, we normally apply seeding irrigation in each furrow,as well as auxiliary or post-emerge irrigations. However, in some soil types post-seeding irrigations may be applied in every alternate furrow, with each successive irrigation occupying furrows not used in the previous irrigation. Use of narrower beds (67-70 cm) provides a large degree of flexibility for gravity irrigated conditions, ensuring more efficient management options for inter-crop weed control, fertiliser banding,irrigation water application, and handling of high levels of crop residues. By using alternate row irrigation strategies, narrow bed planting allows irrigation opportunities similar to those of wider beds for row crops. Our research strategy has been to install a small number of long-term trials that focus mainly on comparing permanent bed planting systems against conventional bed planting with tillage.

Many studies across the IGP have shown that wheat can be grown successfully on raised beds in a range of crop sequences and produce similar or higher yields compared with conventional tillage on the flat (Ram *et al.,* 2005). Growing wheat on beds has many advantages including reduced irrigation water use (by 30-50%), reduced seed rate (by 25-30%), reduced lodging, reduced waterlogging, reduced germination of *Phalaris* *minor,* the opportunity for mechanical weeding and fertiliser placement, and improved timeliness of operations due to better surface drainage. Adoption of wheat on beds in RW systems is likely to remain low until systems for successfully growing rice on beds are developed, allowing all the advantages of permanent bed RW systems to be realised. These advantages include direct drilling of both crops,offering large cost savings diesel, labour, and machinery wear and tear); quicker turn around between crops (more timely sowing); reduced dependence on labour (labour shortage Hira and Khera, 2000). On coarse-textured soils,particular care needs to be taken to avoid water deficit stress during establishment, as the soil in the beds dries more rapidly than in flat layouts (Singh *et al*., 2006). Finally, the limited available data show that the performance of wheat on permanent beds in RW systems of the NW IGP has generally been inferior to that on fresh beds, although the majority of reports on wheat on beds to date have been for fresh beds.

MATERIALS AND METHODS

Site Details

The experiment was conducted on wheat for 3 years from 2008-09 to 2010-11 at the crop research centre of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut ($29^0$01' N, $77^0$45' E, and 237 m above mean sea level) in north-western India. The climate of the area is semiarid, with an average annual rainfall of 805 mm (75-80% of which is received during July to September), minimum temperature of 2 to 4^0C in January, maximum temperature of 41 to 45^0C in June, and relative humidity of 67 to 83% throughout the year. The experimental soil (0-15 cm) was sandy loam in texture.

Experimental Design and Treatments

The experiment comprised on wheat crop, and was designed as a randomised complete block design with three replicates, commencing with wheat in 2008-09. The main plots consisted of tweleve layout or crop establishment straw treatments. The sites, treatments and management are briefly summarised here for convenience, together with details of the water and soil water monitoring.

Replicated Small Plot Experiment

Replicated experiments was established on sandy loam soils to compare tweleve flat and bed treatments for wheat crop over 3 years (Table 1). The width of the narrow beds (mid furrow to mid-furrow) was 67 cm, with 37 cm wide flat tops and 15 cm furrow depth and the width of the wide beds (mid furrow to mid furrow) was 137cm, with 107 cm wide flat tops and 12 cm furrow depth. Plot size was 15 × 10 m, with earth bunds around each plot. The depth to the groundwater was over 23 m.

Table 1: Treatments in the Small Plot Replicated Experiment in Wheat Crop on Sandy Loam Soil

Layout	Abbrevations
T_1 – Wheat planted by turbo happy seeder	ZT-HS
T_2 – Wheat on wide beds + mulch	WBedZT-DSW +M
T_3 – Wheat on wide beds – mulch	WBedZT-DSW – M
T_4 – Wheat on narrow beds + mulch	NBedZT-DSW + M
T_5 – Wheat on narrow beds – mulch	NBedZT-DSW – M
T_6 – Wheat planted by ZT controlled traffic + mulch	ZT-DSW CT + M
T_7 – Wheat planted by ZT controlled traffic – mulch	ZT-DSW CT – M
T_8 – Wheat planted by ZT paired row + mulch	ZT-DSW PR + M
T_9 – Wheat planted by ZT paired row – mulch	ZT-DSW PR – M
T_{10} – Wheat planted by ZT normal spacing + mulch	ZT-DSW + M
T_{11} – Wheat planted by ZT normal spacing – mulch	ZT-DSW – M
T_{12} – conventional practices	CT-BCW

Prior to wheat sowing, all treatments received a pre-sowing irrigation, followed by a common irrigation around the time of crown root initiation (applied on the same day in all treatments). Subsequent irrigation scheduling for both flats and beds was based on net cumulative pan evaporation IW/CPE-ratio, using IW/CPE-ratio of 0.9 to 1.0 (Prihar et al. 1974), where IW is the amount of irrigation water.

Farmer Field Experiments

Fresh and permanent beds were compared with conventional tillage on the sandy loam soil in large, unreplicated blocks running the full length (~60 m) of a farmer's field (Figures 2a and b). Dimensions of the beds were as for the small plots.

Figure 2a: First Post-Sowing Irrigation of Conventionally Tilled Wheat (CT-BCW) in Small Plots

Figure 2b: First Post-Sowing Irrigation of Wheat on Fresh Beds in Small Plots

Measurement of irrigation water application, as affected by layout and irrigation management, commenced in 2008-09. The same flow-meter was used for measuring irrigation applications to all large blocks and small plots.

Irrigation Treatments

Irrigation scheduling for both flats and beds was based on net cumulative pan evaporation IW/CPE-ratio, using IW/CPE-ratio of 0.9 to 1.0 (Prihar et al. 1974), where IW is the amount of irrigation water.

Soil Water Depletion (Small Plots Only)

The soil was sampled at sowing (after pre-irrigation) and harvest of the wheat crops by augering to 180 cm harvest (and soil sampling) of wheat were done as soon as grain moisture had decreased to a few percent, which occurred 2-4 weeks after the last irrigation. Volumetric soil water content (VWC) was determined from gravimetric water content and bulk density. Field capacity was determined in two bare small plots in the buffer areas by ponding water for about 1 week and then collecting (by 75 mm auger) soil samples to a depth of 180 cm after ponding ceased. The samples were collected at depth increments of 15 cm for the top two layers, and at increments of 30 cm from 30 cm to 180 cm.Sampling was continued until the soil water content became relatively constant (field capacity).

RESULTS AND DISCUSSION

Water Requirement and Irrigation of Wheat

Irrigation amounts on the beds were usually less than on the flats (because of the volume limitation of the furrows), use of the same irrigation scheduling rule for beds and flats meant that the beds were usually irrigated slightly more frequently in residue removal treatments. Total water input (post-sowing irrigation + rain) to wheat on both beds and flats in the small plots was much higher in 2008–09 than in the following 3 years Table 3. Total input was 381 mm and 313 mm on the flats and beds in 2008–09, respectively, compared with 266-346 mm in all other years. The relative amount of irrigation water applied to the beds and flat plots was largely influenced by the residue retain or residue removal in relation to irrigation—the treatments were often irrigated on different dates because of the different irrigation amounts applied to flats and furrows while using the same ratio of IW/CPE-ratio for both. As with the small plots, total irrigation application in 2009-10 in the large blocks was similar for fresh beds, permanent beds and ZT-HS in residue retain treatments (309-336 mm including pre-sowing irrigation). Total irrigation in the large blocks was almost identical to that in the small plots at the same site in the same season (272-310 mm) Table 3, suggesting that the small plots were reasonably representative of the large blocks in terms of irrigation amount.

Soil Water Depletion During Wheat

At the time of wheat harvest the profile had dried to the depth of sampling (180 cm) each year. The extent of drying to depth was greater in the over irrigated crops on the in 2008–09. While there was evidence of roots to 140–160 cm on both beds and flats at heading in 2008–09 and 2009–10. Soil water depletion generally tended to be greater in the top soil of the beds without residue retain than the flats, but less in the beds than flats at depth. The magnitude of soil water depletion between sowing and harvest ranged from 107 mm (2008-09) to 131 mm (2009-10) in CT-BCW.

Table 2: Wheat Grain Yield (t ha^{-1}), Input Costs (Rs ha^{-1}), and Net Income (Rs ha^{-1}) Under Different Till Age and Crop Establishment Methods

Treatment	Grain yield	Crop establishment cost	Seed cost	Irrigation cost	Fertilizer cost	Herbicide cost	Net income
ZT-HS	5.20	2000	2000	724	3300	200	25,530
WBedZT-DSW +M	5.53	3500	1600	515	3300	-	25,720
WBedZT-DSW – M	5.35	2700	1600	604	3300	550	24,985
NBedZT-DSW +M	5.23	3500	1600	612	3300	-	24,925
NBedZT-DSW - M	5.05	2700	1600	690	3300	550	23,410
ZT-DSW CT + M	5.25	1150	2000	680	3300	-	26,095
ZT-DSW CT - M	5.10	650	2000	801	3300	200	25,345
ZT-DSW PR + M	5.35	1150	2000	697	3300	-	26,590
ZT-DSW PR - M	5.14	650	2000	793	3300	450	25,245
ZT-DSW + M	5.07	1150	2000	699	3300	-	25,195
ZT-DSW – M	4.82	650	2000	811	3300	500	23,655
CT-BCW	4.59	4500	2000	955	3300	650	18,815
C D at 5%	0.47	83.6	41.7	32.4	-	23.8	-

Table 3: Wheat Productivity, Water Application and Water Productivity in Wheat With Various Tillage and Crop Establishment Techniques

Crop Establishment	Grain Yield (t/ha)			Irrigation Water Applied (mm ha^{-1})			RE Means	Water Productivity (kg grain m^{-3})			RE Means
	2008 -09	2009 -10	2010 -11	2008 -09	2009 -10	2010 -11		2008 -09	2009 -10	2010 -11	
ZT-HS	5.15	5.20	5.25	364	336	310	336.7	1.41	1.55	1.69	1.54
WBedZT-DSW + M	5.60	5.55	5.45	317	309	272	299.3	1.77	1.79	2.00	1.85
WBedZT-DSW – M	5.43	5.35	5.27	336	315	285	312.0	1.62	1.70	1.85	1.71
NBedZT-DSW + M	5.30	5.25	5.10	306	335	273	304.7	1.73	1.57	1.87	1.71
NBedZT-DSW – M	5.07	5.05	5.02	353	324	286	321.0	1.44	1.56	1.76	1.57
ZT-DSW CT + M	5.20	5.25	5.30	342	314	293	316.3	1.52	1.67	1.81	1.66
ZT-DSW CT – M	5.15	5.10	5.04	392	372	354	372.7	1.31	1.37	1.42	1.37
ZT-DSW PR + M	5.25	5.30	5.35	349	321	302	324.0	1.50	1.65	1.77	1.64
ZT-DSW PR – M	5.20	5.12	5.10	391	367	348	368.7	1.33	1.40	1.47	1.39
ZT-DSW + M	5.05	5.07	5.10	346	324	305	325.0	1.46	1.56	1.67	1.56
ZT-DSW – M	4.85	4.82	4.80	398	376	358	377.3	1.22	1.28	1.34	1.28
CT-BCW	4.65	4.35	4.73	467	455	415	445.7	1.00	0.96	1.14	1.03
C D at 5%	0.49	0.41	0.35	364	336	310	336.7	1.41	1.55	1.69	1.54

Water Balance of Wheat

The water balance calculations (sowing to harvest) show significant deep drainage (beyond 180 cm) on both beds and flats in 2008-09 (135-184 mm), a result of unusually rainfall in a short period of time in 2009 and subsequent over irrigation. Drainage was higher on the beds than flats,where the narrow beds with residue retain received 45 mm less irrigation; but drainage was less on the wide beds than the flats, where the wide beds with residue retain received 50 mm less irrigation.

Effect of Soil Management on Wheat Irrigation and Total Water Use

There was a consistent trend for lower water input in beds on either soil in either the small plots or the large blocks. The clear trend is expected in studies because irrigations were based on IW/CPE-ratio and used the same ratio for raised beds and flats in residue retain and residue removal treatments.These results are in accordance with the findings in the literature in both small plots and farmers' fields (Choudhury *et al*., 2006; Bhushan *et al*., 2007; and Jat *et al*., 2008). However, Naresh *et al*., 2012 found average irrigation water saving of 15-26%. In many of the small plot studies the raised beds and flats were always irrigated on the same day, with less water applied to the raised beds because it takes less water to fill the furrows than to flood the flat plots.In the studies in farmers' fields, irrigation management is not known. In practical terms the lowest application rate that can be applied and provide full coverage of a 'flat' field will depend on how well the field has been levelled and on the flow rate. Laser levelled fields in Western Uttar Pradesh, resulted in average wheat irrigation water savings of 21% in comparison with non lasered fields (Naresh *et al.*, 2011).

Soil Moisture Conservation

Straw retention significantly influenced the soil moisture in wheat crops at 40 DAS. In the 0–30 cm soil layer the maximum soil moisture (18.6%) was in residue retention + permanent raised beds,more than double that (7.8%) of 0% without residue retention. Retention of straw improves soil water-holding capacity, and retention on the soil surface also reduces soil evaporation. In trials its observed that the straw retention allows sufficient water to be saved (calculated at 13-108 mm Table 4) to either reduce the number of irrigations by one or delay irrigation time by an average of 19%, or to increase yield in water limiting situations.

Grain Yields

Commonly, conversion from conventional tillage to reduced-till systems with straw retention requires several crop cycles before potential advantages or disadvantages become apparent. In trials straw retention increased yield rapidly, starting from the second crop cycle. We believe this is an important finding because, if repeated on farmers' fields,farmers will quickly realise the benefits and be more interested in adopting the technology (Table 3) represents the grain yields from 2008-09 to 2010-11. The highest yields occurred in wide beds with residue retain. Yields tended to be lower in CT-BCW than wide or narrow beds without residue retain. Yields on raised beds consistently increased as residue retain increased from 0% to 100%, but the differences between ZT-HS and ZT-DSW PR with residue retain were not always significant for the three wheat crop cycles. This is an extremely important finding in relation to practical management of such systems by farmers.Since there is high demand of straw for fodder, fuel or building materials in the IGP, especially by small- and medium-scale farmers, it is encouraging that retaining only 50% of the straw will provide adequate benefit to the crop while the remainder can be removed for other uses.

Profitability: Profitability of wheat was remarkably higher in no-till practices with laser leveled (ZT-DSW PR and Wbed-ZTDSW) due to higher productivity and less cost of production compared to conventional tillage practices (CT-BCW). Further, the profitability was remarkably higher with residue retention compared to residue removal and the difference was more under ZT-DSWPR + M, Wbed-ZTDSW + M compared to other practices. The maximum net income was recorded with Wbed –ZTDSW + M followed by ZT-DSW PR + M and the lowest being with conventional wheat system (CT - BCW) Table 3.

Water Application and Water Productivity: The input water application includes the irrigation water applied and the rainwater during the wheat season (71 mm). The water application in wheat was remarkably lower with permanent wide and narrow beds compared to other practices (Tables 3 and 4). The higher irrigation water application in wheat under residue removal treatments as compared to residue retain plots. The savings in water use with beds with laser leveled plot and without laser leveled plot were 19.2% and 22.1% as compared to conventional seeding.

Planting System and Soil Quality: Permanent raised beds with full residue retention had a

Table 4: Water Application(mm ha-1) and Grain Yield (t ha^{-1}) in Laser-Leveled and Traditionally Leveled Field Under Different Tillage and Crop Establishment Methods of Wheat Crop at Farmers Field

Crop Establishment	Laser-aided land leveling		Traditional land leveling		Water Productivity		Net Return (Rs ha^{-1})	
	Water	Yield	Water	Yield	L.L.L.	T.L.L.	L.L.L.	T.L.L.
ZT-HS	331	5.02	444	4.60	1.52	1.04	25,710	23,055
WBedZT-DSW +M	290	5.21	363	4.86	1.80	1.34	26,675	24,360
WBedZT-DSW – M	306	5.12	387	4.79	1.67	1.24	26,215	24,010
NBedZT-DSW +M	310	5.16	392	4.75	1.66	1.21	26,420	23,810
NBedZT-DSW - M	317	5.07	402	4.67	1.60	1.16	25,960	23,410
ZT-DSW CT + M	329	5.05	421	4.64	1.53	1.10	25,860	23,260
ZT-DSW CT - M	337	4.98	430	4.60	1.48	1.07	25,505	23,060
ZT-DSW PR + M	341	5.09	449	4.77	1.49	1.06	26,060	23,910
ZT-DSW PR - M	350	5.04	459	4.73	1.44	1.03	25,805	23,708
ZT-DSW + M	357	4.93	454	4.56	1.38	1.00	25,245	22,855
ZT-DSW – M	365	4.84	464	4.51	1.33	0.97	24,780	22,605
CT-BCW	392	4.61	478	4.38	1.18	0.92	21,325	19,645
C.D. at 5%	-	0.27	-	0.36	-	-	-	-

Note: L.L.L. = Laser-aided land leveling; T.L.L. = Traditional land leveling.

significantly higher MWD compared to those with residue removal (Table 5). The effect of plant residue removal on soil structure in permanent raised beds was very clear as the MWD decreased with decreasing amounts of residues retained. Infiltration rates in the bottom of the furrow were significantly higher for conventionally tilled compared to permanent raised beds, but not on top of the raised beds. At initial time bulk density of surface layers remains lower under residue retained bed planting than under conventional tillage. This is because top of beds remains loose. The lower bulk density means more porosity especially in upper surface. The cone index was increased significantly under all the tillage and crop establishment techniques but the extent of increase was more under conventional tillage systems.

Permanent raised bed planting practices have been developed to reduce production costs while conserving resources and sustaining the environment and numerous benefits have been observed in comparison with other planting systems. Reduced tillage systems offer advantages over conventional tillage through reduction in costs and by conserving soil and water. Retention of crop residues together with zero-till permanent bed soil systems offer an important soil restorative management strategy likely to have a long-term positive impact on soil quality and crop productivity in intensive wheat growing areas in India. Lignified residual straw and roots added more organic matter and nutrients into the soils under permanent raised beds, resulting in increased nutrient uptake by

Table 5: Soil Physical Characteristics of the 0-5 cm and 5-20 cm Soil Layer After 03 Years in Tilled and Permanent Beds and Different Residue Management

Crop Establishment	Bulk Density (Mg m^{-3})	Infiltration rate (mm/h)	Cone Index	MWD (mm)	Field Capacity (% Moisture)		Permanent Wilting Point (% Moisture)	
					0-5 cm	5-20 cm	0-5 cm	5-20 cm
ZT-HS	1.57	52.2	2.54	0.40	29	30	13	12
WBedZT-DSW +M	1.54	78.6	2.44	0.46	30	32	12	12
WBedZT-DSW – M	1.56	81.4	2.46	0.43	28	30	11	11
NBedZT-DSW +M	1.55	82.3	2.49	0.45	31	32	12	12
NBedZT-DSW – M	1.58	84.7	2.51	0.41	29	30	11	11
ZT-DSW CT + M	1.53	72.4	2.57	0.37	29	31	13	11
ZT-DSW CT - M	1.54	76.3	2.60	0.34	28	29	11	10
ZT-DSW PR + M	1.55	69.5	2.59	0.42	29	31	13	11
ZT-DSW PR - M	1.58	73.4	2.63	0.38	27	29	11	10
ZT-DSW + M	1.59	55.7	2.78	0.29	29	31	13	11
ZT-DSW – M	1.60	50.3	2.79	0.23	28	29	11	10
CT-BCW	1.65	36.4	2.83	0.24	28	29	11	10
Initial	1.50	-	2.26	0.32	–	–	–	–
C D at 5%	0.09	10.62	0.17	0.06	–	–	–	–

the crops. Crop yields on beds with straw retention rose by about 12% for wheat over a 3-year cycle compared with conventional tillage on the flat beds. Retention of crop residues as a mulch reduced moisture depletion and increased SOM content over relatively short periods of time. Permanent raised beds will also help ameliorate the adverse effects of tillage on soil structure, which lead to waterlogging under excess water conditions and hamper establishment, growth and development of the crop.

CONCLUSION

Permanent raised bed planting practices have been developed to reduce production costs while conserving resources and sustaining the environment.

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