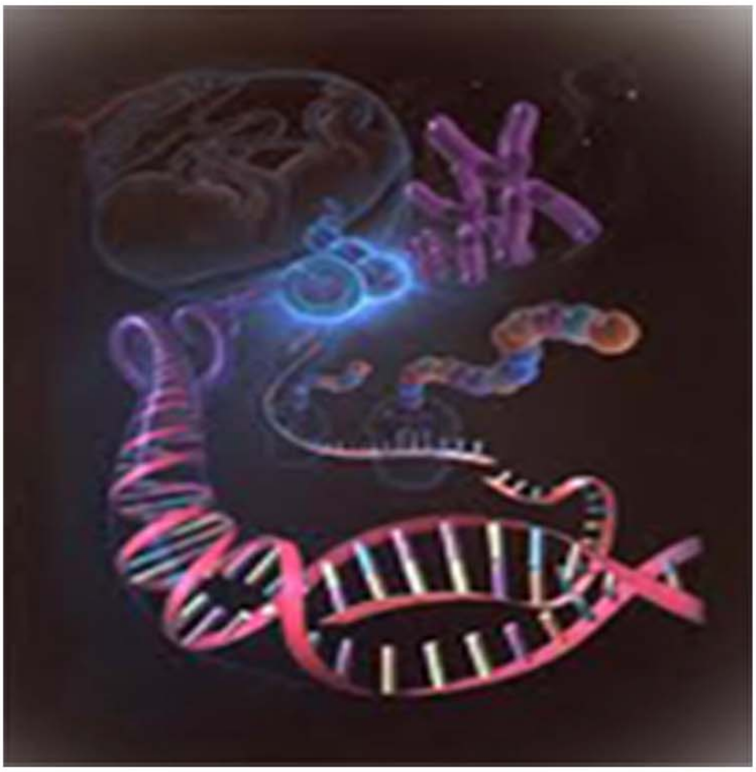
IJLBPR

ISSN 2250 - 3137
Vo1. 2, No. 2, April 2013

International Journal of Life Sciences Biotechnology and Pharma Research



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International Journal of Life Sciences Biotechnology and Pharma Research
Hyderabad, INDIA

Email : editorijlbpr@gmail.com or editor@ijlbpr.com

Int. J. LifeSc. Bt & Pharm. Res. 2013

International Journal of Life Sciences Biotechnology and Pharma Research

ISSN 2250-3137 www.ijlbpr.com
Vol. 2, No. 2, April 2013

Research Paper

EXPERIENCE WITH MANAGING RICE RESIDUES IN INTENSIVE RICE-WHEAT CROPPING SYSTEM IN NORTH- WESTERN INDIA

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Rice-wheat (RW) is the dominant cropping system in North-Western India and is of immense importance for national food security. However, the sustainability of the RW system is threatened by water shortage and nutrient mining. A field experiment was conducted over 02 years in Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, U.P., India, to compare conventional and Zero Till drill RW cropping systems, with and without retention of crop residues, in terms of crop performance and nitrogen use efficiency (NUE). The experiment investigated N management for wheat mulched with rice straw. There were eight Nmanagement treatments for the wheat mulched with rice straw, including the recommended practice (2/3 broadcast before sowing,1/3 broadcast before the first irrigation after sowing). There was also an unmulched control treatment with N applied using recommended practice. Fertiliser application with three split doses (50% drilled at sowing + 25% broadcast before the each of the first and second irrigations) resulted in significantly higher grain yield,agronomic efficiency and N recovery efficiency than all other treatments.In the presence of mulch,drilling the urea at sowing gave higher yields and efficiency than broadcasting. Zero Till drill for RW seem to have limited potential under the soil and climatic conditions of Western Uttar Pradesh, India,with current technology, even with full residue retention for both crops. Further research on Zero Till drill should focus on selection of rice and wheat cultivars;soil health issues such as nematodes and iron deficiency; weed control; N,water and residue management; and machinery development and practices.

Keywords: Productivity enhancement, Cropping systems, Sustainability, Tillage

INTRODUCTION

The Indo-Gangetic Plain (IGP), the food basket of India, is of great significance in the food security of the country It extends over a length of about 1,600 km and a width of 320 km, including the arid and semi-arid environments in Rajasthan and Punjab and the humid and perhumid deltaic plains in West Bengal (Shankaranarayana 1982). A

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decline in land productivity, particularly of the rice–wheat (RW) system, has been observed over the past few years in the northern and north-western IGP despite the application of optimum levels of inputs under assured irrigation (Paroda 1997) Reflecting this, the fertiliser recommendation has been revised upwards for both rice and wheat crops. Agriculture in north-western India has, until now,been focused on achieving food security through increased area under high-yielding varieties of rice and wheat, expansion of irrigation and increased use of external inputs like chemical fertilisers and pesticides (Yadav *et al.*, 1998) The support price system for rice and wheat crops, coupled with subsidies on fertilisers and irrigation water, made the RW system the most profitable option This enabled rice and wheat crops, covering an estimated area of around 10 million hectares (Mha), to emerge as the major cropping system in the IGP, leading to the Green Revolution These two crops together contribute more than 70% of total cereal production in India from an area of around 25 Mha under wheat and about 40 Mha under rice. With unabated increases in population, more and more land will be required for urbanisation, and productivity needs to be increased to meet the rising domestic and industrial demand. The indiscriminate use, or rather misuse, of natural resources, especially water, has led to pollution and depletion of groundwater resources (Nayar and Gill 1994). The situation is serious if it is not improved, India may face water wars in the near future. There are early signs of this already visible in the surface water dispute between Punjab and Haryana, and between some other states in India. Depleting soil organic C status, decreasing soil fertility and reduced factor productivity are other issues of concern (Yadav *et al.*, 1998). This evidence indicates that the RW system, especially residue burning, intensive tillage and injudicious use of water, has weakened the natural resource base. If exploitation of natural resources at the current level continues, productivity and sustainability are bound to suffer. Therefore, to achieve sustainable or higher productivity, efforts must be focused on reversing the trend in natural resource degradation.

CROP RESIDUES—A KEY TO SUSTAINABILITY

Crop residues could be an important component of soil fertility management. They are currently burnt, especially rice residues in the high-yielding states like Punjab, Haryana and western Uttar Pradesh leading to degradation of natural resources. Rice residues can be converted to high-value manure of a better quality than farmyard manure, and their use, along with chemical fertilisers, can help sustain or even increase yield (Sharma *et al.*, 2006). Inorganic fertilisers have played a highly significant role in intensive cropping systems, bringing about varied increases in crop production. However, with the increased use of inorganic fertilisers alone,often in an unbalanced manner, problems such as diminishing soil health and multiple nutrient deficiencies have started appearing recently in various pockets of the highly productive IGP (Fujisaka *et al.*,1994). Efficient crop residue management can play a vital role in refurbishing soil productivity as well as in increasing the efficiency of inorganic fertiliser. Residue management is receiving a great deal of attention because of its diverse and positive effects on soil physical, chemical and biological properties.Crop residues must be considered a natural resource and not a waste.

CROP RESIDUE MANAGEMENT OPTIONS

The management of crop residues must be an integral part of future tillage practices for sustainable RW production systems. There are several options available to farmers for the management of crop residues,

including burning—the common practice, baling and removal, incorporation and surface retention. Burning, in addition to promoting loss of organic matter, nutrients and soil biota, also causes air pollution and associated ill effects on human and animal health. Baling is not practised at the farmer level. Removal of crop residues, especially of wheat and scented rice, is a loss of organic sources for soil health but is necessary to feed livestock and sustain mixed farming. Incorporation is a better option but it requires large amounts of energy and time; leads to temporary immobilisation of nutrients, especially nitrogen; and the C:N ratio needs to be corrected by applying nitrogen at the time of incorporation (Sharma and Bali 1998). Farmers resort to burning as it is an easier disposal option and allows a shorter turnaround time between crops than incorporation, which is especially important between rice harvest and wheat sowing. Incorporation is also a more costly operation and, until recently, surface retention was not a viable option due to the lack of suitable machines able to seed into the loose residues left after combine harvesting.

However, two machines, i.e., Happy Seeder for seeding into loose residues and Rotary disc drill for seeding into loose residues are now available that are capable of seeding into full, surface-retained rice residues.

AVAILABILITY OF CROP RESIDUES IN THE RICE-WHEAT SYSTEM

Factual information on the availability of crop residues is not available, and what is reported is based on estimates taken from grain production

Figure 1: A View of Residue Burning

and grain to straw ratios, which vary from report to report. Thus, Pal *et al*., (1985) estimated annual total crop residue production in India of 250 Mt, of which only about one-fifth is available for energy conversion. Sarkar *et al*. (1999) estimated 356 Mt, of which one-third is available for soil incorporation or surface retention. Of the total crop residue production in India, wheat and rice together contributed about 60% (213 Mt). Recently, Pal *et al*. (2002) estimated the crop residue produced by rice and wheat crops to be 240 Mt, of which one-third is available for recycling. The total residue produced in the system was 126 Mt, of which 42 Mt is available for recycling. By taking the prevailing price, in Indian rupees (Rs), of 1 kg N as Rs. 9.35, of P as Rs. 15.40 and of K as Rs. 7.45, the fertiliser replacement value was estimated to be 3.58 billion Rs/year.

MATERIALS AND METHODS

Biophysical, Demographic, and Socio-economic Profile

Two set of experiments on different crop establishment and N fertilizer management techniques involving residue retition or residue removal were conducted under researcher-designed and farmer-managed,with a single replicate, repeated over many farmers.Initially, a baseline survey of randomly selected farmers from different villages was conducted to understand their social, economic, and educational status in addition to input use (seed, irrigation, tractor, labor, fertilizer, and pesticide use) and outputs (biological yield) in conventional farmers' practices (CTFBP-CTFBS), that is, conventional-tilled,flat beds planted (CT-FBP) and conventional till flat beds seeding (CT-FBS). The study was conducted for two years from June 2009 to May 2011 in 40 farmers' fields at Sardar Vallabhbhai Patel University of Agriculture &Technology Meerut sites in the North West India. Out of 40 farmers 61% had landholdings of <2 ha, 31% had 2 to 4 ha, and 9% had more than 4 ha. About 75% of the farmers were literate, out of which 32% were middle-school pass, 52% were high-school pass, and 21% were college pass. The literacy rate was higher for large farmers than for small farmers. The average family size was 5.4 family members for evaluation and promotion of integrated crop and resource management in the rice-wheat system in north western India per household. The large farmers usually lived in joint families, where as medium and small farmers had a separate nucleus family. Out of 216 family members of the 40 households surveyed, 49% were fully engaged in agriculture and 41% partly engaged, whereas 35% were students who also helped with agricultural activities during vacation and/or leisure periods. 35% of the farmers were members of different cooperatives existing in the area. Rice and wheat were the major source of income for 48% of the farmers, followed by sugarcane (38%), vegetables (12%), and oilseeds (9%).

Experimental 1

Layout and Treatments

On-farm trials were conducted in the RW system of western Uttar Pradesh from June 2009 to may 2011 involving 30 farmers. These trials were researcher-designed and farmer-managed,with a single replicate, repeated over many farmers. Therefore, the experimental design was an unbalanced block design in which the number of treatments varied from farmer to farmer, with the farmer as a replicate/block. The sites, treatments and management are briefly summarized 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 eight flat and bed treatments for maize-wheat system over 02 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.

Experiment II: The farmers' participatory trials on crop establishment and N fertilizer management techniques were carried out at ten locations (one farmer at each location) in Ghaziabad district for two years. On farm trials grew rice which was combine harvested prior to wheat establishment. Two straw management treatments were established at—straw retained (mulched) and straw removed (no mulch). In the 'no mulch' treatments the straw was burnt prior to sowing wheat. In the mulched treatments the loose straw in windrows from the combine harvester was distributed evenly across the plots prior to sowing with the Turbo Happy Seeder. The wheat (PBW343) was sown at 100 kg/ha with 20 cm row spacings. All treatments were direct drilled into rice residues with the Turbo Happy Seeder except the control (T_8), in which the straw was burnt prior to direct drilling according to recommended practice. Details of the N fertiliser treatments are provided in Table 2. All treatments received a total of 120 kg N/ha as urea in a range of splits (from one to three). All urea applied at sowing was drilled 5–6 cm below the soil surface the day before sowing using a hand drill, except for T_7 and T_8 which used the recommended practice of broadcasting 60 kg N/ha before sowing. The purpose of drilling the fertiliser the day before sowing was to minimise contact of the seed with high concentrations of urea and so avoid fertiliser damage. Post sowing applications of urea were broadcast immediately before the first and/or second irrigations. A basal dose of 26 kg P/ha as single super phosphate and 25 kg K/ha as muriate of potash was drilled below the seed at the time of sowing on 07 November, 2009. An area of 20 m^2 from the centre of each plot was harvested for grain and straw yield.

Table 1: Treatments in the Small Plot Replicated Experiment in Rice-wheat Crop on Sandy Loam Soil

Layout	Abbrevations	Layout	Abbrevations
T_1–Rice seeded by zero till seeddrill	ZT-DSR	T_1 – Wheat planted by turbo happy seeder	ZT-HS
T_2 -TPR on wide beds + mulch	WBed-TPR +M	T_2 - Wheat on wide beds + mulch	WBedZT-DSW + M
T_3 -TPR on wide beds – mulch	WBed-TPR – M	T_3 – Wheat on wide beds – mulch	WBedZT-DSW – M
T_4 –UP TPR in paired row + mulch	UPTPRPR + M	T_4 - Wheat planted by ZT paired row + mulch	ZT-DSW PR + M
T_5 –UPTPR in paired row – mulch	UPTPR PR – M	T_5 – Wheat planted by ZT paired row – mulch	ZT-DSW PR – M
T_6 –UPTPR in normal spacing + mulch	UPTPR + M	T_6–Wheat planted byZTnormal spacing+ mulch	ZT-DSW + M
T_7– UPTPR in normal spacing – mulch	UPTPR – M	T_{7-} Wheat planted by ZT normal spacing– mulch	ZT-DSW – M
T_8 – conventional practices	CT-TPR	T_8– conventional practices	CT-BCW

Table 2: Details of Treatments on N Fertilizer Management

Treatment	N Rate				Treatment details
	Sowing	1st Irrigation	2nd Irrigation	Straw Management	N Management
T_1 (No N)	0	0	0	Mulch	No N control
T_2	120	0	0	Mulch	120 kg N drilled at sowing
T_3	90	0	30	Mulch	90 kg N/ha drilled at sowing and 30 kg N/ha topdressed at second irrigation
T_4	60	60	0	Mulch	60 kg N/ha drilled at sowing and 60 kg N/ha topdressed at first irrigation
T_5	60	30	30	Mulch	60 kg N/ha drilled at sowing and 30 kg N/ha topdressed at first and second irrigation
T_6	30	30	60	Mulch	30 kg N/ha drilled at sowing, 30 kg N/ha topdressed at first irrigation and 60 kg N/ha at second irrigation
T_7	90	30	0	Mulch	90 kg N/ha applied as surface broadcast at sowing and 30 kg N/ha top dressed at first irrigation
T_8 (control)	60	60	0	Burn	60 kg N/ha applied as surface broadcast at sowing and 60 kg N/ha top dressed at first irrigation

RESULTS AND DISCUSSION

Avoidance of Puddling

The impact of puddling (Figure 2) for rice on the performance of wheat after rice appears to be variable, depending on site history, soil type, degree of puddling and management of the wheat crop. Aggarwal *et al*. (1995) showed that the effects of puddling on soil physical properties increase with intensity, depth and history of puddling.It may take one to several years before this significantly affects the performance of wheat when starting with a soil with no puddling history or a compacted layer. Puddling for rice induces high bulk density, high soil strength and low permeability in subsurface layers (Aggarwal *et al*., 1995), which can restrict root development and water and nutrient use from the soil profile for wheat after rice (Ishaq *et al*., 2001).The hardpan also leads to aeration stress in wheat at the time of the first irrigation after sowing, resulting in a yellowing of the leaves which is typical of N deficiency, despite the presence of adequate N in the soil. This problem is widespread in the region and may be associated with subsurface compaction or heavy-textured soils. Naresh *et al*., (2010) found that wheat grain yield decreased by 8% after the third year of puddled transplanted rice (PTR) due to the formation of a dense soil layer at 15-20 cm depth and restricted growth of roots in the lower layers. While avoidance of puddling may help improve soil structure and wheat yield, the implications for rice establishment and water use also need to be considered. However, it is well known that puddling *per se* is not a prerequisite for achieving high rice yields. In changing from puddled flat fields to direct drilled raised beds on soils with a long history of puddling (and therefore a well-developed hardpan), there is also the question of whether the hardpan should be broken by deep tillage prior to bed formation. There may be implications in doing this for water use and performance of both crops.

Crop Yields

The various tillage and crop establishment techniques had a significant effect on rice yield (Table 3). Yield were similar when rice was conventionally puddled transplanted (CT-TPR), transplanted on wide raised beds (WBedTR) unpuddled transplanted in paired rows slits after no tillage (UPTPRPR) and unpuddled transplanted in normal spacing (UPTPR) in all techniques with or without residue retained. This indicated that puddling of soil, for which normally a large amount of water and labour are required can be avoided without any penalty in rice.Treatments UPTPRPR +M, and UPTPR +M were at par with each other, however,they recorded higher grain yield over ZT-DSR treatment which recorded lowest grain yield (4.35 tha^{-1}). UPTPRPR+M yielded 6 to 11.8 % higher than unpuddled transplanting equal spacing with or without residue retained (UPTPR) and direct seeded rice by zero till drill.

The wheat grain yield t ha^{-1} resource conserving technologies when practiced as such which includes sowing earlier than conventional tillage resulted in higher wheat yield over conventional tillage over all treatments.Treatment WBedZT-DSW+M was found significantly superior to all the treatments, and recorded maximum grain yield.Grain yield increased significantly within various resource conserving technologies with mulch.Treatment ZT-DSWPR+M was significantly superior to the remaining treatments. ZTWCTM, ZT-HS, ZT-DSW +M ZT-DSW-M and ZT-DSW –M were at par with each other, however, they recorded significantly higher grain yield over CT-BCW treatment which recorded lowest grain yield. ZT-DSWPR +M or –M (paired rows) seed yields for twin-row plantings were approximately 6 to 8 % greater for equal spacing conventional practices. The crop residues retained as surface mulch (partially anchored and partially loose) @ 6.0 Mg ha^{-1} that helped in regulating the soil temperature and moisture and more response was mainly due the aberration in weather conditions during the crop growth period.

Figure 2: A View of Puddling at Meerut, Western Uttar Pradesh, India, in June 2009

Table 3: Crop Yield,Water Application and Productivity of Rice-wheat System Under Various Tillage and Crop Establishment Techniques

Crop Establishment		Grain Yield (t/ha)				Irrigation Water Applied (mm ha^{-1})				Water Productivity (kg Grain m^{-3})			
		2009-10		2010-11		2009-10		2010-11					
Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
ZT-DSR	ZT-HS	4.35	4.95	3.85	5.20	2540	350	2380	305	0.18	1.41	0.17	1.70
WBed-TPR Bed+M	WZT-DSW +M	5.48	5.12	5.07	5.53	2185	322	2070	280	0.25	1.59	0.24	1.98
WBed-TPR – M	WBedZT-DSW – M	5.20	5.05	4.87	5.15	2360	338	2225	294	0.22	1.49	0.22	1.75
UPTPRPR + M	ZT-DSW PR + M	4.93	4.70	4.86	4.85	2770	360	2595	320	0.18	1.31	0.19	1.52
UPTPR PR – M	ZT-DSW PR – M	4.83	4.65	4.59	4.72	2965	375	2780	335	0.16	1.24	0.17	1.41
UPTPR + M	ZT-DSW + M	4.65	4.61	4.47	4.67	2880	335	2698	310	0.16	1.33	0.17	1.51
UPTPR – M	ZT-DSW – M	4.52	4.43	4.33	4.50	3085	355	2885	328	0.15	1.25	0.15	1.36
CT-TPR	CT-BCW	5.65	4.30	5.35	4.45	3325	425	3115	395	0.17	1.01	0.18	1.13
C D at 5 %		5.48	5.12	5.07	5.53	-	-	-	-	-	-	-	-

Water Application and Water Productivity

The input water application includes the irrigation water applied and the rainwater during the rice season (634 mm) and wheat season (71 mm). The total water application in rice varied markedly due to tillage and crop establishment techniques (Table 3). The conventional puddled transplanted rice consumed more water (3220 mm ha^{-1}) compared to transplanted rice on wide raised beds with residue retained Wbed-TPR +M,rice seeded by zero till drill ZT-DSR and unpuddled transplanted rice in paired rows with residue retained UPTPTPR +M (2128 mm, 2460 mm and 2683 mm).The savings in water use with beds with or without residue retained was 28.8 to 33.9% compared to conventional puddled transplanted rice.Similarly, the water application in wheat was remarkably lower with permanent beds compared to other practices. The higher irrigation water application in wheat under residue removal treatments as compared to residue retain plots.The total system water use was remarkably lower with permanent beds compared to other practices but the maximum water use was recorded with CT-TPR, CT-BCW. The system irrigation water productivity under permanent beds was higher compared to other tillage and crop establishment techniques and lowest system water productivity was recorded with UPTPR – M, CT-BCW.

TOTAL SYSTEM PRODUCTIVITY

Straw retention increased productivity rapidly, starting from the second crop cycle. We believe this is an important findings because, if repeated on farmers fields, farmers will quickly realize the benefits and be more interested in adopting the technology. Total system productivity increased by 8-13% in straw retention with 80% N placement system over conventional (Table 4). Total system productivity of rice-wheat (R-W) was 11.05 t $ha^{-1}yr^{-1}$. For both crops the highest system yields occurred in full straw retained,but the differences between straw burnt and full straw retained were always significant for both the crops. Lower system productivity also occurred from straw burnt due to reduced crop growth. Yields tended to be lower in with lower levels of straw retention for both crops.

N Fertilizer Management

Grain yields ranged from 1.78 t/ha in the unfertilised treatment to 5.40 t/ha in the treatment (T_7) (Table 5). Agronomic efficiency of N (AE, kg grain/kg N applied) ranged from 14.8 to 20.4. Recovery efficiency (RE), the difference between

Table 4: Total System Productivity Under Tillage Options and Straw Levels in Rice-wheat Systems

Treatment	Crop Yield (t/ha)		
	Rice	Wheat	System
T1	1.36	1.78	3.14
T2	4.45	4.53	8.98
T3	4.65	5.15	9.80
T4	4.35	4.25	8.60
T5	4.40	4.45	8.85
T6	4.10	4.15	8.25
T7	5.65	5.40	11.05
T8 (burnt)	3.85	4.10	7.95
	C D at 5%	1.07	0.56 0.83

Table 5: Effect of Fertilizer N Management on Yield, total N Uptake, Agronomic Efficiency (AE) and Recovery Efficiency (RE) of N in Wheat

Treatment	N Management	Grain Yield (t/ha)	Straw Yield (t/ha)	Total N Uptake (kg/ha)	AE (kg grain/kg N)	RE (%)
T_1	0,0,0	1.78	2.91	32.3	–	–
T_2	120,0,0	4.53	5.16	88.4	17.7	44.8
T_3	90,0,30	5.15	5.97	87.8	19.4	47.4
T_4	60,60,0	4.25	4.84	80.2	16.3	39.7
T_5	60,30,30	4.45	5.12	85.6	17.9	38.6
T_6	30,30,60	4.15	4.73	82.3	16.9	35.8
T_7	90,30,0	5.40	6.26	75.8	20.4	48.7
T_8 (burnt)	60,60,0	4.10	4.67	86.9	14.8	43.2
LSD (0.05)	-	0.56	0.92	8.3	2.9	3.1

N uptake in the fertilised and control treatments as a percentage of the amount of fertiliser N applied, ranged from 35.8 % to 48.7 %. Grain and straw yields and total N uptake were significantly increased with N application over the no N control, and trends in total N uptake were similar to trends in yield (Table 5). Grain yield, total N uptake and RE with the recommended practice (T_8, with straw burnt and 60 kg N/ha broadcast at sowing and before the first irrigation) were significantly lower than with the 90 kgN/ha broadcast at sowing and 30 kgN/ha before first irrigation in the presence of residues (T_7). However, drilling the 1st 60 kg N/ha at sowing in the presence of rice residues (T_4) restored yield and N uptake to similar values to the control. These data suggest greater immobilisation or N losses from surface-applied N in the presence of straw than when the straw was burnt before sowing, which is consistent with the findings of others (Patra *et al*., 2004). Drilling part of the fertiliser below the soil surface at sowing may have reduced these losses due to reduction in fertiliser N contact with straw (Rao and Dao 1996). Despite this,Sidhu *et al*., (2007) found an average 9-15% higher yield of wheat with the Happy Seeder sowing into rice residues, with the fertiliser broadcast at sowing and before the first irrigation, compared with farmer practice (conventional tillage after burning, where as we used zero tillage in (T_8) in the adjacent field. Grain yield of T_3 and T_7 was usually significantly higher than all other treatments. As with grain and straw yield and N uptake, AE and RE were highest in T_3 and T_7 and lowest in T8. There are several possible reasons for the superior performance of the triple split with the last application delayed to the time of the second irrigation. These include greater canopy cover and reduced presence of mulch due to decomposition, and reduction of the potential for N immobilisation and ammonia volatilization. Drilling all the fertiliser N at sowing (T_2) resulted in grain yield similar to that of the recommended practice of applying N in two equal split doses at sowing and with the first post-sowing irrigation (T_4). When the amount of N drilled at sowing was reduced to 30 kg N/ha, with 30 and 60 kg N/ha before the first and second irrigations, respectively, grain yield was reduced significantly in comparison with T_3 and T_7. These results suggest that delaying half the N fertiliser application until the second irrigation is too late.

CONCLUSION

It has been widely reported that crop residue retention on the soil surface has many benefits. It conserves soil moisture, moderates temperature, suppresses weeds, improves soil physico-chemical properties and helps make the system sustainable. The results from Western Uttar Pradesh, both in research station experiment and trials in farmers' fields, show similar or slightly higher yields with residue retention. The potential benefits in terms of cost reduction, timeliness of planting and similar or higher yield are proving to be of interest to farmers in India's north-western states.Moreover, further intensive investigations are required on the size of residue load that can be sustained for a long time, as well as the potential effects on insect pests, diseases and weeds, if any. Researchers working with residue retention must remain vigilant and should adopt an interdisciplinary approach to address the issue of residue management in a holistic manner. Results to date suggest that raised beds have the potential to enable diversification and increase the productivity of cropping systems in NW India through growing a much wider range of crops in the monsoon season and increasing yields of waterlogging sensitive crops by irrigation. These results also suggest significantly reduced irrigation water requirements for crops on beds, saving costs and energy, although whether this is a real water saving is yet to be determined.

ACKNOWLEDGMENT

We are greatly acknowledges to the Director of Research of the Sardar Vallabhbhai Patel University of Agriculture and Technology Meerut U.P. for providing facilities and encouragement. Also, Uttar Pradesh Council of Agricultural Research, Lucknow deserve thanks for their financial assistance under the project "Resource Conservation Technologies for Sustainable Development of Agrculture". Sincere thanks are due to the members of farmers group of Meerut and Ghaziabad districts for their kind efforts and active participation throughout the study periods.

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ISSN 2250-3137