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Effect of direct seeded rice on yield, water productivity and saving of farm energy in reclaimed sodic soil

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ABSTRACT

A field experiment was conducted on conventional rice transplanting (TPR) and direct seeded rice (DSR) in different sets of crop establishment technique with the objective to examine water productivity and save the natural resources. The basmati rice (CSR30) produced maximum grain yield in TPR with and without residue incorporation (3.72 and 3.68 t ha^{-1}, respectively) followed by DSR without residue (3.67 t ha^{-1}). DSR with sesbania co-culture yielded 3.50 t ha^{-1}. High yielding Pusa 44 produced maximum grain yield in TPR with residue incorporation (7.66 t ha^{-1}) followed by TPR without residue (7.40 t ha^{-1}). There was no significant difference in yield of puddled and un-puddled transplanted rice. DSR in wheat stubbles resulted minimum yield (4.54 t ha^{-1}). DSR with sesbania brown manuring yielded 5.79 t ha^{-1}. Water productivity was more in DSR compared to TPR. The maximum water saving (39.4%) was recorded in DSR with sesbania co-culture. Water productivity of rice Pusa 44 was 0.45 kg m^{-3} when grown in DSR without crop residue while it was 0.43 kg m^{-3} with sesbania co-culture. The maximum water saving was 32.3% in DSR with sesbania. In case of permanent raised bed, rice transplanting saved 23.3% irrigation water. DSR in different combinations saved irrigation water 30.2%, reduced diesel consumption by 42% in reduced tillage method and by 86% in zero tillage in comparison to transplanted rice. DSR technology reduced labour requirement by 24% in reduced tillage and 30% in zero tillage, whereas power saving in DSR was more than 29%.

1. INTRODUCTION

The Indo-Gangetic plain (IGP) is of great importance for food security of India as well for South Asia. It is spreading from the arid and semi-arid environment of Rajasthan and Punjab to humid and per-humid deltaic plain of West Bengal (Shankaranarayana, 1982). It is estimated that the demand of milled rice will increase at the rate of 25% per decade at global level. The major challenge is to achieve this goal with less water, labour and chemicals; thereby ensuring long term sustainability. It owed due to the indiscriminate use, or rather misuses of natural resources, especially irrigation water and has led to the pollution and depletion of groundwater resources (Nayar and Gill, 1994). Intensive tillage and residue burning has led to depletion of soil organic carbon resulting in decreased soil fertility and reduced factor productivity (Yadav, 1998). Continued intensification of input-use since the green revolution, has provided lower marginal returns (Ladha *et al.,* 2000). In addition, inappropriate use of applied inputs and over exploitation of natural resources, like land and water leading to degradation in the form of salinization, water-table depletion, physical and chemical deterioration of the soil, *etc.* (Byerlee, 1992 and Murgai *et al.,* 2001). A decline in land productivity 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). Although tillage has been considered an integral part of traditional production system (Reicosky, 2008), but it is also a principal practice resulting into soil perturbation and subsequent modification of the soil structure and soil organic carbon dynamics. Improved agricultural practices such as direct seeding or conservation tillage have the potential to sequester more carbon (C) in soil than conventional practices. In recent years, due to continuous energy crisis and increasing fertilizer prices, green manuring has been considered as a sound practice for enriching soil fertility. Indiscriminate use of high chemical fertilizers resulting in deficiency of nutrients other than the ones applied and causes decline in the organic carbon content (Singh *et al.,* 1999). Kumar and Prasad (2008) also observed that application of green manure along with chemical fertilizers resulted higher organic carbon status and reduced the gap between potential and actual yield to a large extent. The benefits of green manuring of different materials under rice-wheat cropping system have been reported by several scientists (Prasad *et al*., 1995, Bhandari *et al*., 1992, Hundal *et al*., 1992, Singh *et al*., 1999. and Singh *et al*., 1991). To achieve sustainable and higher productivity, efforts must be focused on reversing the trend of reducing natural resource degradation. Moreover, due to rising prices of inputs, it is imperative to develop technologies which save inputs and increase the profit margins of the farmers. Now, it is great concern to achieve the potential level of productivity growth and long term sustainability of rice-wheat system. Proper crop residue management has potential to minimize adverse effects on environment. In view of the problems mentioned above, the present study was undertaken on reclaimed sodic soil with a view to evaluate various resource conservation options for reducing environmental hazards enhancing resource use efficiency and increasing productivity of important crops for sustainability of agriculture in IGP.

2. MATERIALS AND METHODS

Experimental Site

A field experiment was carried out for 4 years at the Research Farm of ICAR-Central Soil Salinity Research Institute Karnal, India ($29^0 43'$N and $76^0 58'$E, 245 m above msl). Basmati rice variety CSR30 was grown during the year 2006 and 2007 whereas rice variety Pusa 44 grown in 2008 and 2009 under rice-wheat cropping system. The soil was deep alluvial sandy loam with low organic carbon content of 0.42%. The surface soil layer (0-15 cm) comprised of 649.4, 163.0 and 187.6 g kg^{-1} sand, silt and clay, respectively. The soil was reclaimed sodic soil (pH 8.0-8.2) having steady state infiltration rate (3.5 mm h^{-1}) with available N, P, K of 100, 18.3 and 165.5 kg ha^{-1}, respectively.

Experimental Setup

The experiment was conducted in randomized block design (strip plot) with 10 tillage options during 2006 with rice and wheat crops replicated 4 times. Tillage treatments in rice followed by wheat crop were T_1= Conventional rice transplanting (TPR)/conventional wheat sowing; T_2= TPR after wheat residue incorporation/wheat sowing after rice residue incorporation; T_3= Direct seeded rice (DSR)/wheat in reduced tillage; T_4= DSR after wheat residue incorporation/wheat in reduced tillage after rice residue incorporation; T_5= DSR in zero tillage/wheat in zero tillage; T_6= DSR in zero tillage with wheat residue/wheat in zero tillage with rice residue ; T_7 = TPR on raised beds/wheat sowing on permanent raised beds; T_8 = TPR in un-puddle field/wheat sowing on fresh beds; T_9 = DSR + sesbania (brown manuring)/wheat sowing in zero tillage; and T_{10}= TPR after sesbania green manuring/wheat sowing in zero tillage. The experiment was conducted in fixed plots size of 1000 m^2 each imposing same treatments for each cropping sequence. Among the two widely growing crops (rice and wheat), rice is considered to be the higher energy and water consuming crop. Basmati rice CSR30 and Pusa 44 varieties were grown with recommended package of practices. DSR was sown in the last week of May and first week of June; however, transplanting was done in the last week of June and first week of July with similar package of practices in respective treatments, 90 kg N ha^{-1} in basmati CSR30 and 150 kg N ha^{-1} in Pusa 44 along with 60 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1} and 30 kg $ZnSO_4$ ha^{-1}. Nursery of basmati CSR30 and Pusa 44 was raised in the last week of May/first week of June during each year. Dhaincha (*Sesbania aculeata*) was sown in the last week of May and first week of June in respective treatment. Nitrogen, phosphorus, potassium and zinc were applied in the form of Urea, Di-amonium phosphate (DAP) muriate of potash and Zinc Sulphate, respectively. One third dose of the recommended nitrogen and full dose of phosphorus and zinc were applied at the time of transplanting and sowing in respective techniques. Remaining dose of nitrogen was applied in two equal doses as a top dressing at 30 and 60 days after transplanting/seed sowing. In transplanted rice none of the chemical was used to control weeds. However, in DSR, weeds were controlled chemically twice during the growing season. Seed sowing of rice was done using seed drill machine. Foremost, herbicide, STOMP (Pendimethalin) @ 2.5 lit ha^{-1} was used after first irrigation (2 or 3 days after rice sowing). Irrigation was applied in transplanted rice one day after disappearance of pounded water except early 20 days, in which maintained submergence conditions required for the establishment of seedlings after transplanting. However, in DSR irrigation was applied 4 days after disappearance of pounded water and soil surface showed minor cracks. The rice crop was harvested in the last week of October. Statistical analyses for individual parameters were performed using MSTAT-e procedures.

Irrigation Water Use

The irrigation water was measured with the help of water meter fitted in the water supply system in liters per unit time and the database was used for computation of water productivity and water saving in respective crop establishment techniques.

Diesel Consumption

The actual consumption of diesel in operating tractor for nursery bed preparation, field preparation before transplanting, puddling, sowing of rice using seed drill machine in DSR techniques was measured. The amount of diesel leftover after a single operation in a specified field at a unit time depicted the actual diesel consumption for that single specified operation.

Human Labour Use

The labourers required in terms of mandays (8 hours) for a particular operation were counted throughout the crop season.

Electricity Consumption

The electricity consumption to irrigate treatment was computed by recording the units hr^{-1}.

3. RESULTS AND DISCUSSION

Rice Productivity in TPR and DSR

The results of two years for CSR 30 and Pusa 44 grown under alternate tillage and crop establishment techniques, presented in Table 1 and Fig. 1, show that the highest rice grain yield of basmati CSR30 was obtained in conventional practice (T_1) compared to DSR in zero tillage without wheat residue (T_5), DSR in zero tillage with wheat residue (T_6), rice transplanting on raised bunds (T_7) and rice transplanting after sesbania green manuring (T_{10}). However, the grain yield of rice in conventional rice transplanting with wheat residue incorporation (T_2), DSR in reduced tillage without wheat residue incorporation (T_3), DSR in reduce tillage with wheat residue (T_4), rice transplanting in un-puddled condition (T_8), and DSR with sesbania brown manuring (T_9) was almost at par to the TPR. However, data shown in Table 1 reveals that Pusa 44 yielded maximum in TPR with residue incorporation (7.66 t ha^{-1}) followed by TPR without residue (7.40 t ha^{-1}). There was no significant difference in yield of puddled and un-puddled transplanted rice. DSR in standing wheat stubble resulted minimum yield (4.54 t ha^{-1}), whereas DSR with sesbania brown manuring yielded 5.79 t ha^{-1}. Further, rice transplanted on raised beds yielded less (5.18 t ha^{-1}) because of less plant population per unit area. Pusa 44, high yielding rice variety grew well both in transplanted and DSR techniques under different methods, but this variety was associated with profuse weed growth and erecting growth behaviour allowed more sun light on soil surface and promotes the weed germination and fast growth relatively during the growing period particularly in the beginning stage between seed germination and 40 days after sowing. *Vice-versa* growth behaviour of CSR 30 was noticed with droopy leaf growth and covered the soil surface within 30 days after sowing and suppressed the incoming weeds with higher growth. Basmati rice, in DSR technique yielded at par with transplanted rice. Basmati

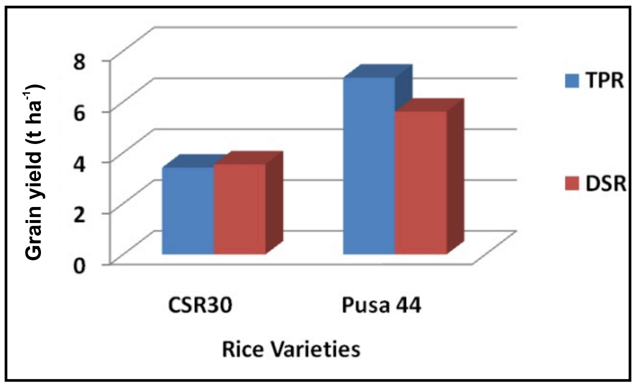

Fig.1. Average grain yield of rice during 2006-2007 (Basmati CSR 30) and 2008-2009 (Pusa 44) in TPR and DSR techniques

Table: 1
Water productivity and saving of irrigation water in DSR and TPR techniques

RCTs	Grain yields* (t ha^{-1})		Water applied (m)		Rainfall (m)		Water Productivity (kg m^{-3})		Irrigation water saving (%)	
	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009
Variety of rice	CSR 30	Pusa 44	CSR 30	Pusa 44	CSR 30	Pusa 44	CSR 30	Pusa 44	CSR 30	Pusa 44
CVT	3.72	7.40	1.27	1.23	0.28	0.41	0.24	0.45	-	-
CVT+WR	3.68	7.66	1.27	1.23	0.28	0.41	0.24	0.47	-	-
DSR	3.67	6.07	0.78	0.83	0.35	0.49	0.32	0.45	35.5	30.2
DSR+ WR	3.45	5.67	0.83	0.83	0.35	0.49	0.30	0.43	35.1	30.2
DSR -ZT	3.32	6.00	0.82	0.86	0.35	0.49	0.29	0.45	35.9	30.2
DSR-ZT+WR	3.29**	4.54	0.83	0.86	0.35	0.49	0.29	0.33	35.1	29.4
PRB(TPR)	3.15	5.18	0.97	0.84	0.28	0.41	0.29	0.39	24.0	23.3
Un-PDL(TPR)	3.49	7.16	1.25	1.21	0.28	0.41	0.23	0.44	01.2	1.25
DSR (S. in rice)	3.50	5.79	0.77	0.83	0.35	0.49	0.33	0.43	39.4	32.3
TPR- (after GM in rice)	2.82**	7.28	1.21	1.21	0.28	0.41	0.19	0.45	4.7	2.85
LSD (P=0.05)	0.35	0.32	-	-	-	-	-	-	-	-

* Grain yield at 14% moisture; **Crop was damaged due to lodging; Mean of two year (2006-2007) for basmati CSR30 and 2008-2009 for Pusa 44; CVT= Conventional; CVT+WR= Conventional with wheat residue; Un-PDL-T= Un-puddled rice transplanting; TPR (after GM in rice)= Transplanting after green manuring. DSR= Direct seeded rice in reduced tillage; DSR+WR = DSR in reduced tillage with wheat residue; DSR+ZT= DSR in zero tillage; DSR +ZT+WR =DSR in zero tillage with wheat residue; DSR (S. in rice) = DSR + sesbania intercropping; PRB (TPR)= Permanent raised beds transplanting.

rice, CSR 30 can be grown successfully both by DSR and TPR methods.

Water Productivity in TPR and DSR

The results shown in Table 1 and Fig. 2 revealed that water productivity of basmati CSR30 was different under different tillage practices and crop establishment techniques. In TPR it varied from 0.19 to 0.33 kg m^{-3}. The lowest water productivity was recorded in those techniques where rice grown under TPR practice and it ranged from 0.19 to 0.24 kg m^{-3}. In DSR method, higher water productivity recorded (T_3, T_4, T_5, T_6, and T_9 treatments), varied from 0.29 to 0.33 kg m^{-3}. Among the DSR techniques, sesbania brown manuring (T_9) saved maximum irrigation water (39.4%) along with higher grain yield (3.50 t ha^{-1}) and water productivity (0.33 kg m^{-3}). The maximum use of water was in T_8 treatment where transplanting was done in unpuddled condition. The lowest volume of irrigation water was required in DSR method (T_3, T_4, T_5 and T_6) as compared to TPR. This was due to early sowing of direct seeded rice (in the last week of May month). Table 1 further shows that Pusa 44 variety produced relatively higher grain yield (7.38 and 5.61 t ha^{-1}) along with higher water productivity (0.45 and 0.42 kg m^{-3}) both in TPR and DSR techniques, respectively as compared to basmati CSR 30. Water productivity of Pusa 44 in DSR varied from 0.33 to 0.45 kg m^{-3} and was lower as compared to TPR techniques (0.44 to 0.47 kg m^{-3}). In case of Pusa 44, maximum water saving was

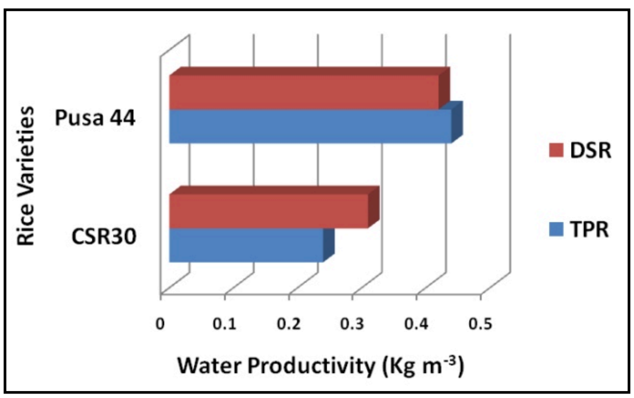

Fig. 2. Average water productivity of rice during 2006-2007 (Basmati CSR30) and 2008-2009 (Pusa 44) in TPR and DSR techniques

in DSR sown with sesbania brown manuring (32.2%) as compared to TPR. Water saving in DSR techniques ranged from 35.1 to 35.5%. It is clear from the results that rice variety Pusa 44 is better in TPR in comparison to DSR (Annonymous, 2007 and 2009).

Rice Productivity Under Crop Residue Management

Results of the study, presented in Table 2, showed that the grain yield of rice variety basmati CSR 30 was higher in first two years when grown without residue. Basmati CSR 30 grain yield decreased in those techniques where crop residue added either through incorporation or crop residue retained on soil surface. Rice grain yield decreased in first two years may be due to microbial activities and their growth enhancement as well as nutrient immobilization. Grain yield decreased by 1.08% in conventional rice with wheat residue. In case of DSR with 50% reduced tillage and wheat residue yield reduction was 5.99%. This was due to high weed infestation and nutrient immobilization because of microbial activities. However, wheat residue on soil surface in zero tillage, grain yield did not decrease and positive effect of crop residue observed on productivity. It indicates that DSR in 50% tillage with wheat residue incorporation grain yield reduced in comparison to DSR with wheat residue retention due to more weed infestation.

Similarly, rice high yielding variety Pusa 44 produced higher yield than that of basmati CSR30 after two years when grown in continuous series. Crop residue incorporation in transplanted rice yielded 3.51% more grain in comparison to conventional transplanting method. DSR in reduced tillage and zero tillage with wheat residue reduced yield potential by 6.59 and 25.04%, compared to DSR without wheat residue, respectively. The results obtained during four years revealed that yield of basmati CSR30 was better than Pusa 44 both in DSR and transplanted methods. Further, it was observed that rice grain yield increased with continuous addition of wheat residue in TPR and DSR. Pusa 44 yielded better in transplanting method than direct seeded rice (Anonymous, 2007 and 2009).

Water Saving in DSR Technique

Results obtained on water saving in TPR and DSR methods under different crop establishment techniques

Table: 2
Rice grain yields under different tillage intensities and crop residue management

RCTs	Without crop residue management Grain yield (t ha^{-1})		With crop residue management* Grain yield (t ha^{-1})		Grain yield increase/decrease (%)	
2 Years mean	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009	2006 & 2007	2008 & 2009
Rice varieties	CSR 30	Pusa 44	CSR 30	Pusa 44	CSR 30	Pusa 44
Conventional tillage with TPR	3.72	7.40	3.68	7.66	-1.08	3.51
50% reduced tillage with DSR	3.67	6.07	3.45	5.67	-5.99	-6.59
Zero tillage with DSR	3.32	6.00	3.29	4.54	-0.90	-24.33
Mean	3.57	6.49	3.47	5.96	-2.69	-9.14
LSD (P=0.05)	0.34	0.36	0.34	0.36	-	-

*Crop residue added to both rice and wheat crops @ 5.0 t ha^{-1}

(Table 1) depict that maximum water saving was in DSR method with sesbania co-culture (T_9) followed by T_3, T_5, T_4 and T_6 DSR methods. Singh *et al.* (2008) reported that traditionally rice is transplanted after puddling which requires huge quantity of water and labour. It also affects the soil health due to dispersion of soil particles, increase in soil compaction and makes tillage operation difficult in succeeding crop and required much energy. Basmati CSR30 in DSR with sesbania, produced higher grain yield, higher water productivity and saves 39.4% of irrigation water. Pusa 44 saved maximum irrigation water (32.3%) when sown in DSR with sesbania brown manuring, produced significantly less grain yield (Table 1).The possible reason of lower grain yield was weed infestation in DSR with sesbania technique. Among DSR techniques in Pusa 44, saved irrigation water between 29.2 to 30.2%.

Diesel Saving in DSR Techniques

The requirement of diesel for various techniques of rice production was calculated and presented in Table 3. It is observed that maximum diesel consumption was in conventional tillage (48.0 lit ha^{-1}) where field preparation required ploughing and puddling before rice transplanting. In DSR method puddling was not required and less quantity of diesel consumed being 28 lit ha^{-1} in reduced tillage and 6.7 lit ha^{-1} in zero tillage. The saving of diesel consumption was 42% in DSR with reduced tillage and 86% in zero tillage when rice transplanting was done on permanent raised bed without tractor operations and without tillage in which no diesel was required.

Labour Saving in DSR Techniques

The actual labour requirement in different rice crop establishment techniques was recorded and is presented in Table 3. The rice is labour intensive crop and acute shortage of labour observed mainly at the time of transplanting and harvesting. Maximum number of labour man days was recorded in conventional tillage method at the time of rice transplanting and harvesting. In TPR technique, 105 mandays ha^{-1} labour required in field preparation for nursery, maintaining and uprooting of nursery, transplanting in the field, irrigation, harvesting, threshing, storing *etc.* In DSR technique labour requirement was less as puddling process is totally escaped and no transplanting required. There was 84 labour man days required ha^{-1} in DSR and 75 man days ha^{-1} in zero tillage. The labour saving was 24% in DSR and 30% in zero tillage.

Electricity Saving in DSR Techniques

Consumption of electricity in different crop establishment techniques is given in Table 3. The number of irrigations was more in TPR and electricity consumption was maximum (2.35 KW ha^{-1}), whereas DSR required less electricity as compared to the TPR. Electricity consumption in DSR with and without crop residue was 1.66 KW ha^{-1}. Electricity consumption in DSR with zero tillage with and without crop residue was 1.66 KW ha^{-1}, while in permanent raised bed technique it was 1.41 KW ha^{-1} because of less requirement of irrigation water. The DSR technique of rice cultivation saved electricity by 29.4% in comparison to TPR, whereas in permanent raised bed system of rice cultivation electricity saving was 40%.

4. CONCLUSIONS

Direct seeded rice is a promising option for sustainable rice production in reclaimed alkali soil of India. Rice transplanting on raised bed provided significantly less yield but saved 24% irrigation water. Yield of direct seeded basmati rice (CSR30) was at par to the TPR in different crop establishment techniques and saved 35% irrigation water. Water productivity of basmati CSR30 rice variety was more in DSR compared to transplanted rice. Water productivity of Pusa 44 variety of rice was higher in DSR and TPR in comparison to basmati CSR30 variety. The maximum water saving was in DSR with sesbania co-culture as a brown manuring (39.4% in CSR30). Water productivity of Pusa 44 variety of rice ranged from 0.33 to 0.47 kg m^{-3} and it was 0.45 kg m^{-3} in DSR (without crop residue incorporation), while it was 0.43 kg m^{-3} when grown with sesbania co-culture. The maximum water saving of irrigation water was 32.3% in DSR with sesbania co-culture. Basmati CSR30 and Pusa 44 yielded better in zero tillage in comparison to zero tillage with wheat residue retention in DSR. Pusa 44 in DSR method with different combinations saved water by

Table: 3
Saving of diesel, electricity and human labour in DSR as compared to TPR techniques in rice cultivation

RCTs	Diesel used (lit ha^{-1})	Diesel saving (%)	Electricity used in irrigation (KW)	Saving in electricity (%)	No. of labours (ha^{-1})	Labour saving (%)
CVT	48	-	2.35	-	105	-
CVT+WR	48	-	2.35	-	105	-
DSR	28	42	1.66	29.4	80	24
DSR+ WR	28	42	1.66	29.4	80	24
DSR -ZT	6.7	86	1.66	29.4	75	30
DSR-ZT+R	6.7	86	1.66	29.4	75	30
PRBT	0.0	-	1.41	40.0	95	9.5
Un-PDL-T	38	21	2.35	-	100	0.5
DSR (S. in rice)	38	21	1.66	29.4	80	24
Trans (GM in rice)	48	-	2.35	-	105	-

30.2 to 32.3% while CSR30 saved irrigation water by 35.1 to 39.4%. Diesel saved by 42% in reduced tillage and by 86% in zero tillage when grown as DSR. Labour saved by 24% in reduced tillage and 30% in zero tillage under DSR techniques. DSR technique saved 29% electricity in pumping of water for irrigation of rice crop. The DSR is also promising for those areas where less irrigation water is available for rice. Crop residue incorporation in transplanted plots yielded 3.51% more grain yields in comparison to conventional transplanted plots. Basmati CSR 30 yielded better than Pusa 44 rice variety both in DSR and TPR methods in reclaimed alkali soil. Rice grain yield was increasing with continuous addition of wheat residue both in TPR and DSR methods of crop production.

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