Open Access

International Journal of Agricultural and Applied Sciences, December 2020, 1(2): 34-44
https://www.agetds.com/ijaas
ISSN: 2582-8053
https://doi.org/10.52804/ijaas2020.125

Research Article

Yield and economic advantage of direct seeded rice: empirical evidence from Nepal

Santosh Marahatta

Agriculture and Forestry University (AFU), Rampur, Chitwan, Nepal
**Corresponding author e-mail: smarahatta@afu.edu.np*
(**Received:** 30/08/2020; **Revised:** 12/09/2020; **Accepted:** 28/09/2020)

ABSTRACT
Puddled transplanted rice (TPR) has been gradually replaced by direct-seeded rice (DSR) because of its low labor requirements and less cost of cultivation. Whether and how DSR can be as productive and profitable as TPR has received widespread attention. Thus a comprehensive analysis was made to quantify the effects of direct seeding on rice yield and profitability under different tillage, residues, varieties, and nitrogen management options. The results revealed that, overall, the yield of DSR was 2.4% lower than that of TPR due to a significant reduction in the number of grains per panicle and a significant increment of sterility percentage. However, the yield loss of DSR relative to TPR was highly variable depending on different tillage and residue management options, ranging from yield advantage of +6.0% to yield penalty of 16.0%. The yield gap between CT-DSR and TPR could be narrowed by not incorporating the residues while more yield could be obtained with the residues retention on the ZT-DSR. Among the different forms of the DSR, ZT with residue retention and CT without residue retention were better in terms of profitability. Adoption of improved or hybrid varieties played the less important role in yield gain and loss under DSR. With respect to nitrogen levels, the yield penalty was eliminated by the higher nitrogen application (>120 kg N ha-1) resulted in the yield advantage of 6.6% for the DSR as compared to the puddled TPR. In conclusion, DSR could produce comparable yields and more profits to TPR, but special attention should be given to optimizing management practices to improve DSR yield performance and narrow down the yield gap. Therefore, there is an urgent need to test, verify, and scale-out the DSR technologies across the different agro-ecologies of Nepal through a farmer-centered partnership among the international institutions, public and private sectors of Nepal.
Keywords: direct-seeded, puddled transplanted, rice yield advantage, economic advantage of DSR

INTRODUCTION
Rice is the most important staple food crop in Nepal both in terms of area (1.46 million ha) and production (5.55 million tons) (MOF, 2020). Rice provides 50% of the total calorie requirement to the Nepalese population (Kharel et al., 2018) and contributes 13.85% to the agriculture gross development product (AGDP) (MOF, 2017). It is grown throughout all agro-ecological regions from terai plains to the high hills up to 3050 maslincluding valleys and foothills (MoAD, 2015). Rice is the major cereal crop of the terai and inner terai (occupy 67.87% of total area). The national average yield of rice (3.69 t ha-1, based on three years average ending in 2019/20) (MOF, 2020)is far below the attainable yield of >8.0 t ha-1, indicating the huge yield gaps. Current rice production of 4.46 million ton is not sufficient to meet the current national demand of 5.26 million ton and by 2030 the rice production must be increased by 1.03 million ton which is equivalent to an overall increase of 22.59% in the coming next 11 years (CBS, 2014; MOF, 2017; Prasad et al., 2011; Tripathi et al., 2018). As the possibility of expanding the area under crops in the future is very limited, the required extra production has to come through an increase in productivity. Under the declining water, labor and increasing cost of production meeting such targets are challenging. Thus the new rice cultivation technology must be developed to address the scarce resources of labor and water by reducing the simultaneously while maintaining the yield potential (Yuan et al., 2017).
Rice is often grown by transplant seedlings into puddled soil. Puddling advantages rice by reducing water percolation losses, managing weeds, facilitating

simple seed plant establishment, and making anaerobic conditions to boost nutrient convenience (Kaur and Singh, 2017). But, continual puddling adversely affects soil physical properties by destroying soil aggregates, reducing porousness in subterranean layers, and forming hard-pans at shallow depths (Aggarwal et al., 1995; Sharma et al., 2003) and the chemical properties reducing the soil organic matter and biodiversity (Biamah et al., 2000). These adverse effects would ultimately hamper the succeeding non-rice crop(Hobbs and Gupta, 2000; Tripathi et al., 2005). Crop establishment consists of four basic following steps: (a) nursery bed preparation, (b) seedling raising, (c) seedling uprooting, and (d) transplanting seedlings into the main field (Xu et al., 2019). The puddled transplanting requires large quantities of the water (1200 liters) to produce 1 kg of rough rice (Morisonet al., 2008) whereas, the per capita water availability decreased significantly till now and predicted to decrease by about 28% by 2050(Bhatt and Kukal, 2015).These practices are highly labor- and water-intensive and becoming less profitable, as these resources are being increasingly scarce. Further puddling and transplanting delay rice transplanting up to three weeks as it demands a large volume of scarce water resources, which further delays the sowing of succeeding non-rice crops in the system. Direct seeded rice (DSR) has emerged as a suitable and sustainable alternative technology to deal with water- and labor-shortages (Sun et al., 2015). Commonly in direct-seeded rice (DSR) pre-germinated or dry rice seeds are broadcasted/drilled into the conventionally tilled field that saved large amounts of scarce resources like water and labor (Ladha et al., 2003).There are three principal methods of DSR: dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddle soils), and water seeding (seeds sown into standing water) (Akhgari and Kaviani, 2011). In recent years, DSR cultivation has been increasingly adopted by farmers in many traditional TPR regions in south Asia (Sun et al., 2015), however, the area of direct seeding is limited to upland rice culture. Due to the efforts of research activities by the International Rice Research Institute (IRRI), International Maize and Wheat Research center (CIMMYT), Nepal Agriculture Research Council (NARC), Agriculture and Forestry University (AFU), Institute of Agriculture and Animal Science (IAAS) and international and national non-governmental organizations (I/NGOs) on the transformation on cultivation practices of rice has stimulated the governments' concerns.

To determine the yields and economic advantages of DSR, series of field experiments at Agronomy Research Block of AFU and the Institute of IAAShavebeen conducted to determine yield differences between DSR and TPR at Rampur, Chitwan, Nepal. Some studies have indicated that the DSR yieldsare equivalent, or even higher than the TPR yield and should, therefore, be widely promoted to farmers because of high net economic returns (Bhushan *et al*., 2007; Liu *et al*., 2014). However, this viewpoint has been challenged by several different studies, that observed apparent yield losses (Chen *et al*., 2017). These conflicting results may be due to variations in ecological and management factors, i.e. soil and climatic conditions, tillage method, weed control, residue management, and nitrogen input(Xu *et al*., 2019). Due to these uncertainties, a comprehensive analysis to synthesize the results of previous studies at AFU and IAAS to evaluate the yield, and economics between DSR and TPR. However, due to some extent of management practices and annual variations on the weather factors, the yield performance of DSR and TPR is still ambiguous.

MATERIALS AND METHODS

Site description

Ten different field experiments were done in the Agronomy Research Block of AFU and IAAS at Rampur, Chitwan located in the central Terai region of Nepal (27^{o}40′ N latitude, 84^{o}19′ Elongitude, and 228 masl) during the rainy season of 2010-2019. The experimental site lies in the subtropical humid climate belt of Nepal with the predominant of sandy loam soil. The area has a sub-humid type of weather condition with cool winter, hot summer, and a distinct rainy season with an annual rainfall of about 2000 mm. The weather data during the cropping seasons were recorded from the metrological station of the National Maize Research Program (NMRP), Rampur, Chitwan (Figure 1).

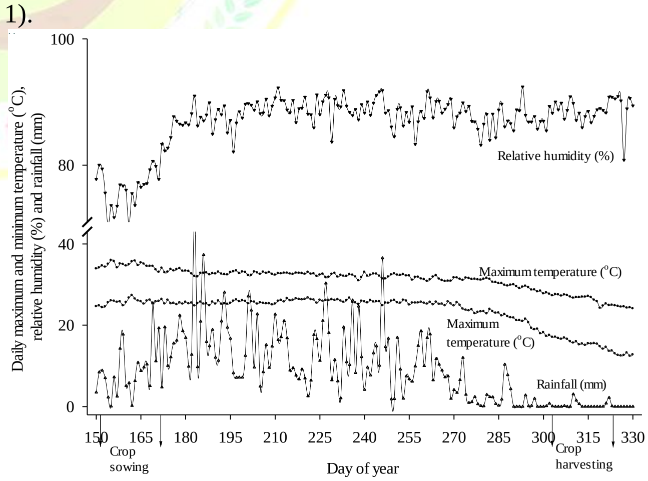


Figure 1. Daily maximum and minimum temperature (^{o}C), relative humidity (%), and rainfall (mm) of the experimental site (average of ten years, 2010-2019) during the experimental period

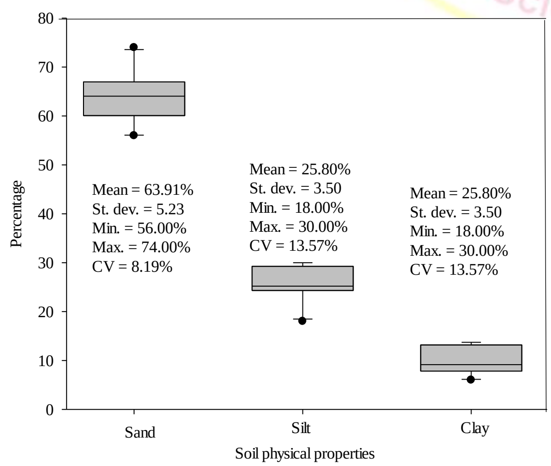
On average, the mean maximum temperature was 32^{o}C and minimum temperature was 24^{o}C, relative humidity was 88% and total rainfall of 1502 mm was received during the rice-growing season of the experiments (Figure 1 and Table 1).

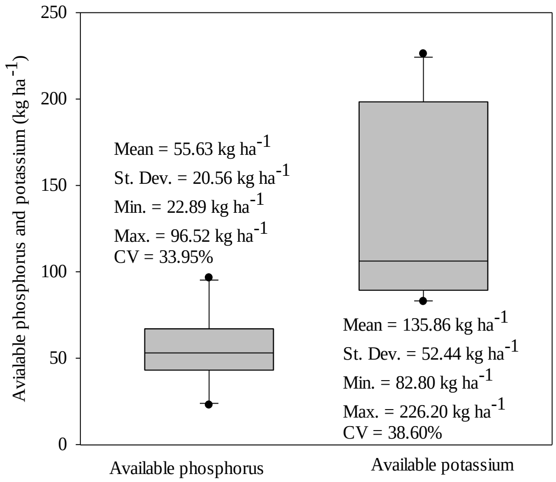
Table 1. Statistics of weather parameters of the experimental site during rice growing period of the different experiments (average of seven years)

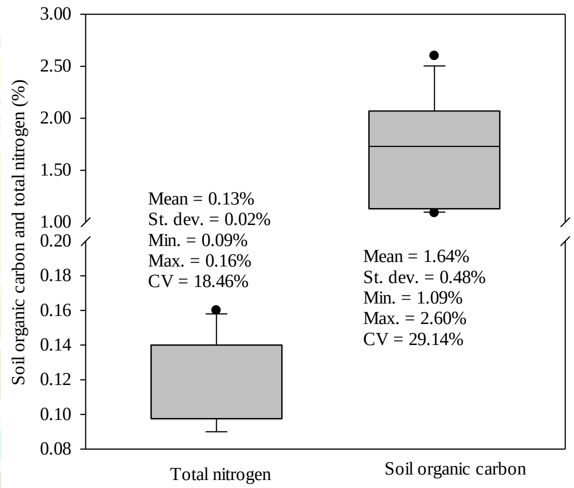
Statistics	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Total rainfall (mm)	Number of rainy days
Average	31.86	24.21	88.03	1502.11	81.00
St.dev.	2.94	4.08	7.62	360.76	21.56
Variance	8.62	16.62	58.12	501.02	501.02
CV	9.22	16.84	8.66	220.54	220.54
CA	-1.16	-1.90	-0.77	-0.26	2.88
Curtose	1.58	4.27	1.27	-0.68	8.62
Minimum	20.75	6.45	48.81	890.40	67.00
First quartile	30.50	23.20	83.37	1274.05	71.25
Median	32.30	25.25	88.00	1546.40	73.00
Third quartile	33.95	26.70	94.61	1773.83	78.75
Maximum	38.70	31.15	100.00	1982.20	144.00
Range	17.95	24.70	51.19	1091.80	77.00

Note:St.dev.,standard deviation; CV, coefficient of variation; CA, coefficient of asymmetry

In each experiment, just before the experimentation composite soil samples were collected using a tube augerform the depth of 0-20 cm. The initial soil physical and chemical properties varied among the trail's fields (Figure 2). Soil pH, the most important chemical property that affects the availability of mineral nutrients, varied from 5.20 to 6.51. The variation on clay was higher than the silt and sand content. The soil carbon and total nitrogen varied from 1.09 to 2.60 and 0.09-0.16 percent, respectively. The variation on the available phosphorus and potassium was higher than the other soil properties.







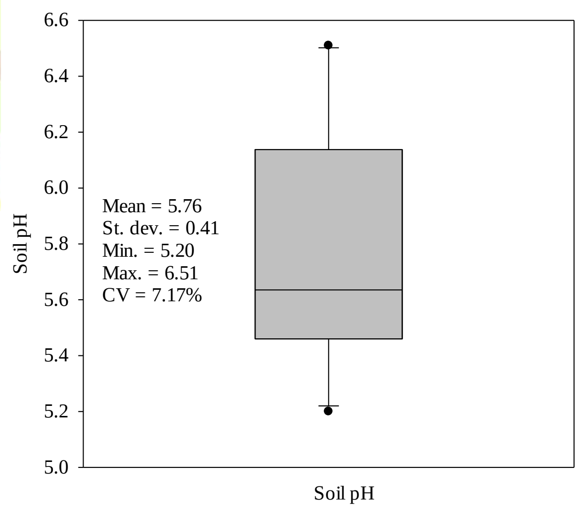


Figure 2. Initial soil properties of the experimental site (average of eleven experiments) at Rampur, Chitwan, Nepalalparasi, Nepal, 2010-2019

Note: St.dev.,standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation

Experimental treatments, design and crop management

To assess the yield and economic performance of DSR over puddled TPR, a series of experiments were conducted in the Agronomy Research Block of AFU and IAAS, which are described as follows:

Experiment 1 (2010-18th June to 7th November): Split-split design was used with establishment methods (i.e. Puddled-TPR, Puddled-system of rice intensification, and dry-DSR) as themain plot factor, varieties (Sabitri, Loktantra, and Radha 4) as sub-plot factor with three replication. In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20cm apart with the seed rate of 45 kg ha^{-1} while for the puddled-TPR, 21 days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm, and for the puddled-SRI, 14 days old 1 seedlings planted per hill with hill spacing of 25 cm x 25 cm. The full dose of phosphorous (30 kg P_2O_5 ha^{-1}), potassium (30 kg P_2O_5 ha^{-1}), zinc (20 kg $ZnSO_4$ ha^{-1}),and half dose of nitrogen (50 kg N ha^{-1}) was applied as basal dose and nitrogen was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage.

Experiment 2 and 3 (2011: 1st July to 5th November and 2012: 10th July to 15th November): A randomized complete block design was used to test different types of rice establishment methods and residue management includes, CT-dry DSR, puddled –TPR, bed planting with residue retention, bed planting without residue retention, ZT-DSR with residue retention, and ZT-DSR without residue retention with three replication and experiment was conducted for two years. In CT-dry DSR plots and ZT-DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20 cm apart with the seed rate of 30 kg ha^{-1} while for the puddled-TPR, 28days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm. An improved rice variety, Sabitri was used in experiments. The full dose of phosphorous (40 kg P_2O_5 ha^{-1}), and potassium (40 kg P_2O_5 ha^{-1}) was applied as basal dose, and nitrogen (100 kg ha^{-1}) was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage.

Experiment 4and 5(2011: 2nd July to November 8th and 2012: 7th July to 11th November): Three-factor strip-split design was used with establishment methods (i.e. zero tillage (ZT) with residue-DSR – ZT-wheat – dibbled mungbean and puddled-TPR without residue - CT-wheat) as a horizontal factor, varieties (hybrid Gorakhnath 509 and improved Sabitri) as vertical factor and nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) as subplot factor with three replication for the two years. In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20 cm apart with the seed rate of 40 kg ha^{-1} while for the puddled-TPR, 26days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm. The full dose of phosphorous (50 kg P_2O_5 ha^{-1}), and potassium (40 kg P_2O_5 ha^{-1}) was applied as basal dose and nitrogen was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage.

Experiment 6and 7(2011: 10th June to 7-9thNovember and 2012:11th June to 5-8th November): Strip-split design was used with establishment methods (i.e. ZT-DSR with the residue of maize, and puddled-TPR without residue) as a horizontal factor, nutrient management practices (130:60:30 kg N, P_2O_5 and K_2O ha^{-1}; and 60: 30:0 kg N, P_2O_5 and K_2O ha^{-1}) as a vertical factor, and weed management practices (two-manual weeding/hand pulling and chemical management, i.e. Pendimethalin @ 1 kg a.i. ha^{-1} for DSR and Butachlor@1 kg a.i. ha^{-1} for DSR as the pre-emergence application) as the sub-sub plot with three replication for two years. The variety used in the experiment was Sabitri. In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20 cm apart with the seed rate of 40 kg ha^{-1} while for the puddled and unpuddled-TPR, 21-24days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm. based on the nature of treatments, fertilizers were applied. The full dose of phosphorous (30 kg P_2O_5 ha^{-1}), potassium (30 kg P_2O_5 ha^{-1}), and zinc (25 kg $ZnSO_4$ ha^{-1}) was applied as basal dose and nitrogen was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage.

Experiment 8 (2014-8th June to 15th October): Strip-split design was used with establishment methods (i.e. CT-DSR, puddled-TPR, and unpuddled-TPR) as a horizontal factor, nutrient management practices (100% recommended NPK (100:30:30 kg N, P_2O_5 and K_2O ha^{-1}; leaf color chart (LCC) based N management + recommended P and K; farmers fertility management practices (49:35:0 kg N, P_2O_5 and K_2O ha^{-1}; 150% of recommended NPK; 0 N + recommended P and K; 0 P + recommended N and K; and 0 K + recommended N and K) as a vertical factor with three replication. In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20 cm apart with the seed rate of 50 kg ha^{-1} while for the puddled and unpuddled-TPR, 21 days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm. based on the nature of treatments, fertilizers were applied. The full dose of phosphorous (30 kg P_2O_5 ha^{-1}), potassium (30 kg P_2O_5 ha^{-1}), and zinc (25 kg $ZnSO_4$ ha^{-1}) was applied as basal dose and nitrogen was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage. In the case of LCC based nitrogen management, 25 kg N ha^{-1} was applied as basal and top dressing of nitrogen through the LCC reading (reading was taken from 20 days after sowing for CT-DSR and 14 days after transplanting up to flowering) at the critical value (≤4) at 20 kg N ha^{-1}. Nitrogen amount of 35 kg N ha^{-1} was applied as basal and 14 kg N ha^{-1} top-dressed at the tillering stage.

Experiment 9(2015: 16th June to 17th November):Three-factor strip-split design was used with establishment methods (i.e. zero tillage with residue-DSR and puddled-TPR) as a horizontal factor, varieties (hybrid Gorakhnath 509 and improved Sabitri) as vertical factor and nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) as subplot factor with three replication. In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20cm apart with the seed rate of 45 kg ha^{-1} while for the puddled-TPR, 21 days old 2-3 seedlings planted per hill with hill spacing of 20cm x 20 cm. The full dose of phosphorous (30 kg P_2O_5 ha^{-1}), potassium (30 kg P_2O_5 ha^{-1})zinc (25 kg $ZnSO_4$ ha^{-1}) wasapplied as basal dose and nitrogen was applied at three splits: half at basal, one fourth at active tillering, and one fourth at the panicle initiation stage.

Experiment 10 (2016: 22ndJune to 13thNovember): Three-factor strip-split design was used with establishment methods (i.e. zero tillage -DSR and puddled-TPR) as a horizontal factor, residue management (residue kept and residue removed) as a vertical factor, and nitrogen levels (50, and 100 kg N ha^{-1}) as subplot factor with three replication. The variety used in the experiment was Ramdhan, an improved variety.In DSR plots, rice seeds were sown continuously in mechanically drawn rows spaced 20cm apart with the seed rate of 50 kg ha^{-1} while for the puddled-TPR, 30 days old 2-3 seedlings planted per hill with hill spacing of 20 cm x 20 cm. Pendimethalin was sprayed on the next day after sowing at the rate of 1 kg a.i. ha^{-1}. P_2O_5 and K_2O at the rate of 30:30 kg ha^{-1} and 1/3rdN was applied at the basal dose and remaining 1/3rdN at the active tillering stage and remaining N 1/3rdat the panicle initiation stage. Two hand weeding was done at 20 days after sowing (DAS) and 40 DAS.

Experiment 11 (2018: 15th June to 29th October): Three-factor split-split design with three replications which included two cropping system (rice-wheat and rice-maize) as main plot treatments, two establishment methods (ZT-DSR and puddled-TPR) as subplots, and four nutrient management practices (100% recommended dose of fertilizer (150: 45:45kg N, P_2O_5 and K_2O ha^{-1}), Residue retention of previous crops, i.e. wheat and maize (5 t ha^{-1}) + 75% RDF, nutrient expert dose (140:56:53 kg N, P_2O_5 and K_2O ha^{-1}), brown/green manuring + 75% RDF) as sub-sub plot treatments. Rice seed was directly sown at the seed rate of 45 kg ha^{-1}in the no-till field for ZT-DSR and transplanting of seedlingsof 30 days for puddled-TPR. Hybrid variety US-312 was used. The nutrient expert dose was determined using the Nutrient Expert Beta Version prepared by the International Plant Nutrition Institute (IPNI). The *Sesbania* seeds @ 60 kg ha^{-1} were sown in the field with rice and knocked down by spraying 2, 4-D and plot maintained as the brown manuring for direct-seeded rice and while for green manuring, *Sesbania* seeds @ 60 kg ha^{-1} were sown in the field 30 days before transplanting and incorporating immediately before the transplanting of rice.

Sampling and measurements

Grain yield was obtained from the net plot area of 12-20 m^2in the center of each plot, avoiding plot borders at harvestable maturity and from the same area straw yield, and harvest index was calculated. Grain yield, calculated to take account of row spacing, is reported in t ha^{-1} adjusted to the standard moisture content of 14%. The sampled straw used to determine the moisture percentage. Plant samples were dried at 65°C for 72 hours.Additionally for rice plant parameters number of effective tillers per square meter, the number of grains per panicle, sterility percentage, and thousand grains weight were also collected. From the one or two quadrate of 1 m^2 number of panicle bearing tillers were recorded. Twenty panicles were randomly selected from each plot to count the average number of grains per panicle and sterility percentage. After threshing, seeds were cleaned and weighed. A sample of 250 grains was weighed from each replicate to derive thousand-grain weights and recalculate for a 14% moisture basis. Seed moisture content mass was measured using a Farmcomp Grain moisture tester (Wile 55).

The total variable cost was calculated by adding up the cost of seed, fertilizers, herbicides, machinery, human labor, and irrigation water. Human labor for tillage, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting, and threshing of different treatments were recorded. The price of human labor, machinery used, seeds, pesticides, grain, and straw was collected through a market survey in each experiment. Machinery cost was based on the hiring of machines and the cost of irrigation water was calculated based on the duration of irrigation and rate per unit area. Gross return was calculated by adding the revenue from grain and straw. The straw yield on a dry-weight basis was used in the calculation. The netreturn was calculated by deducting the total variable cost of cultivation from the gross return. The B:C ratio was calculated by dividing gross return with the total variable cost of cultivation.

Data analysis

The paired wise comparison was made to evaluate the performance of DSR and puddled-TPR by using the paired t-test. To observe the effect of different management factors such as residue management, nitrogen management, and varieties, general categories were maintained such as the residue retention of any amount was regarded as the residue retained treatments, nitrogen application lower than <60 kg ha^{-1} was categorized at the lower dose, 100-120 kg N ha^{-1} as the recommended dose and >130 as the higher dose, and the all improved varieties of any varietal duration was categorized as the improves and another category was the hybrids.

RESULTS AND DISCUSSION

Across all observations, DSR yield was only 2.4% lower than the yield of puddled transplanted rice (Table 2 and Figure 3). In an all unweighted analysis, the number of effective tillers per square meter showed a positive and significant response to the DSR whereas the number of grains per panicle was significantly reduced the sterility percentage was significantly increased. There is no significant difference in the thousand-grain weight between the DSR and puddled TPR with a slightly negative response to the DSR (Table 2 and Figure 3). The straw yield was significantly higher in DSR as compared to the puddled TPR. The lower grain yield and higher straw yield results in a significantly lower harvest index in the case of DSR.

DSR yields were lower than the puddled TPR in most of the cases (Table 2 and Figure 4). Among the different forms of DSR, 4.6%yield was decreased under CT-DSR without residues and 7.1% under CT-DSR with residue retention of the previous crops. The yield penalty (by 16.6%) was further increased in the case of ZT-DSR without residues but considerably increased the yield (by 5.4%) of ZT-DSR with residue retention as compared to puddled TPR. In all forms of the DSR, effective tillers per square meter were significantly higher than the puddled TPR whereas just reverse for the number of grains per panicle. DSR under ZT with residue retention responded positively for thousand grains weight which consequently resulted in yield gain whereas ZT DSR without residue retention grieved highest yield penalty because of reduction in thousand grains weight and significant increment in sterility percentage.The more yield loss in residue retention over no residue was due tosignificant increment in sterility percentage.

The establishment of rice under different tillage systems proved that rice can be successfully grown under ZT-DSR and proved to be more suitable alternative of conventional method of puddled TPR. Overall, it is not surprising with slightly lower yield of DSR than the puddled-TPR (Table 2 and Figure 3), but due to more benefits and low cost of cultivation, DSR is more advantageous (Figure 3B, 4B, 4C, and 4D), which is why DSR is also regarded as a labour- and water-saving rice production technique. This was in contrast with previous studies because diversities of studies were compiled in the present analysis. Farooq et al. (2006a, 2006b) and Farooq et al. (2009) grain yield in DSR is comparatively less than TPR. Sharma et al. (2004), Singh et al. (2001), and Tripathi et al.(2005) also reported lower grain yield of rice under DSR whereas Gathala et al. (2013) and Timsina et al. (2010) reported the higher yield while Hossain et al. (2020) reported that similar grain yield under ZT-DSR as compared to conventional puddled TPR. Experiments were conducted at farmers' fields to study the effect of the ZT system on the growth and yield of rice and observed that the grain yield of rice under ZT was similar to the puddled TPR (Reddy et al., 2005). The CT-DSR had a similar grain yield as the ZT-DSR plots after 4 years of cropping(Bhattacharyya et al., 2008) but the ZT practice had lower cultivation costs. The significantly same grain yield was recorded with ZT-DSR with residue retention and puddled TPR. However, Gathala et al. (2011) observed a 9-10% higher yield under ZT combined with residue mulch compared to the conventional tillage and ZT without crop residue. Higher rice yield under residue retention may be attributed to improvement in soil physical conditions (Singh et al., 2016) resulting in better soil moisture and nutrient availability (Yadvinder-Singh et al., 2004), and higher weed suppression through providing a physical barrier on the surface (Schuster et al., 2019). But the incorporation of residues is disadvantageous as it increased the immobilization of inorganic nitrogen and its adverse effect due to nitrogen deficiency might be the cause of lower yield under residues retention on the CT-DSR. Thus proper fertilizer management practices should be formulated to overcome these issues of nitrogen immobilization due to the incorporation of crop residues.

The direct-seeded rice had more number of effective tillers per square meter (Figure 3A) which was likely attributed to higher population density than the transplanted rice.(Saharawat *et al*., 2010) reported that number of effective tillers was numerically (9 per cent) higher in DSR as compared to the puddled TPR. The lower yield of DSR was mainly due to fewer number of grains per panicle (Figure 3A). But there was a compensation relationship between the number of effective tillers per square meter and the number of the grains per panicle, thus there was no severe yield loss under DSR. Differences in thousand grain weight were not significant between transplanted and direct-seeded rice. These findings indicate the existence of several yield compensation mechanisms enabling lowland rice to respond to various microclimatic conditions associated with different methods of crop establishment.

Table 2. Comparison of yield and yield component between the direct-seeded rice to puddled-transplanted rice across a wide range of management and environmental conditions

Establishment methods	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Effect tillers m^{-2}	Grains per panicle	Thousand grain weight (g)	Sterility (%)
DSR#	4.14	5.61	40.46	298.87	121.76	20.16	13.38
Pu-TPR	4.24	5.20	42.99	246.41	138.21	20.30	12.04
Mean diff.	-0.10	0.41	-2.54	52.46	-16.44	-0.14	1.34
No. of pair	150	150	150	150	150	150	150
SEm (±)	0.08	0.09	0.44	7.26	2.32	0.12	0.40
t-value	-1.26	4.52	-5.78	7.23	-7.09	-1.23	3.33
Probability	0.21	0.00	0.00	0.00	0.00	0.22	0.00
CT-DSR	3.97	5.77	38.72	263.66	107.37	21.67	15.20
Pu-TPR	4.16	5.60	39.69	217.23	129.65	21.73	14.43
Mean diff.	-0.18	0.18	-0.97	46.43	-22.28	-0.06	0.77
No. of pair	38.00	38.00	38.00	38.00	38.00	38.00	38.00
SEm (±)	0.20	0.19	0.84	11.82	6.21	0.27	0.79
t-value	-0.94	0.95	-1.15	3.93	-3.59	-0.22	0.97
Probability	0.35	0.35	0.26	0.00	0.00	0.82	0.34
CT-DSR + R	4.18	5.49	41.02	270.78	129.81	18.55	17.98
Pu-TPR	4.50	5.56	42.34	223.34	153.46	18.76	15.11
Mean diff.	-0.32	-0.07	-1.32	47.44	-23.66	-0.21	2.87
No. of pair	32	32	32	32	32	32	32
SEm (±)	0.14	0.14	0.65	10.54	4.29	0.30	0.87
t-value	-2.23	-0.51	-2.01	4.50	-5.52	-0.70	3.31
Probability	0.03	0.62	0.05	0.00	0.00	0.49	0.00
ZT-DSR	3.77	5.17	41.44	246.21	100.05	20.63	12.74
Pu-TPR	4.52	5.06	45.16	237.13	123.43	21.57	8.76
Mean diff.	-0.75	0.11	-3.72	9.08	-23.38	-0.94	3.98
No. of pair	16	16	16	16	16	16	16
SEm (±)	0.23	0.21	1.18	8.85	4.38	0.18	1.22
t-value	-3.25	0.51	-3.15	1.03	-5.34	-5.27	3.26
Probability	0.01	0.62	0.01	0.32	0.00	0.00	0.01
ZT-DSR + R	4.32	5.68	40.96	346.99	131.71	19.94	10.17
Pu-TPR	4.10	4.83	44.75	277.58	139.35	19.90	9.91
Mean diff.	0.22	0.86	-3.79	69.40	-7.64	0.04	0.26
No. of pair	64	64	64	64	64	64	64
SEm (±)	0.11	0.14	0.75	14.10	2.92	0.15	0.58
t-value	1.95	6.07	-5.04	4.92	-2.61	0.28	0.45
Probability	0.06	0.00	0.00	0.00	0.01	0.78	0.66

Note: #, includes all form of DSR; CT-DSR, conventional tillage-direct seeded rice; Pu-TPR, Puddled transplanted rice; + R, with residue; ZT-DSR, Zero tillage direct-seeded rice; Mean diff., mean difference; SEm (±), standard error of the mean of the mean difference series

The direct-seeded rice had more number of effective tillers per square meter (Figure 3A) which was likely attributed to higher population density than the transplanted rice.(Saharawat *et al*., 2010) reported that number of effective tillers was numerically (9 per cent) higher in DSR as compared to the puddled TPR. The lower yield of DSR was mainly due to fewer number of grains per panicle (Figure 3A). But there was a compensation relationship between the number of effective tillers per square meter and the number of the grains per panicle, thus there was no severe yield loss under DSR. Differences in thousand grain weight were not significant between transplanted and direct-seeded rice. These findings indicate the existence of several yield compensation mechanisms enabling lowland rice to respond to various microclimatic conditions associated with different methods of crop establishment.

DSR yields were lower than TPR yields in most cases, however, the yield gapbetween DSR and TPR could be narrowed by appropriate management (Figure 4A). Compared toTPR, the yield in DSR was only 0.29% lower in improved varieties, whereas the yield penalty was 1.35% in hybrids. In the case of CT-DSR, the

3.97% yield loss could be minimized to 2.44%, when the residues were not applied. Contrastingly, the yield loss of 16.03% could be minimized and 5.96% more yield could be achieved, when the residues were retained for ZT-DSR.In case of no nitrogen and high nitrogen level yield advantage (12.29 and 6.64%, respectively) of DSR compared to puddled TPR whereas at the low and recommended nitrogen yield loss were 1.57 and 8.36% respectively.

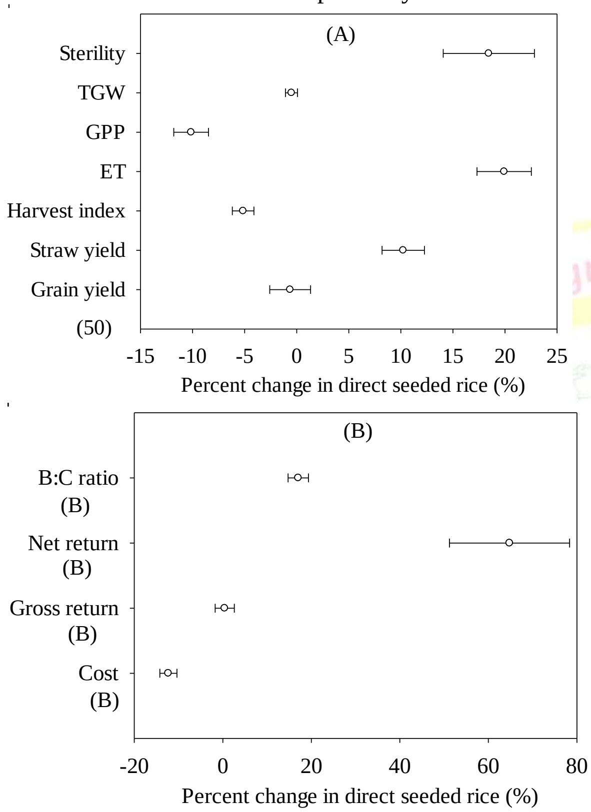
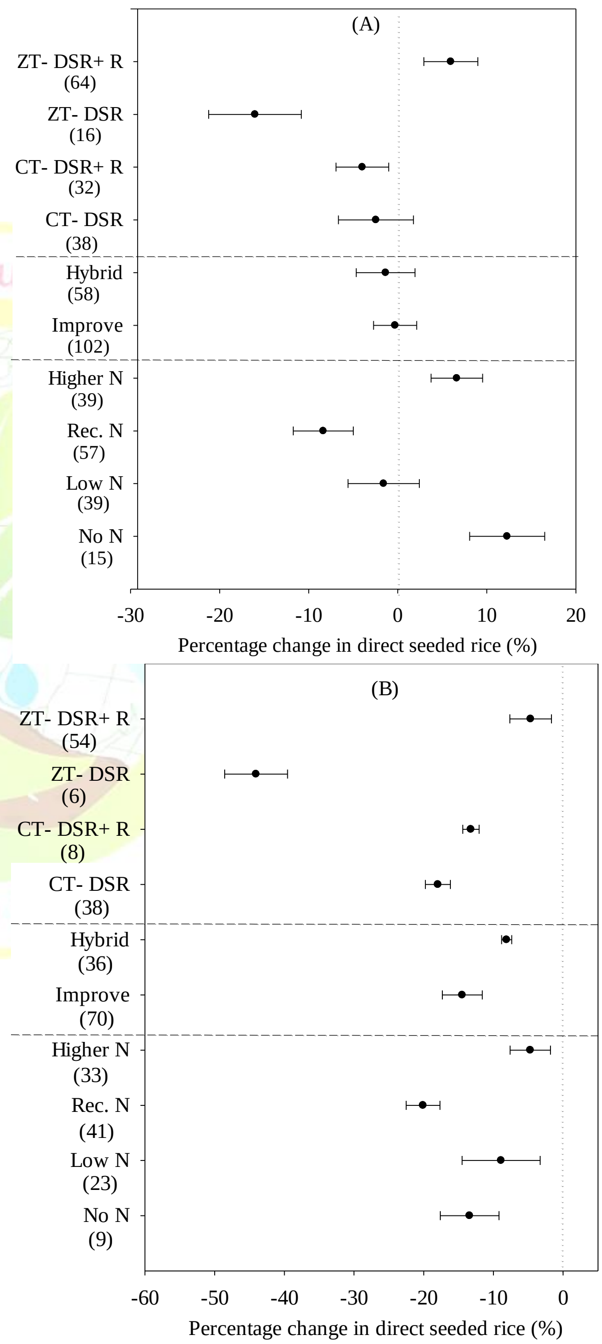


Figure 3. Change in (A) yield and yield attributes, and (B) economics of production comparing direct-seeded rice to puddled transplanted rice across a wide range of management conditions. The number of paired observations included in each dataset is presented in parenthesis.

For DSR, due to the high seed cost for hybrid, improved variety was slightly better in terms of economic benefits. Percent benefits on nitrogen omission were the highest for DSR than puddled TPR as compared to nitrogen applied situation, but the gross and net return was 21.8 and 43.4% higher in nitrogen applied treatments as compared to nitrogen omission in DSR. Despite the yield loss under DSR, the cost of cultivation was drastically reduced and more profit was obtained (Figure 3). The high cost of residues and more yield penalty for CT-DSR with residue retention resulted in the reduction of net return whereas the B:C ratio was even lower than the puddled TPR. Though the highest yield loss was calculated for ZT-DSR without residue retention, the highest reduction in the cost of cultivation made it comparable to the ZT-DSR in terms of net profit and higher B:C ratio than the CT-DSR with residue retention. Among the different forms of the DSR, ZT with residue retention and CT without residue retention was better in terms of profitability. ZT-DSR with residue retention compensate the cost of the residue by yield improvement.



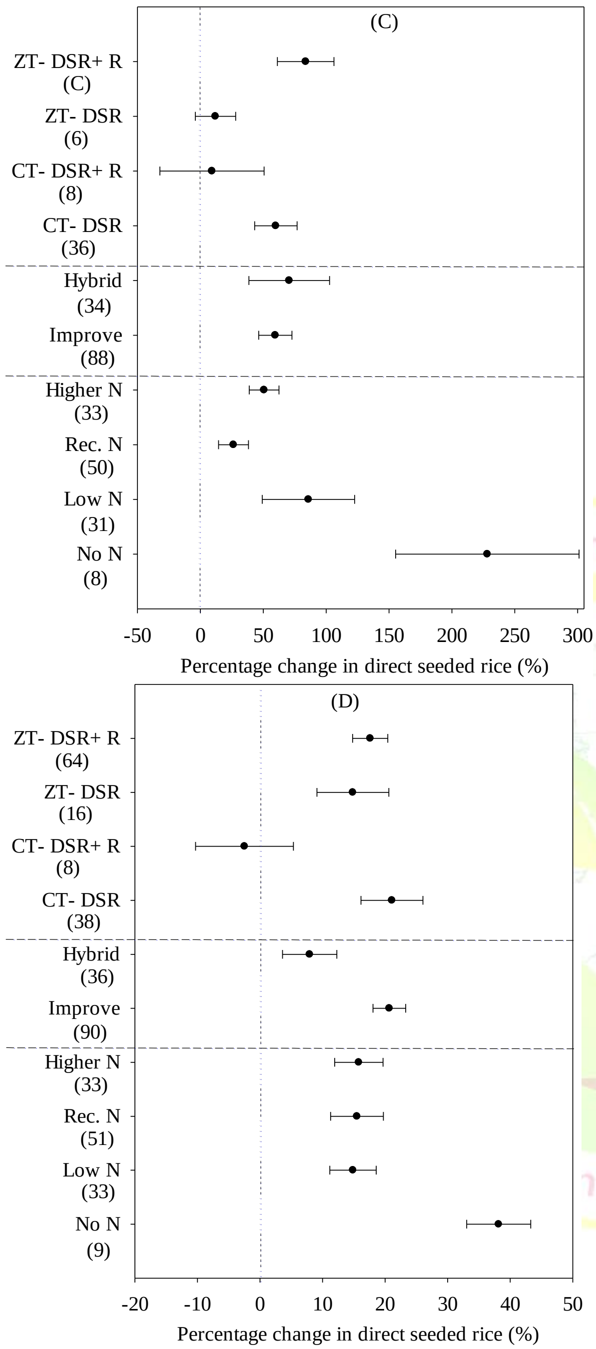


Figure 4. Influence of different establishment methods and residues, varieties, and nitrogen input on the (A) yield change, (B) cost of cultivation, (C) net return, and (D) B:C ratio of direct-seeded rice relative to transplanted rice. The number of paired observations included in each dataset is presented in parenthesis

CONCLUSIONS

This analysis concluded that DSR yield was slightly lower than that of TPR. The lower yield of DSR was due to reduction in number of grains per panicle and higher sterility. However, the yield gapbetween CT-DSR and puddled TPR could be narrowed without incorporating the residues whereas more yield could be obtained with the residues retention on the ZT-DSR. Under the nitrogen omission and higher nitrogen application, DSR was more productive as compared to puddled TPR. Among the different forms of the DSR, ZT with residue retention and CT without residue retention were better in terms of profitability. ZT-DSR with residue retention compensate the cost of the residue by yield improvement along with the improvement of the soil qualities in long run.

REFERENCES

Aggarwal, G. C., Sidhu, A. S., Sekhon, N. K., Sandhu, K. S. and Sur, H. S. 1995. Puddling and N management effects on crop response in a rice-wheat cropping system. Soil and Tillage Research, 36(3-4): 129-139. https://doi.org/10.1016/0167-1987(95)00504-8

Akhgari, H. and Kaviani, B. (2011). Assessment of direct seeded and transplanting methods of rice cultivars in the northern part of Iran. African Journal of Agricultural Research, **6(31)**: 6492-6498. https://doi.org/10.5897/AJAR11.973

Bhatt, R. and Kukal, S. (2015). Direct Seeded Rice in South Asia. In E. Lichtfouse (Ed.), Sustainable Agriculture Reviews (pp. 218–245). https://doi.org/10.1007/978-3-319-21629-4_7

Bhattacharyya, R., Kundu, S., Pandey, S. C., Singh, K. P. and Gupta, H. S. (2008). Tillage and irrigation effects on crop yields and soil properties under the rice–wheat system in the Indian Himalayas. Agricultural Water Management, **95(9)**: 993-1002.https://doi.org/https://doi.org/10.1016/j.agwat.2008.03.007

Bhushan, L., Ladha, J. K., Gupta, R. K., Singh, S., Tirol-Padre, A., Saharawat, Y. S., Gathala, M. K. and Pathak, H. (2007). Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. Agronomy Journal, **99(5)**: 1288-1296. https://doi.org/10.2134/agronj2006.0227

Biamah, E. K., Rockstrom, J. and Okwach, J. (2000). Conservation tillage for dryland farming. Technological options and experiences in Eastern and Southern Africa. RELMA Workshop. Nairobi, Swedish International Development Corporation (SIDA) Regional Land Management Unit (RELMA).

CBS. 2014. National population and housing census 2011 (Population projection 2011-2031) (Vol. 08). Central Bureau of Statistics, Government of Nepal, Kathmandu, Nepal.

Chen, S., Ge, Q., Chu, G., Xu, C., Yan, J., Zhang, X. and Wang, D. 2017. Seasonal differences in the rice grain yield and nitrogen use efficiency response to seedling establishment methods in the Middle and Lower reaches of the Yangtze River in China. Field Crops Research, 205: 157–169. https://doi.org/https://doi.org/10.1016/j.fcr.2016.12.026

FAO. 2016. FAOSTAT. Retrieved from http://faostat.fao.org

Farooq, M., Barsa, S. M. A. and Wahid, A. 2006. Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. Plant Growth Regulation, 49(2): 285-294. https://doi.org/10.1007/s10725-006-9138-y

Farooq, M., Basra, S. M. A., Ahmad, N. and Murtaza, G. 2009. Enhancing the performance of transplanted coarse rice by seed priming. Paddy and Water Environment, **7(1)**: 55-63. https://doi.org/10.1007/s10333-008-0143-9

Farooq, M., Basra, S. M. A., Tabassum, R. and Afzal, I. 2006. Enhancing the performance of direct seeded fine rice by seed priming. Plant Production Science, **9(4)**: 446-456. https://doi.org/10.1626/pps.9.446

Gathala, M K, Vivak, K., Virender, K., Saharawat, Y. S., Blackwell, J. and Ladha, J. K. 2011. Happy Seeder technology: a solution for residue management for the sustainability and improved production of the rice-wheat system of the Indo-Gangetic Plains.Resilient Food Systems for a changing World Proc. of the 5th world Congress of Conservation Agriculture Incorporating 3rd farming Systems Design Conference. Brisbane (Australia); 26-29 Sep 2011 (CIMMYT.).

Gathala, Mahesh K., Kumar, V., Sharma, P. C., Saharawat, Y. S., Jat, H. S., Singh, M., Kumar, A., Jat, M. L., Humphreys, E., Sharma, D. K., Sharma, S. and Ladha, J. K. 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. Agriculture, Ecosystems & Environment, 177: 85-97. https://doi.org/10.1016/j.agee.2013.06.002

Hobbs, P. R. and Gupta, R. K. 2000. International conference on managing natural resources for sustainable production in 21st century. Sustainable Resource Management in Intensively Cultivated Irrigated Rice–Wheat Cropping Systems of the Indo-Gangetic Plains of South Asia: Strategies and Options, 584-592. New Delhi, India.

Hossain, K., Timsina, J., Johnson, D. E., Gathala, M. K. and Krupnik, T. J.2020. Multi-year weed community dynamics and rice yields as influenced by tillage, crop establishment, and weed control: Implications for rice-maize rotations in the eastern Gangetic plains. Crop Protection, 138, 105334. https://doi.org/https://doi.org/10.1016/j.cropro.2020.105334

Kaur, J. and Singh, A. 2017. Direct seeded rice: prospects, problems/constraints and researchable issues in India. Current Agriculture Research Journal, **5(1)**: 13-32. https://doi.org/10.12944/carj.5.1.03

Kharel, L. P., Ghimire, S. K., Shrestha, J., Kunwar, C. B. and Sharma, S. 2018. Evaluation of rice genotypes for its response to added fertility levels and induced drought tolerance during reproductive phase. Journal of AgriSearch, **5(01)**: 13-18. https://doi.org/10.21921/jas.v5i01.11126

Ladha, J. K., Dawe, D., Pathak, H., Padre, A. T., Yadav, R. L., Singh, B., Singh, Y., Singh, Y., Singh, P., Kundu, A. L., Sakal, R., Ram, N., Regmi, A. P., Gami, S. K., Bhandari, A. L., Amin, R., Yadav, C. R., Bhattarai, E. M., Das, S., Aggarwal, H. P., Gupta, R. K. and Hobbs, P. R. 2003. How extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crops Research, **81(2-3)**: 159–180. https://doi.org/10.1016/S0378-4290(02)00219-8

Liu, H., Hussain, S., Zheng, M., Peng, S., Huang, J., Cui, K. and Nie, L. 2014. Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. Agronomy for Sustainable Development, **35**: 285-294.

MoAD. 2015. Rice varietal mapping in Nepal: implication for development and adoption. Retrieved from http://doacrop.gov.np/

MOF. 2017. Economic survey 2016-2017. Retrieved from http://mof.gov.np/

MOF. 2020. Economic survey 2019-20. Retrieved from http://mof.gov.np/

Morison, J. I. L., Baker, N. R., Mullineaux, P. M. and Davies, W. J. 2008. Improving water use in crop production. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 363(1491): 639–658. https://doi.org/10.1098/rstb.2007.2175

Prasad, S. K., Pullabhotla, H. and Kumar, A. G. 2011. Supply and demand for cereals in Nepal , 2010-2030 (IFPRI Disc). New Delhi: Environment and Production Technology Division.

Reddy, C. V., Malik, R. K. and Yadav, A. 2005. Evaluation of double zero tillage in rice-wheat cropping system. Accelaration of Resource Conservation Technologies in Rice-Wheat Systems of the Indo-Gangetic Plains. Hisar: CCS HAU, Hisar.

Saharawat, Y. S., Singh, B., Malik, R. K., Ladha, J. K., Gathala, M., Jat, M. L. and Kumar, V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. Field Crops Research, **116(3)**:260–267. https://doi.org/10.1016/j.fcr.2010.01.003

Schuster, M. Z., Lustosa, S. B. C., Pelissari, A., Harrison, S. K., Sulc, R. M., Deiss, L., Lang, C. R., de Faccio Carvalho, P. C., Gazziero, D. L. P. and de Moraes, A. 2019. Optimizing forage allowance for productivity and weed management in integrated crop-livestock systems. Agronomy for Sustainable Development,**39(18)**. https://doi.org/10.1007/s13593-019-0564-4

Sharma, P. K., Ladha, J. K. and Bhushan, L. 2003. Soil physical effects of puddling in rice-wheat cropping systems. In ASA Special Publication SV - 65. Improving the productivity and sustainability of rice–wheat Systems: issues and impacts (pp. 97-113). https://doi.org/10.2134/asaspecpub65.c5

Sharma, P., Tripathi, R. P., Singh, S. and Kumar, R. 2004. Effects of tillage on soil physical properties and crop performance under rice-wheat system. Journal of the Indian Society of Soil Science, 52(1): 12–16. Retrieved from https://www.indianjournals.com/

Singh, S., Sharma, S. N. and Prasad, R. 2001. The effect of seeding and tillage methods on productivity of rice–wheat cropping system. Soil and Tillage Research, **61(3)**: 125-131. https://doi.org/https://doi.org/10.1016/S0167-1987(00)00188-4

Singh, V. K., Yadvinder-Singh, Dwivedi, B. S., Singh, S. K., Majumdar, K., Jat, M. L., Mishra, R and Rani, M. 2016. Soil physical properties, yield trends and economics after five years of conservation agriculture based rice-maize system in north-western India. Soil and Tillage Research,155:133–148. ttps://doi.org/https://doi.org/10.1016/j.still.2015.08.001

Sun, L., Hussain, S., Liu, H., Peng, S., Huang, J., Cui, K. and Nie, L. 2015. Implications of low sowing rate for hybrid rice varieties under dry direct-seeded rice system in Central China. Field Crops Research, 175: 87–95. https://doi.org/https://doi.org/10.1016/j.fcr.2015.02.009

Timsina, J., Haque, A., Johnson, Chauhan, B. S. and Johnson, D. E. 2010. Impact of tillage and rice establishment methods on rice and weed growth in the rice-maize-mung bean rotation in northern Bangladesh. 28th International Rice Research Conference, 8-12 November 2010. Retrieved from http://www.academia.edu/

Tripathi, B. P., Bhandari, H. N. and Ladha, J. K.2018. Rice strategy for Nepal. Acta Scientific Agriculture, 3(2):171-180.

Tripathi, R. P., Sharma, P. and Singh, S. 2005. Tilth index: an approach to optimize tillage in rice-wheat system. Soil and Tillage Research, **80(1-2)**: 125-137. https://doi.org/10.1016/j.still.2004.03.004

Xu, L., Li, X., Wang, X., Xiong, D. and Wang, F. 2019. Comparing the grain yields of direct-seeded and transplanted rice: a meta-analysis. Agronomy, **9(11)**: 767. https://doi.org/10.3390/agronomy9110767

Yadvinder-Singh, Bijay-Singh, Ladha, J. K., Khind, C. S., Gupta, R. K., Meelu, O. P. and Pasuquin, E. 2004. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. Soil Science Society of America Journal, **68(3)**: 845-853. https://doi.org/10.2136/sssaj2004.8450

Yuan, S., Nie, L., Wang, F., Huang, J. and Peng, S. 2017. Agronomic performance of inbred and hybrid rice cultivars under simplified and reduced-input practices. Field Crops Research, 210:129-135. https://doi.org/https://doi.org/10.1016/j.fcr.2017.05.024