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Research Paper

Alternate tillage and crop-establishment techniques in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system for increased system productivity and profitability in eastern sub-Himalayan plains of India

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ABSTRACT

This study was undertaken from the rainy season 2015 to winter season 2016–17 at the Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal. The aim of the study was to arrive at optimal tillage requirement in rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system to economize on energy, labour and time, and to work out the production economics of rice–wheat system as a whole under various crop-establishment techniques. Unpuddled rice (UPTR) followed by zero tillage (ZT) wheat recorded superior yield performances to conventional tillage-based systems over the years. Fuel and labour requirement was reduced by 86.93 and 51.85%, 66.28 and 45.67% and 77.84 and 48.97% under rice (direct seeding)–wheat (surface seeding), rice (UPTR)–wheat (ZT) and rice (bed planting)–wheat (bed planting), respectively. Rice (UPTR)–wheat (ZT) also recorded the maximum energy efficiency (12.15) and energy productivity (0.94 kg/MJ) with lowest specific energy (31.67) which was reflective of the better system output. Despite lesser cost of cultivation under rice (direct seeding)–wheat (surface seeding) system, the monetary returns as well as benefit: cost ratio were much lesser under this system due to poor crop stand owing to high pre-monsoon and monsoon shower. The maximum net returns (₹33,888 and ₹42,835/ha during 2015–16 and 2016–17 respectively) and benefit: cost ratio (1.68 and 1.85 during 2015–16 and 2016–17 respectively) under rice (UPTR)–wheat (ZT) system reflected its superiority to the other establishment techniques.

Key Words: Alternate tillage, Crop-establishment techniques, Energy relations, Productivity, Profitability, Rice–wheat system

Rice–wheat is a major cropping sequence in the Indo-Gangetic Plains (IGP) of entire South Asia which covers over 13.5 million ha in Bangladesh, India, Nepal and Pakistan and source of livelihood to millions of people (Timsina and Connor, 2001). The indiscriminate use or rather misuse of natural resources, especially water, has led to the pollution and depletion of groundwater resources which has a significant effect on ecological services (Li *et al*., 2021). Growing conventional puddled rice has led to over-exploitation of groundwater leading to an alarming fall of waterable in many parts of North-Western India (Humphreys *et al.,* 2010). Intensive tillage and residue burning has led to soil-health deterioration, particularly depletion of soil organic C status resulting in decreased soil fertility and reduced factor productivity (Jat *et al*., 2021). To achieve sustainable higher productivity, attempts must be focused on protecting the natural resources, and it is imperative to develop technologies which save on inputs, time and labour to increase the profit margins of the farmers due to rising prices of inputs. Alternative tillage and crop-establishment (ATCE) techniques could provide a strong foundation for maintaining or raising yields with increasing farmers' income and reducing energy use (Islam *et al*., 2019). Under the perspective, conservation agriculture (CA) is gaining popularity as a means of ensuring food security and agricultural sustainability under degrading natural resource base (Sharma, 2021).

In eastern sub-Himalayan plains, rice–wheat is also a common cropping sequence where rice is grown under puddled condition and wheat is grown with conventional tillage after harvesting rice. Again due to high residual moisture even after harvesting medium-long duration varieties of rice, the sowing of subsequent wheat in the rotation gets delayed. Under such condition, the technologies like zero tillage, surface seeding or bed planting in wheat are supposed to be very promising. Substantial savings of time and fuel can also be made by adopting these ATCEs to make the production of rice–wheat system more cost

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effective and can address the issue of profit maximization with conservation of natural resources.

All agricultural operations and inputs require energy (Kumar *et al.,* 2013; Rahman and Rahman, 2013), the majority of which comes from non-renewable and increasingly costly fossil fuels (Aghaalikhani *et al.,* 2013). Soil tillage is one of the greatest energy and labour consumers in the cultivation of arable crops. Increasing energy efficiency is crucial for environmental and economic sustainability (Aravindakshan *et al.,* 2015). Apart from fertilizers and irrigations, land preparation and planting practices are also considered to be an important energy investor in conventionally managed agricultural systems (Aghaalikhani *et al.,* 2013).

Field experiments with ZT in wheat at some locations in eastern sub-Himalayan plains have shown encouraging results in terms of increased yield (Mondal *et al*., 2018; Mitra and Patra, 2019) and profitability (Mitra *et al*., 2019) owing to timely seeding with reduced cultivation costs. However, no work on ATCEs in rice–wheat system as a whole has been done in this zone despite a good area under rice–wheat system. Keeping these in background, this study was conducted to arrive at optimal tillage requirement in rice–wheat system to economize on energy, labour and time and to work out the production economics of rice–wheat system as a whole under various crop-establishment techniques.

MATERIALS AND METHODS

The experiment was conducted at the Instructional Farm of the Uttar Banga Krishi Viswavidyalaya, Pundibari, (26°24’02.2"N, 89°23’21.7"E, 43 m above mean sea-level) Coochbehar, West Bengal, India. It was carried out for 2 consecutive rice–wheat rotations, i.e. rainy season (*kharif*) of 2015 to winter season (*rabi*) *of* 2016–17. The soil was sandy loam in texture, with *p*H 5.54, organic C% (0.91), low mineralizable N (128.36 kg/ha), medium available P(17.52 kg/ha) and low available K(122.09 kg/ha). Four different crop-establishment techniques, viz. T_1, direct-seeded rice (DSR) followed by surface seeding (SS) in wheat; T_2, bed planting (BP) in rice followed by bed planting (BP) in wheat; T_3, unpuddled transplanted rice (UPTR) followed by zero tillage (ZT) in wheat; and T_4, conventional puddled transplanted rice (PTR) followed by conventional tilled (CT) wheat, were put in long narrow strips with a size of each experimental plot of 100 m × 5 m. The experiment was laid out in a randomized block design (RBD), replicated 5 times.

Mat-type nursery beds were raised on a polythene sheet using soil and farmyard manure (FYM) @ 3 : 1 as a media. Care was taken while mixing the FYM with the soil to discard all sorts of stones, hard materials from the mixture, otherwise there will be braking of arm-needle for which there will be missing problem during transplanting. The thickness of soil + FYM layer was kept at exactly 2.5 cm, to facilitate the picking of seedlings from the tray. The polythene sheet prevented the seedling roots from penetrating the underlying soil, creating a dense mat. This type of nursery was a pre-requisite for machine transplanting. The mat was cut into desired shapes and sizes (58 cm × 28 cm × 2.50 cm), to fit into the trays of the self-propelled transplanter. After seeding, the seeds were covered with straw/ banana leaves and watering was done twice a day, once in morning and once in evening, for initial 3–4 days. The straw materials were removed when the seedlings attained a height of 2–3 cm. 2% Diammonium phosphate 2 was sprayed 12 days after seeding. Seedlings were ready for transplanting in 17–18 days. For unpuddled transplanting, the land was ploughed once with the 2-wheel drive tractor and the seedlings were then transplanted with the help of 4-row self-propelled transplanter. While for PTR in rice, conventional raised nursery bed was prepared with a width of 1.22 m. The final land was prepared by 2 passes of rotovator, followed by exposure to sun for 2 weeks and then inundation of the field, ploughing twice again with cultivator and once with rotavator and finally harrowing under standing water. The seedlings raised in conventional nursery beds were transplanted manually. Zero tillage in wheat was performed with national zero till drill (9-Tyne). Through a single pass, seeds as well as fertilizers were placed in the furrow. The DSR in rice was also performed by this machine. Bed planting was done with 2-wheel drive bed planter. It formed the bed with a single pass over the previous crop stubbles. The beds were loose with a height of only 5–7 cm. It was basically direct seeding with localized placement of fertilizers, as fertilizers were thrown over the rows only during seeding. Under surface seeding, wheat seeds were placed onto a saturated soil surface without any land preparation. Wheat seeds were broadcast within rice stubbles. A light pre-sowing irrigation was given to maintain desirable moisture as all the sowing operations were performed on the same date and the soil moisture was in lesser side during sowing. For conventional tillage in wheat, the land was prepared by ploughing twice with a rotavator and then the soil was brought into good tilth with a power tiller. Levelling was done with ladder.

The fertilizer doses for rice and wheat were 80-40-40 and 150-60-40 (N- P_2O_5- K_2O kg/ha) respectively. Full P and K along with half of the N was applied basal during final land preparation for both the crops, while the remaining N was applied in 2 equal splits, i.e. once 3 weeks after sowing/transplanting and the next one 6 weeks after sowing/transplanting. In wheat, boron was applied twice @

0.20% with solubor (B 20%), once 35–40 days after sowing (DAS) and the next 55–60 DAS. Check-basin method of irrigation was followed keeping the depth of irrigation at 5 cm. In DSR, ZT and BP plots, for killing the existing weeds, a pre-plant glyphosate 41% SL @ 3.75 L/ha in 550 L water 7 days prior to sowing was applied. Broad-leaf weeds were controlled with bispyribac-Na @ 25 g a.i./ha 20 days after sowing in rice, 2, 4-D Na salt 80% WP @ 1 kg a.i./ha at 4–5 weeks after sowing was applied to kill the broad leaf weed flora in wheat. The variety used in the experiment was 'MTU 7029' for rice and 'HD 2967' for wheat.

The entire produce from the net plot area of 12.8 m^2 (8 rows of 1 m length with 20 cm spacing) was harvested and weighed after thorough drying under the sun. Grain yield from that area was converted into per unit area basis (t/ha). The rice equivalent yield (REY) of the system was worked out with the output price of rice and wheat as ₹11 and ₹13, respectively, in the first year and ₹11.5 and ₹14, respectively, in the second year. The energy requirement for cultivation was estimated in terms of renewable and non-renewable energy. Renewable energy components were manual, animal/bullock drafts, seeds, and manure, while chemical fertilizers (NPK), tractor, diesel, electricity, lubricants, machinery, and agro-chemicals constituted the non-renewable energy inputs. The physical output was related to both grain and straw yields. The energy values for inputs (e.g. seeds, fertilizer and labour) and outputs (grain and straw) were estimated using energy equivalents as recommended by Mittal and Dhawan (1988). The details on energy equivalents are given in Table 1.

Total cost of production/ha for each treatment was calculated on the basis of existing market rate of inputs. Gross return was calculated also on the basis of prevailing market price of the products and accordingly net return was calculated. On the basis of benefit: cost ratio, the most beneficial treatment for the crop sequence was determined. Data were subjected to analysis of variance (ANOVA) and analysed using the SPSS window version 17.0 (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

While assessing the performance of these cropping systems, it was revealed that mean rice-equivalent yield (REY) was significantly higher in conventional system (8.549 t/ha) where rice was grown under PTR and wheat under CT (Table 2), being at par with rice (UPTR)–wheat (ZT) where the mean REY was 8.545 t/ha. Rice under

Table 1. Energy equivalents for different inputs and outputs

Particulars	Units	Equivalent energy (MJ)
Input		
Human labor		
Adult man	Man-hour	1.96
Woman	Woman-hour	1.57
Diesel	L	56.31
Electricity	KW h	11.93
Machinery		
Electric motor	kg	64.8
Farm Machinery including self propelled machines	kg	62.7
Chemical fertilizer		
Nitrogen	kg	60.60
Phosphate (P_2O_5)	kg	11.1
Potash (K_2O)	kg	6.7
Chemicals		
Superior chemicals	kg	120
Seed	As output of crop production system	
Output		
Main product		
Grain	kg	14.7
By product		
straw	kg	12.5

Source: Mittal and Dhawan (1988)
Following energy parameters were calculated as suggested by Singh *et al.* (1997).
Energy efficiency = [Energy output (MJ/ha)/Energy input (MJ/ha)]
Net energy (MJ/ha) = [Energy output (MJ/ha)"Energy input (MJ/ha)]
Energy productivity (kg/MJ) = [Output (grain+stover) (kg/ha)/Energy input (MJ/ha)]
Specific energy (MJ/kg) = [Total energy input (MJ/ha)/ Output (grain+stover) (kg/ha)]

Table 2. Rice-equivalent yield of rice-wheat (RW) system under alternative tillage and crop-establishment techniques

RW system under various CET	2015–16			2016–17			Mean rice-equivalent yield (t/ha)
	Rice (t/ha)	Wheat (t/ha)	Rice equivalent yield (t/ha)	Rice (t/ha)	Wheat (t/ha)	Rice equivalent yield (t/ha)	
Rice (DSR)–wheat (SS)	2.25	2.13	4.77	2.75	2.07	5.27	5.02
Rice (BP)–wheat (BP)	3.03	3.71	7.42	3.03	3.67	7.59	7.47
Rice (UPTR)–wheat (ZT)	4.14	3.45	8.22	4.62	3.49	8.87	8.55
Rice (PTR)–wheat (CT)	4.50	3.43	8.56	4.61	3.23	8.54	8.55
SEm±	0.12	0.10	0.20	0.12	0.09	0.22	0.24
CD (P=0.05)	0.39	0.32	0.65	0.38	0.30	0.72	0.76

CET, Crop-establishment techniques; DSR, direct-seeded rice; SS, surface seeding; BP, bed planting; UPTR, unpuddled transplanting; ZT, zero tillage; PTR, puddle transplanted rice; CT, conventional tillage

UPTR followed by wheat under ZT recorded lower rice-equivalent yield (8.223 t/ha) than conventional system (8.560 t/ha) in the first year, but in the second year, the REY obtained with rice (UPTR)–wheat (ZT) was much higher (8.867 t/ha) than the conventional system (8.538 t/ha). Despite better performance of wheat under bed planting, Rice (BP)–wheat (BP) showed much lower mean REY (7.472 t/ha) due to poor performance of rice under BP. The lowest mean REY (5.017 t/ha) was noted in the system where DSR of rice was followed by SS of wheat. Poor performance of both the crops under this system attributed to lower yield performance. Due to high pre-monsoon and monsoon rainfall, the crop stand was not satisfactory under DSR as well as under temporary beds formed by BP. Soon after seeding, there was receipt of around 600 mm rainfall in next 3 weeks for which the crop suffered badly. Again slightly elevated beds under BP were not capable to withstand the problem of water stagnation. Similarly, after the harvesting of the rice crop the stand of wheat was also affected due to uneven distribution of seeds as well as quick exhaustion of soil moisture. In the experimental site, zero tillage was in vogue for last 2 years (even before start of experimentation, 2 crop rotations were under ZT for both rice and wheat). Better soil properties and nutrient availability with the successive crop seasons probably resulted in higher yield performances under rice (UPTR)–wheat (ZT). Jat *et al.* (2017) assessed the soil properties under conservation agriculture (CA) based rice–wheat cropping systems in north-west India and reported a better soil environment under CA-based cropping systems. Our results also reflected the superiority of CA-based system when it was practiced over couple of years instead of a single season.

The fuel requirement can be reduced to 86.93, 66.28 and 77.84% under rice (DSR)–wheat (SS), rice (UPTR)–wheat (ZT) and rice (BP)–wheat (BP), respectively, over conventional tillage (Table 3). Fuel requirement was very high (132.00 L/ha) when PTR was followed by CT-wheat. More number of tillage operations was the main reason for this increased fuel requirement. As there was no land preparation in rice (DSR)–wheat (SS) system, the fuel requirement was the lowest (17.25 L/ha) amongst ATCE practices. The labour requirement was also maximum in rice (PTR)–wheat (CT) system (243 man-days/ha). Rice (DSR)–wheat (SS), rice (UPTR)–wheat (ZT) and rice (BP)–wheat (BP) resulted in 51.85, 45.67 and 48.97% labour saving compared to the conventional rice (PTR)-wheat (CT) system, respectively. Use of machineries particularly during seeding/transplanting reduced the labour requirement under these alternate crop-establishment techniques. Owing to the use of bed planter, zero tillage machine as well as paddy transplanter under BP, ZT and UPTR, respectively, time requirement was saved to a considerable extent for land preparation as well as

Table 3. Fuel, labour and time saving of rice–wheat (RW) system under alternative tillage and crop-establishment techniques

RW system under various CET	Fuel requirement (L/ha)	Fuel saving (%)	Labour requirement (Man-days/ha)	Labour saving (%)	Time requirement (hours)	Time saving (%)
Rice (PTR)–wheat (CT)	132.00	–	243	–	38.625	–
Rice (DSR)–wheat (SS)	17.25	86.93	117	51.85	6.875	82.20
Rice (UPTR)–wheat (ZT)	44.50	66.28	132	45.67	16.00	58.57
Rice (BP)–wheat (BP)	29.25	77.84	124	48.97	11.875	69.25

CET, Crop-establishment techniques; DSR, direct seeded rice; SS, surface seeding; BP, bed planting; UPTR, unpuddled transplanting; ZT, zero tillage; PTR, puddle transplanted rice; CT, conventional tillage transplanting or seeding. For this reason, 82.20, 58.57 and 69.25 % time could be saved under rice (DSR)–wheat (SS), rice (UPTR)–wheat (ZT) and rice (BP)–wheat (BP), respectively. Naresh *et al*. (2011) studied resource-conservation technologies in rice–wheat cropping system and reported savings in labour, time as well as cost of production in alternate establishments compared to conventional seeding. Saharawat *et al*. (2010) also reported reduced fuel and water requirement with reduced cost of production, improved the system productivity and soil health.

The PTR (rice)–CT (wheat) recorded significantly higher energy input (26,807 MJ/ha) due to consumption of increased human labour as well as higher quantity of diesel fuel towards land preparation and irrigation (Table 4). Despite use of similar fertilizers and chemicals under all crop-establishment techniques, lesser human labour and diesel fuel revealed the least energy input under rice (DSR)–wheat (SS) system (19,040.2 MJ/ha). Rice (PTR)–wheat (CT) gave higher grain and straw yields, which in turn resulted in the maximum energy output (270,749.2 MJ/ha). Rice (DSR)–wheat (SS) system recorded the minimum energy output (175,473.5 MJ/ha) due to production of the lowest grain and straw yields amongst all the crop establishment techniques. It was noted that, rice (UPTR)–wheat (ZT) showed significantly higher net energy gain (247,495.8 MJ/ha) due to appreciable energy output with reduced input, while the minimum net energy gain (156,433.3 MJ/ha) was recorded under rice (DSR)–wheat (SS) system.

Rice (UPTR)–wheat (ZT) also revealed significantly higher energy efficiency (12.15), reflecting the higher proportion of output, viz. grain and straw with minimum energy input. Energy productivity under the same system, i.e. rice (UPTR)–wheat (ZT), also showed significantly higher value (0.94 kg/MJ). The lowest specific energy under rice (UPTR)–wheat (ZT) was reflective of the better system output.

Among 4 cropping systems, significantly higher net returns (₹33,888 and ₹42,835/ha during 2015–16 and 2016–17 respectively) and benefit: cost (B : C) (1.68 and 1.85) during 2015–16 and 2016–17, respectively) were recorded with rice (UPTR)–wheat (ZT) system. It was followed by rice (BP)–wheat (BP) system which registered a net returns of ₹24,812 and ₹27,259/ha with a B : C of 1.50 and 1.54 during 2015–16 and 2016–17 respectively (Table 5). Despite higher gross returns under conventional system owing to higher yields, the B : C was much lower due to more production cost associated with more tillage operations and labour requirement. Lesser cost involvement with higher yield performance under BP- and ZT-based system particularly in wheat resulted in better B : C over CT. Economically zero tillage was superior to the conventional

Table 4. Energy relations in rice–wheat (RW) system as influenced by alternative tillage and crop-establishment techniques

RW system under various CET	Energy inputs (MJ/ ha)	Energy output (MJ/ ha)	Net energy (MJ/ha)	Energy efficiency	Energy productivity (kg/MJ)	Specific energy (MJ/kg)
Rice (PTR)–wheat (CT)	19,040	175,473	156,434	9.22	0.69	34.97
Rice (DSR)–wheat (SS)	20,271	239,563	219,292	11.82	0.89	32.06
Rice (UPTR)–wheat (ZT)	21,503	268,999	247,496	12.51	0.94	31.48
Rice (BP)–wheat (BP)	26,807	270,749	243,942	10.10	0.76	31.67
SEm±	795	7,668	6,612	0.23	0.03	0.80
CD (P=0.05)	2,567	24,768	21,357	0.75	0.09	2.57

CET, Crop-establishment techniques; DSR, direct-seeded rice; SS, surface seeding; BP, bed planting; UPTR, unpuddled transplanting; ZT, zero tillage; PTR, puddle transplanted rice; CT, conventional tillage

Table 5. Production economics of rice–wheat (RW) system under various alternative tillage and crop-establishment techniques

RW system under CET	Cost of cultivation (₹/ha)		Gross returns (₹/ha)		Net returns (₹/ha)		Benefit : cost (B:C) ratio	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Rice (DSR)–wheat (SS)	46,046	46,896	48,191	55,396	2,146	8,500	1.05	1.18
Rice (BP)–wheat (BP)	49,328	50,078	74,140	77,338	24,812	27,260	1.50	1.54
Rice (UPTR)–wheat (ZT)	49,657	50,407	83,545	93,242	33,888	42,835	1.68	1.85
Rice (PTR)–wheat (CT)	72,964	73,714	87,296	90,114	14,333	16,401	1.20	1.22
SEm±	980	1,214	1,748	2,023	615	692	0.04	0,04
CD (P=0.05)	3,168	3,922	5,647	6,535	1,987	2,235	0.13	0.14

CET, Crop-establishment technique; DSR, direct-seeded rice; SS, surface seeding; BP, bed planting; UPTR, unpuddled transplanting; ZT, zero tillage; PTR, puddle transplanted rice; CT, conventional tillage method of planting, as more net returns were obtained on zero-tillage farms than conventional tilled field in addition to its superiority for environment friendly practices. It can be concluded that, unpuddled transplanted rice followed by wheat under zero tillage would be the most viable option in rice–wheat cropping system under eastern sub-Himalayan plains of India in terms of productivity and profitability. By following this alternate tillage practices, fair amounts of labour, time, fuel as well as energy can be saved.

REFERENCES

Aghaalikhani, M., Kazemi-Poshtmasari, H. and Habibzadeh, F. 2013. Energy use pattern in rice production: A case study from Mazandaran province, Iran. *Energy Conversion and Management* **69**: 157–162.

Aravindakshan, S., Rossi, F. and Krupnik T.J. 2015. What does benchmarking of wheat farmers practicing conservation tillage in the eastern Indo-Gangetic Plains tell us about energy use efficiency? An application of slack-based data envelopment analysis. *Energy* **90**: 483–493.

Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Singh, B., Yadav, S. and Sharma, R. K. 2010. Halting the groundwater decline in north-west India–Which crop technologies will be winners? *Advances in Agronomy* **109**: 155–217.

Islam, S., Gathala, M.K., Tiwari, T.P., Timsina, J., Liang, A.M., Maharajan, S., Chowdhury, A.K., Bhattacharya, P.M., Dhar, T., Mitra, B., Kumar, S., Srivastava, P.K., Dutta, S.K., Shrestha, R., Manandhar, S., Shrestha, S.R., Paneru, P., Siddique, N., Hossain, A., Islam, R., Ghosh, A.K., Rahman, M.A., Kumar, U., Rao, K.K and Gerard, B. 2019. Conservation agriculture-based sustainable intensification: Increasing yields and water productivity for smallholders of the Eastern Gangetic Plains. *Field Crops Research* **238**: 1–17.

Jat, H.S., Datta, A., Choudhary, M., Yadav, A.K., Choudhary, V., Sharma, P.C., Gathala, M.K., Jat, M.L. and Mcdonald, A. 2021. Effect of tillage, crop establishment and diversification of soil organic carbon, aggregation, aggregate associated carbon and productivity in cereal systems of semi-arid Northwest India. *Soil and Tillage Research* **190**: 128–138.

Jat, H.S., Datta, S., Sharma, P.C., Kumar, V., Yadav, Y.K., Choudhary, M., Choudhary, V., Gathala, M.K., Sharma, D.K., Jat, M.L., Yaduvanshi, N.P.S., Singh, G. and Mcdonald, A. 2017. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. *Archives of Agronomy and Soil Science* https://doi.org/10.1080/03650340.2017.1359415

Kumar, V., Saharawat, Y.S., Gathala, M.K., Jat, A.S., Singh, S.K., Chaudhary, N. and Jat, M. L. 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. *Field Crops Research* **142**: 1–8.

Li, P., Karunanidhi, D., Subramani, T. and Srinivasamoorthy, K. 2021. Sources and consequences of groundwater contamination. *Archives of Environmental Contamination and Toxicology* **80**(1): 1–10.

Mitra, B., Patra, K., Bhattacharya, P.M. and Chowdhury, A.K. 2018. Unpuddled transplanting: A productive, profitable and energy-efficient establishment technique in rice under Eastern sub-Himalayan plains. *Oryza* **55**(3): 459–466.

Mitra, B., Majumdar, K., Dutta, S.K., Mondal, T., Das, S., Banerjee, H., Ray, K. and Satyanarayana, T. 2019. Nutrient management in wheat (*Triticum aestivum*) production system under conventional and zero tillage in eastern sub-Himalayan plains of India. *Indian Journal of Agricultural Sciences* **89**(5): 775–784.

Mitra, B. and Patra, K. 2019. Performance of rice–wheat cropping system under conservation agriculture-based establishment techniques in eastern Indian plains. *Journal of Cereal Research* **11**(3): 278–274.

Mittal, J.P. and Dhawan, K.C. 1988. *Research Manual on Energy Requirements in Agricultural Sector*. Indian Council of Agricultural Research, New Delhi, pp. 20–23.

Mondal, T., Mitra, B. and Das, S. 2018. Precision nutrient management in wheat (*Triticum aestivum* L.) using Nutrient Expert: Growth phenology, yield, nitrogen- use efficiency and profitability under eastern sub-Himalayan plains. *Indian Journal of Agronomy* **63**(2): 174–180.

Naresh, R. K., Gupta, R.K., Gangwar, L.K., Kumar, A., Singh, P.K. and Tomar, S.S. 2011. Wheat cultivars and nitrogen placement on yield and yield contributing characters of wheat in relation to resource conservation technologies. *Plant Archives* **11**(2): 665–671.

Rahman, S. and Rahman, S. 2013. Energy productivity and efficiency of maize accounting for the choice of growing season and environmental factors: anempirical analysis from Bangladesh. *Energy* **49**: 339–346.

Saharawat, Y. S., Singh, B., Malik, R.K., Ladha, J.K., Gathala, M. K., Jat, M.L. and Kumar, V. 2010. Evaluation of alternative tillage and crop-establishment methods in a rice–wheat rotation in Northwestern IGP. *Field Crops Research* **116**: 260–267.

Sharma, A.R. 2021. Conservation agriculture in India: History, progress and way forward. *Indian Journal of Agronomy* **66**(1): 1–18.

Sharma, P.K., Ladha, J.K. and Bhushan, L. 2003. Soil physical effects of puddling in rice–wheat cropping system. (In) *Improving the productivity and sustainability of rice–wheat systems: Issues and impacts,* Ladha, J.K. *et al.* (Eds). ASA Special Publication 65 ASA, CSSA and SSSA, Madison, WI. pp. 97–114.

Singh, M.K., Pal, S.K., Thakur, R. and Verma, V.N. 1997. Energy input–output relationship of cropping systems. *Indian Journal of Agricultural Sciences* **67**: 262–264.

Timsina, J. and Connor, D.J. 2001. Productivity and management of rice–wheat cropping systems: Issues and challenges. *Field Crops Research* **69**: 93–132.