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RESEARCH ARTICLE

Innovative crop establishment strategies vis-à-vis weed management practices can improve nutrient uptake and soil nutrient balance in the rice-green gram cropping system

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Abstract

Finding a suitable crop establishment strategy that sustains rice production vis-à-vis soil health with minimum loss of yield due to weed menace is the need of the hour. A field experiment was conducted during 2016-17 and 2017-18 on the development of an innovative rice establishment method coupled with the best weed management for rice-green gram system. Establishment methods comprised of direct mechanical seeding of rice (DSR), sprouted rice seedling (WSR), rice transplanting in unpuddled soil (NPTR) and rice transplanting in puddled soil (PTR). There was six weed control measures viz. weedy check [W1], bensulfuron methyl 0.6% + pretilachlor 6% (pre emergence (PE)) at 0.660 kgha^{-1}followed by (*fb*) manual weeding (HW) at 30 days after sowing or transplanting (DAS/T) [W2], W2 herbicidesat0.495kg ha^{-1}*fb* HW at 30 (DAS/T) [W3], W2 herbicidesat0.495kgha^{-1}*fb*0.025 kg ha^{-1} of bispyribac sodium (post emergence (POE)) at during 15 DAS/T [W4], mechanical weeding during 15 DAS/T using cono weeder (CW) *fb* hand weeding at 30 DAS/T [W5] and brown manuring/ green manuring [W6]. The study revealed that the highest nutrient uptake by rice was found under PTR, thereby resulting in the best rice yield. Weed management W2 resulted in better weed management and yield of the crops. The soil NPK balance was found to be best under the brown/green manured plot, while under different establishment methods, the best N-balance was found in DSR. However, this establishment was found to be poor concerning P and K balance in soil.

Keywords: crop nutrient uptake; green gram; NPK-balance in soil; rice; weed nutrient removal; yield

Introduction

Rice cultivation stands as the backbone of the agricultural sector in sub-tropical and tropical countries. This crop are growing in an area of ~150 million hectares, with a production of around 573 million tons, following an average productivity of 3.82 tons per hectare. India stands in second position in the world in regard to rice production and consumption (1). Rice covers approximately 4.4 million hectares of area in India, with a production of 113 million tonnes and an average productivity of 2.6 tonnes per hectare. The national average productivity of rice is far behind the world average productivity. There is an additional requirement of 1.7 million tons of rice production each year to secure food security due to high population growth (2,3).

Direct-seeded rice (DSR) is a low-cost establishment method that saves ~7-10 days of the cropping system due to early maturity. It also saves water and labor by avoiding operations such as nursery preparation, puddling and transplanting (4). However, it is more prone to aggressive weed attacks due to a lack of puddling and standing water, as well as the co-emergence of rice and weed seeds, which ultimately encourages crop-weed competition and loss in the quantity and quality of economic produce (5, 6). Wet-seeded rice is also an important rice establishment method, where sprouted seeds are sown directly in puddled soil, resulting in lower weed competition due to puddling (7). Non-puddled transplanted rice is an aerobic transplanting method where rice seedlings are transplanted in moist, well-cultivated soil without puddling (8). It is the most effective alternative to DSR in rainfed areas with high rainfall (9). Puddled transplanted rice adopts the extreme form of tillage, involving puddling in standing water, which results in a low weed count. It also encourages higher growth and yield of rice (10), while there is a risk of the breakdown of soil aggregates and soil structure deterioration, impacting the growth and yield of succeeding crops (11, 12). Crop establishment methods affect the nutrient uptake by crops and weeds in addition to their immense impact on crops vis-à-vis weeds' growth and development.

Weed growth is very dynamic and weeds have higher nutrient content than crop plants and they absorb nutrients more rapidly than crops due to their fast growth (6, 13). Nutrient uptake by unweeded check plots is nine times higher than chemical and manual weed control treatments (14). The highest removal of N, P and K by weeds has been found in drum-seeded rice due to faster weed growth under DSR conditions previously (15). For achieving optimal yield for securing food stability, crop establishment methods and weed management techniques are critical aspects of rice production practices. Selection of appropriate and prominent weed management practices in rice helps in weed reduction and lessens crop weed competition and makes more nutrients available to crop plants, ultimately promoting crop yield and profitability (16). A lot of new and novel herbicide mixtures, mechanical weeding and organic weed control methods are available for effective weed management in rice (17). However, the best weed management under the most feasible establishment method of rice production remains to be explored. Thus, a significant research gap exists in this aspect, particularly in the coastal rainfed rice ecology of the Indian subcontinent.

Narrowing such a wide research gap, the current study was conducted to determine the best rice establishment and weed management that ensure better nutrient uptake by rice, green gram and lower nutrient removal by weeds in rice-green gram cropping system in the coastal ecosystem of Odisha, India, with improved soil nutrient status.

Material and Methods

Study site

In the kharif and rabi seasons of 2016-17 and 2017-18, the field experiment was carried out at the Agronomy Research Farm of OUAT in Bhubaneswar, Odisha, India. At experiment initiation, representative composite soil samples were collected in a zig-zag manner from a depth of 0-10 cm using a soil auger to study soil physico-chemical and textural properties. The sandy loam texture of the experimental site had a medium organic carbon content (0.53%), a slightly acidic pH (5.9) and an electrical conductivity (EC) of 0.134 dS m^{-1}. Soil available N, P and K fall under the low, high and medium ranges, respectively. The data from the soil analysis are presented in Table 1.

Experimental procedure

A split-plot design (two-way ANOVA) was used for the field study and it was replicated three times with 24 (4*6) treatments. The main plot included four distinct crop establishment techniques, while the subplot included six different weed management techniques. Rice establishment methods were M1: direct rice seed sowing with seed drill (DSR); M2: sprouted rice seed sowing with seed drill (WSR); M3: rice transplanting in non-puddled soil (NPTR) and M4: rice transplanting in puddled soil (PTR). Weed control measures were, W1: weedy check; W2: pre-emergence (PE) application of 0.660 kg ha^{-1} ready-mix herbicide that contains bensulfuron methyl 0.6% + pretilachlor 6% followed by (*fb*) hand weeding (HW) at 30 days after sowing (DAS) for direct seeding and days after transplanting for transplanted rice (DAT); W3: PE application of W2herbicides at a lower dose of 0.495 kg ha^{-1}*fb* HW at 30 DAS/T; W4: PE application of W2 herbicides at 0.495 kg ha^{-1}*fb*bispyribac sodium application at 0.025 kg ha^{-1}as post -emergence (POE) at 15 DAS/T; W5: mechanical weeding with cono weeder *fb* HW after one month; W6: brown or green manuring. Medium duration rice variety (115-130 days), Naveen and green gram variety, IPM-02014 (75-80 days) were taken as test crops during kharif and rabi seasons, respectively. The farmers well adopted both these varieties. Under direct-seeded rice (M1), the experimental field was dry-ploughed, harrowed and leveled and dry rice seeds were sown at a row-to-row spacing of 20 with a mechanical seed drill machine directly on the soil. Under wet-seeded rice (M2), pre-soaked (24 hr) and pre-incubated (48 hr) sprouted rice seeds were also sown, maintaining 20 cm row spacing in wet puddled soil with a seed drill. For transplanting under both non-puddled (M3) and puddled (M4) conditions, a dry nursery was prepared. The nursery was slightly irrigated on the day of transplanting and 21 days old seedlings were uprooted and transplanted at 2-3 seedlings per hill at a spacing of 20 cm x 10 cm in both non-puddled (M3) and puddled conditions (M4). Under non-puddled transplanting (M3), the main field was dry ploughed, harrowed, leveled and watering was done for soil moistening, followed by settling for 12-24 hr and 21 days old seedlings were transplanted at a spacing of 20 cm x 10 cm on that moistened soil. Under puddled transplanting (M4), 21 days old seedlings were transplanted at a spacing of 20 cm x 10 cm on puddled and leveled soil. Irrespective of the treatment imposed, well-decomposed farm yard manure (FYM) at 5 t ha^{-1} and inorganic chemical fertilizer at 80-40-40 kg ha^{-1} N, P_2O_5 and K_2O, respectively, were applied to each experimental plot. At the time of final land ploughing/ puddling, FYM, phosphorus (P), potassium (K) in full amount and 25% nitrogen (N) were applied to the experimental plots. In contrast, the rest of the N was applied in a 2:1 ratio at tillering and panicle initiation stage, correspondingly. Sesbania seeds at a seed rate of 22 kg ha^{-1} were co-cultured with rice and at 28 days old, sesbania plants of ~35 cm tall were knocked down with 2,4-D ester application at 500 g ha^{-1} (W6), known as brown manuring. Mechanical weeding with cono weeder (CW) at 15 DAS/T and manual weeding with the hand (HW) at 30 DAS/T were carried out in W5 plots. As per treatments, herbicides were applied uniformly for better weed control efficiency. Ready mix herbicide combination, bensulfuronmethyl + pretilachlor is a PE herbicide; thereby, the herbicide was applied at 3 (DAS/T) as per the doses mentioned in treatment, W2 and W3, while in W4, post-emergence herbicide bispyribac sodium at 0.025 kg ha^{-1} was applied at 15 DAS/T. Hand weeding operation at 30 DAS/T was carried out in W2 and W3

Table 1. The research area's climate is classified as typical sub-tropical, humid and coastal

Parameters	Values	Remarks
Sand (%)	83.7	-
Silt (%)	6.8	-
Clay (%)	10.4	-
Soil reaction (pH)	5.9	Acidic
SOC (%)	0.53	Medium
Nitrogen available in soil (kg ha^{-1})	226.4	Low
Phosphorus available in soil (kg ha^{-1})	32.6	High
Potassium available in soil (kg ha^{-1})	132.6	Medium

plots. No weed control measurement was taken in weedy check plots (W1). For sowing rabi season green gram, the field was prepared by power tiller without disturbing the plots and green gram seeds were sown in lines at a row spacing of 30 cm at a recommended seed rate of 25 kg ha^{-1}. Inorganic chemical fertilizers at 20-40-40 kg ha^{-1} N, P_2O_5 and K_2O, respectively, were applied to each experimental plot of green gram.

Analytical procedure

Composite plant samples of both weeds and grown crops, viz. rice and green gram of three replications for each treatment, were collected and analyzed for N, P and K contents after oven drying at 70 °C, followed by finely grinding and sieving through a 2 mm sieve. The detailed procedure of plant NPK analysis is mentioned in our previous publication (18). NPK uptakes by weeds or crops were estimated by multiplying the biomass production of weeds or crops by their respective nutrient contents and presented in kg ha^{-1}. Similarly, soil NPK contents were also analyzed to calculate the nutrient balance sheet, as mentioned in the study (19).

Statistical analysis

The variance analysis approach developed by Fisher was used to analyze the experiment's results (20). For this study, the two-way ANOVA model was used. Treatment variation was examined using the least significant difference (LSD) values at a 5% threshold of significance and regression analysis was carried out using the procedures outlined by Cochran and Cox (21).

Results

Nutrient uptake by crops

The highest nitrogen uptake by rice grain and straw was recorded in puddled transplanted rice (PTR), which WSR and NPTR followed, while the lowest was recorded by DSR during the 1st and 2nd years, both (Table 2). Comparing diverse weed management practices, W2, i.e., bensulfuron methyl + pretilachlor at 0.660 kg ha^{-1} *fb* HW after 1 month, showed the maximum values of grain and straw N uptake. At the same time, the lowest was recorded in the weedy check. The highest phosphorus uptake by rice grain was recorded in NPTR, followed by PTR, while among weed management practices, there was the highest P uptake by both rice grain and straw under W2 during both years. The highest P uptake by rice straw was recorded in PTR and WSR. The highest Potassium uptake by rice grain and straw was recorded in the PTR plot, followed by WSR among the different establishment methods adopted. Among the different weed control measures, the highest K uptake was found with W2 during both years. Concerning succeeding crop green gram during the rabi season, the highest N uptake by green gram seeds and haulm was recorded in succeeding plot of NPTR followed by DSR among crop establishment methods adopted, while the highest N-uptake by green gram was recorded in W_6 (brown manured plot) followed by W2 comparing different weed control measures adopted in rice cultivation in the kharif during both years (Table 3).

The highest P uptake by green gram seed was recorded in succeeding plots of NPTR concerning varied establishments and in green/brown manuring plots concerning different weed management aspects during both years. On the other hand, the highest P uptake by green gram haulm was recorded in the succeeding plots of DSR. Similar results as recorded in the case of P-uptake by green gram were also observed regarding K-uptake by green gram seeds and haulm.

Nutrient uptake by weeds in rice

Significantly highest uptake of nitrogen, phosphorus and potassium by weed was recorded in DSR and this establishment was followed by NPTR, WSR and PTR (Table 4). PTR resulted in the best attainments of nutrient uptake by the crop and the least values of nutrient removal by the weeds, while the DSR system showed just the opposite results. The lowest nutrient uptake by weed was recorded with the W2 being followed by W4, while the maximum amount of uptake was found under the weedy check (W1).

Table 2. Rice grain and straw nutrient uptake (kg ha^{-1}) under different crop establishments and weed management practices applied in rice

Treatment	Nitrogen						Phosphorus						Potassium					
	Grain		Straw		Total		Grain		Straw		Total		Grain		Straw		Total	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Establishment Methods																		
M_1	40.7^b	45.4^c	18.0^d	18.9^c	58.7^c	64.3^c	10.0^c	11.2^c	3.7^b	3.8^c	13.7^c	15.0^c	13.5^c	15.0^c	66.5^c	69.4^c	80.0^d	84.4^c
M_2	58.6^a	63.0^b	25.2^c	26.0^b	83.8^{ab}	89.0^b	14.1^b	15.3^b	5.1^a	5.2^a	19.2^b	20.5^b	19.0^a	20.5^{ab}	91.9^{ab}	93.6^a	110.9^b	114.1^a
M_3	57.3^a	61.3^b	25.7^b	26.2^b	83.0^b	87.5^b	15.2^a	16.1^a	5.1^a	5.1^b	20.3^a	21.2^a	18.5^b	19.8^b	91.4^b	92.0^b	109.9^c	111.7^b
M_4	60.8^a	65.5^a	26.1^a	27.0^a	86.9^a	92.5^a	14.2^{ab}	15.4^b	5.1^a	5.2^a	19.2^b	20.6^b	19.2^a	20.7^a	92.8^a	94.6^a	112.0^a	115.3^a
LSD (0.05)	4.19	2.33	0.31	0.46	3.9	2.33	1.05	0.56	0.06	0.09	1.01	0.55	1.32	0.74	1.14	1.62	0.85	1.69
Weed management measures																		
W_1	22.6^e	20.5^f	12.0^d	9.8^e	34.7^d	30.3^d	5.3^e	4.8^e	2.4^e	2.0^d	7.7e	6.9e	6.3.0e	5.8^f	42.5^e	35.7^e	48.8^e	41.5^e
W_2	67.9^a	73.4^a	28.4^a	29.6^a	96.3^a	102.9^a	16.9^a	18.1^a	5.4^a	5.5^{ab}	22.3^a	23.6^a	22.4^a	24.0^a	100.0^a	102.6^a	122.4^a	126.6^a
W_3	53.4^d	58.4^e	23.4^c	25.2^d	76.8^c	83.6^c	12.7^d	14.0^d	4.8^d	4.9^c	17.5^d	18.9^d	15.9^d	17.4^e	85.2^d	88.5^d	101.1^d	105.8^d
W_4	66.6^a	71.4^b	26.1^b	26.6^c	92.7^a	98.0^a	16.0^b	17.3^b	5.2^c	5.4^b	21.2^b	22.6^b	21.7^a	23.3^b	96.2^b	97.0^c	117.9^b	120.3^c
W_5	58.9^b	65.5^c	26.3^b	28.2^b	85.2^b	93.7^b	15.8^b	17.5^{ab}	5.3^b	5.6^a	21.1^b	23.2^{ab}	20.0^b	22.2^c	96.8^b	101.7^b	116.8^b	123.9^b
W_6	56.7^c	63.7^d	26.2^b	27.7^b	82.9^{bc}	91.5^b	13.6^c	15.2^c	5.2^c	5.6^a	18.8^c	20.7^c	19.0^c	21.3^d	93.2^c	98.7^c	112.2^c	120.0^c
LSD (0.05)	NS	NS	0.61	0.92	6.79	5.23	0.77	0.78	0.07	0.11	0.78	0.81	0.91	0.99	1.21	1.89	1.65	2.23

M_1- DSR, M_2- WSR, M_3-NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1}*fb*manual hand-weeding at 30 DAS/T, W_3- W2 herbicidesat 0.495kgha^{-1}*fb* HW after 1 month, W_4- W2 herbicides at 0.495kgha^{-1}*fb*post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring. Mean values followed by varied small letters are statistically significant at a 5% probability level; NS: non-significant.

Foot Notes: - DSR: Direct seeded Rice, WSR: Wet Seeded Rice, NPTR: Non-Puddled Transplanted Rice, PTR: Puddled Transplanted Rice

Table 3. Green gram grain and haulm nutrient uptake (kg ha^{-1}) under different crop establishments and weed management practices applied in rice

Treatment	Nitrogen						Phosphorus						Potassium					
	Grain		Haulm		Total		Grain		Haulm		Total		Grain		Haulm		Total	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Establishment methods																		
M_1	16.1^{b}	16.7^{b}	36.7^{a}	36.4^{a}	52.8^{b}	53.1^{a}	1.2^{b}	1.3^{b}	3.2^{a}	3.4^{a}	4.4^{a}	4.8^{a}	5.0^{b}	4.6^{b}	31.4^{a}	31.7^{a}	36.3^{a}	36.2^{a}
M_2	14.8^{c}	15.5^{c}	30.1^{c}	32.1^{c}	44.8^{d}	47.6^{c}	1.1^{c}	1.2^{c}	2.5^{c}	2.9^{c}	3.6^{b}	4.1^{c}	4.5^{c}	4.4^{c}	25.5^{c}	27.1^{c}	30.0^{c}	31.5^{c}
M_3	17.1^{a}	17.5^{a}	36.7^{a}	33.7^{b}	53.7^{a}	51.2^{b}	1.3^{a}	1.4^{a}	3.1^{b}	3.2^{b}	4.4^{a}	4.6^{b}	5.4^{a}	4.9^{a}	30.9^{a}	28.6^{b}	36.4^{a}	33.5^{b}
M_4	14.1^{d}	14.1^{d}	32.7^{b}	31.7^{d}	46.8^{c}	45.8^{d}	1.0^{d}	1.1^{d}	2.5^{c}	2.7^{d}	3.6^{b}	3.8^{d}	4.3^{d}	3.8^{d}	27.1^{b}	26.8^{d}	31.4^{b}	30.6^{d}
LSD (0.05)	0.46	0.22	0.71	0.48	0.83	0.49	0.04	0.02	0.06	0.05	0.07	0.06	0.14	0.06	0.59	0.46	0.6	0.47
Weed management measures																		
W_1	12.4^{e}	13.7^{e}	28.8^{d}	31.1^{e}	41.3^{d}	44.8^{d}	0.8^{d}	0.9^{d}	2.3^{e}	2.6^{e}	3.1^{d}	3.6^{e}	3.2^{f}	3.4^{f}	23.4^{e}	25.3^{d}	26.6^{e}	28.7^{e}
W_2	16.4^{b}	16.2^{c}	34.7^{b}	33.0^{c}	51.0^{b}	49.2^{b}	1.2^{b}	1.3^{b}	2.9^{b}	3.1^{c}	4.0^{b}	4.3^{c}	5.1^{b}	4.3^{d}	30.2^{b}	29.2^{b}	35.3^{b}	33.4^{c}
W_3	15.0^{d}	15.0^{d}	34.6^{b}	31.3^{d}	49.6^{bc}	46.2^{c}	1.0^{c}	1.2^{c}	2.7^{d}	2.8^{d}	3.8^{c}	4.0^{d}	4.7^{e}	4.1^{e}	29.9^{b}	28.0^{c}	34.6^{c}	32.1^{d}
W_4	15.5^{c}	16.5^{b}	34.0^{c}	35.5^{a}	49.4^{c}	52.0^{a}	1.2^{b}	1.3^{b}	2.8^{c}	3.2^{b}	4.0^{b}	4.5^{b}	4.9^{d}	4.6^{c}	29.4^{c}	30.6^{a}	34.3^{c}	35.2^{a}
W_5	15.6^{c}	16.7^{b}	33.7^{c}	35.5^{a}	49.2^{c}	52.2^{a}	1.2^{b}	1.3^{b}	2.8^{c}	3.2^{b}	4.0^{b}	4.5^{b}	5.0^{c}	4.8^{b}	28.6^{d}	29.2^{b}	33.6^{d}	34.0^{b}
W_6	18.2^{a}	17.5^{a}	38.4^{a}	34.6^{b}	56.7^{a}	52.1^{a}	1.6^{a}	1.6^{a}	3.5^{a}	3.4^{a}	5.1^{a}	5.0^{a}	5.9^{a}	5.3^{a}	31.0^{a}	29.0^{b}	36.8^{a}	34.3^{b}
LSD (0.05)	0.307	0.285	0.432	0.42	0.535	0.613	0.024	0.023	0.036	0.06	0.045	0.06	0.096	0.079	0.361	0.555	0.376	0.546

M_1- DSR, M_2- WSR, M_3- NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1}*fb* manual hand-weeding at 30 DAS/T, W_3- W2 herbicides at 0.495 kg ha^{-1}*fb* HW after 1 month, W_4- W2 herbicides at 0.495 kg ha^{-1}*fb* post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring. Mean values followed by varied small letters are statistically significant at a 5% probability level.

Foot Notes: - DSR: Direct seeded Rice, WSR: Wet Seeded Rice, NPTR: non-puddled Transplanted Rice, PTR: Puddled transplanted rice

Table 4. Nutrient removal (uptake) by weed (kg ha^{-1}) under varied rice establishments and weed control measures

Treatments	Nitrogen		Phosphorus		Potassium	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Establishment methods						
M_1	11.3^{a}	12.7^{a}	5.4^{a}	6.2^{a}	17.8^{a}	19.9^{a}
M_2	8.2^{b}	9.1^{b}	4.4^{b}	4.9^{b}	13.2^{b}	14.9^{b}
M_3	8.5^{b}	9.4^{b}	4.3^{bc}	4.8^{b}	13.6^{b}	15.0^{b}
M_4	6.9^{c}	7.9^{c}	3.9^{c}	4.5^{b}	10.9^{c}	12.3^{c}
LSD (0.05)	0.6	0.7	0.5	0.4	0.7	0.6
Weed management measures						
W_1	25.1^{a}	28.3^{a}	13.1^{a}	14.9^{a}	39.8^{a}	45.0^{a}
W_2	2.7^{f}	3.2^{f}	1.3^{e}	1.6^{e}	4.3^{f}	5.1^{f}
W_3	7.1^{c}	7.6^{c}	3.6^{c}	3.9^{c}	11.5^{c}	12.1^{c}
W_4	3.9^{e}	4.7^{e}	2.0^{d}	2.3^{d}	6.3^{e}	7.4^{e}
W_5	5.3^{d}	5.8^{d}	2.7^{c}	2.9^{d}	8.5^{d}	9.3^{d}
W_6	8.1^{b}	9.0^{b}	4.2^{b}	4.8^{b}	12.8^{b}	14.4^{b}
LSD (0.05)	0.3	0.6	0.5	0.6	0.6	0.5

M_1- DSR, M_2- WSR, M_3- NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1}*fb* manual hand-weeding at 30 DAS/T, W_3- W2 herbicides at 0.495 kg ha^{-1}*fb* HW after 1 month, W_4- W2 herbicides at 0.495 kg ha^{-1}*fb* post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring. Mean values followed by varied small letters are statistically significant at a 5% probability level.

Foot Notes: - DSR: Direct seeded Rice, WSR: Wet Seeded Rice, NPTR: non-puddled Transplanted Rice, PTR: Puddled transplanted rice

Nutrient balance in the soil

Fig. 1a-c represents the nutrient balance in soil under different establishment and weed management practices. Detailed estimations are included in Supplementary Tables 1, 2 & 3. An inspection of data disclosed that there was the highest gain of total soil available nitrogen in DSR in both years, followed by NPTR among crop establishment methods, while among weed management practices, it was found to be the highest under green/brown manuring plots. Total gain of available soil phosphorus was found to be the highest under PTR, followed by WSR among crop establishment methods. At the same time, the brown-manured plot resulted in the best attainments concerning soil P-balance. The highest gain of soil available potassium was recorded in NPTR, followed by DSR, concerning rice establishments. On the other hand, the green/brown manuring plots again showed the best result regarding soil K-balance.

Yield

Different crop establishment techniques and weed control measures had a significant impact on rice grain output. The highest values of rice economic (grain) and by-product (straw) yield were recorded in PTR among different crop establishment methods. The weed control practice, W2, exhibited the highest grain and straw yield during both years, concerning different weed management approaches (Fig. 2). Among . In contrast, DSR plots yielded the highest haulm during the 1st and 2nd years. The various crop establishment methods adopted for kharif rice resulted in the succeeding plot of NPTR showing the highest green gram seed yield. In contrast, the DSR plots yielded the highest haulm during the 1st and 2nd years. Concerning diverse weed management practices followed in different rice-establishment methods, the succeeding plots of W6 exhibited the highest seed yield during both years and the highest haulm yield was recorded under W2 (Fig. 3). The grain yield and nutrient uptake relationship were depicted in Figure

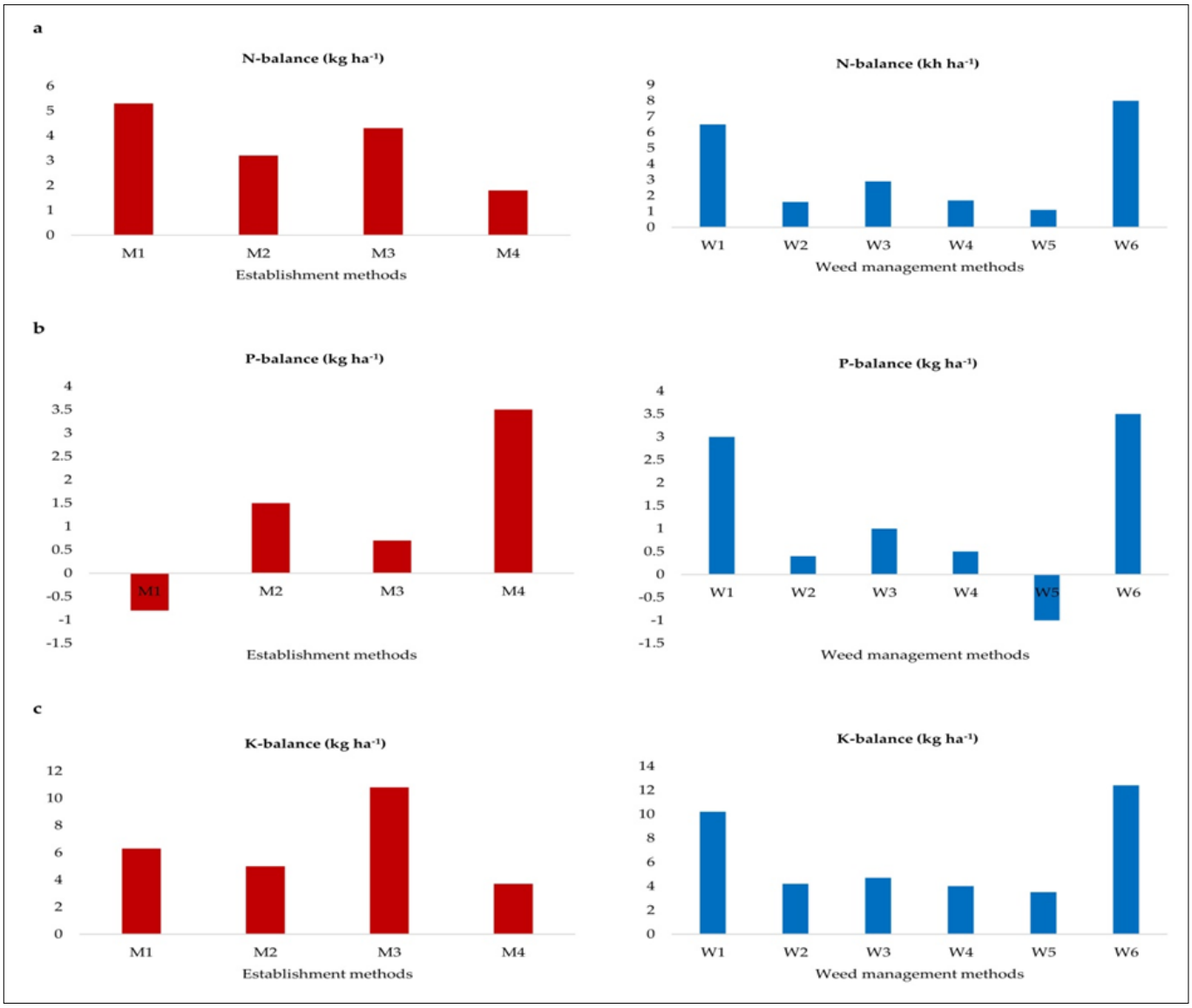

Fig. 1. Nutrient balance, a. N-balance, b. P-balance, c. K-balance under different treatments adopted in rice.

M_1- DSR, M_2- WSR, M_3- NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1} *fb* manual hand-weeding at 30 DAS/T, W_3- W2 herbicides at 0.495 kg ha^{-1} *fb* HW after 1 month, W_4- W2 herbicides at 0.495 kg ha^{-1} *fb* post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring.

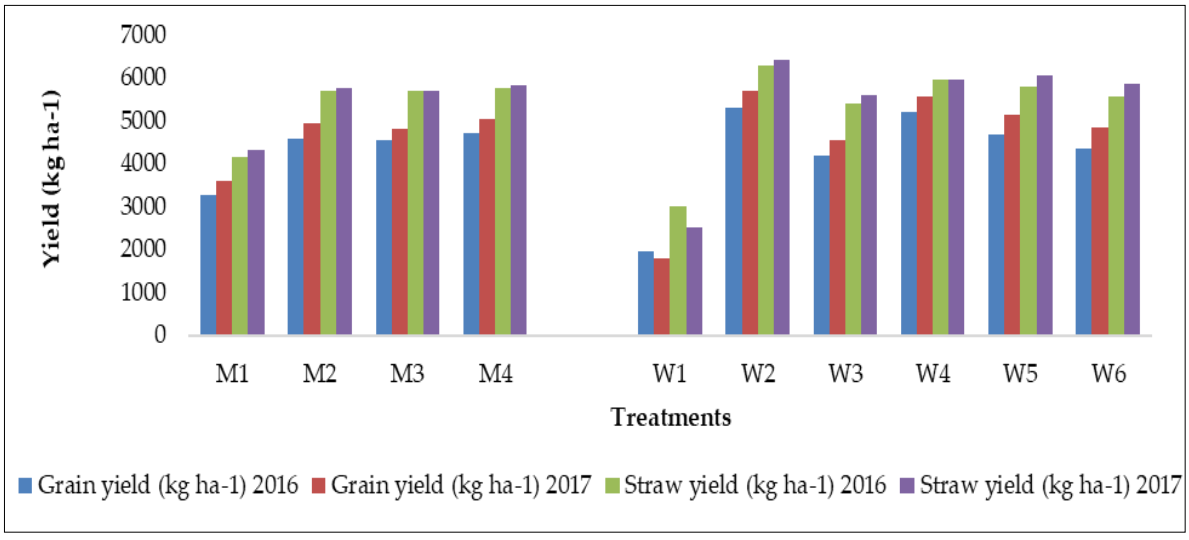

Fig. 2. The impact of crop establishment techniques and weed control measures on rice grain and straw yield (kg ha-1).

M_1- DSR, M_2- WSR, M_3- NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1} *fb* manual hand-weeding at 30 DAS/T, W_3- W2 herbicides at 0.495 kg ha^{-1} *fb* HW after 1 month, W_4- W2 herbicides at 0.495 kg ha^{-1} *fb* post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring.

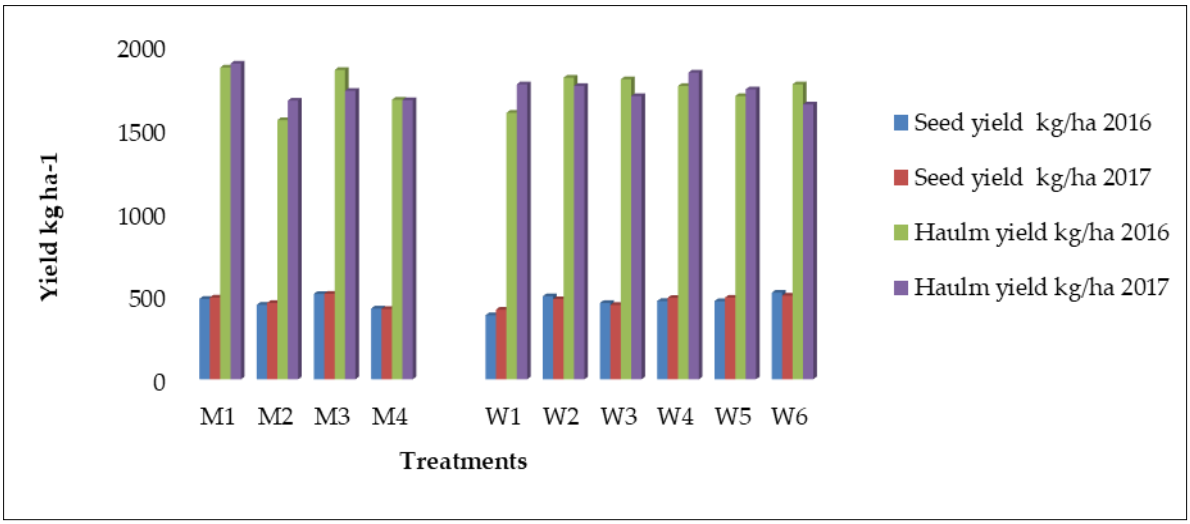

Fig. 3. Seed and haulm yield (kg ha^{-1}) of the succeeding crop, green gram under different treatments adopted in rice.

M_1- DSR, M_2- WSR, M_3- NPTR, M_4- PTR; W_1- no weed management (weedy check), W_2- Bensulfuron methyl 0.6% + Pretilachlor 6% (PE) at 0.660 kg ha^{-1}*fb* manual hand-weeding at 30 DAS/T, W_3- W2 herbicides at 0.495 kg ha^{-1}*fb* HW after 1 month, W_4- W2 herbicides at 0.495 kg ha^{-1}*fb* post-emergence bispyribac sodium at 0.025 kg ha^{-1} at 15 DAS/T, W_5- mechanical weeding with cono-weeder at 15 DAS/T *fb* hand weeding 30 DAS/T, W_6- Brown manuring/ green manuring.

4a-c. The numbers also showed that grain yield increased by 74 and 73 units in 2016 and 2017, respectively, for every unit increase in nitrogen uptake. In both years, the variance in grain yield explained by nitrogen uptake was around 99%; in contrast, phosphorus increased by 284 and 286 units, respectively. The percentages of variation explained are approximately 97% and 91%, respectively. Grain yield for 2016 and 2017 will fluctuate by 208 and 211 units, respectively, for every unit change in potassium. For the years 2016 and 2017, potassium accounts for 88% and 90% of the fluctuation, respectively.

Discussion

PTR recorded the highest total nitrogen and phosphorus uptake, where the trend was as follows: PTR> WSR> NPTR > DSR. NPTR recorded the highest phosphorus uptake, where the trend was NPTR> PTR >WSR >DSR. Higher uptake of nutrients (Nitrogen, Phosphorus and Potassium) in puddled transplanted rice (22). At the same time, the lowest was also recorded in dry direct-seeded rice, which might be the result of a favourable soil environment for nutrient uptake that enhanced the dry matter production (23, 24). DSR recorded the highest total nitrogen, phosphorus and potassium uptake by green gram, which NPTR, PTR and WSR followed. Better NPK uptake by rice under PTR might be explained by lower weed pressure in this establishment, as weed suppression is common during puddling (25). Low weed pressure facilitated low nutrient removal by weeds, resulting in better nutrient availability for the crop, thereby ensuring higher uptake (25). Higher nutrient uptake by weeds recorded in DSR plots might be attributed to higher weed count and dry weight in DSR (26). In contrast, the lowest nutrient uptake by weeds was recorded in PTR treatment, which might be due to low weed population and weed dry weight, which is a combined result of methods of crop establishment, soil puddling that churned weeds and decomposed that and maintaining standing water preventing the weeds seeds to germinate that in turn resulted in lower weed population, weed dry weight and low nutrient uptake by weeds (27). Application of W2 treatment showed the highest uptake of nitrogen, phosphorus and potassium by rice, which might be due to maintaining almost weed-free conditions year-round that enabled the plants to utilize the maximum nutrients from the soils. In succeeding green gram, the highest values of nutrient uptake in green gram were recorded in green/brown manuring plots, which might be attributed to better nutrient availability due to green or brown manuring (28). The lowest values of nutrient uptake by both crops were recorded in the weedy check plot, as under this treatment, there were no weed management measures adopted, resulting in the maximum weed growth as well as biomass, which ultimately facilitated higher NPK uptake by weeds (29).

Puddled transplanted rice (PTR) recorded the highest rice grain yield, which was at par with WSR and NPTR. PTR, WSR and NPTR recorded 29.6%, 27.8% and 26.7% higher grain yields than those under DSR. The combined influence of yield-attributing traits, such as panicle m^{-2}, panicle length, number of whole grains and test weight, results in higher grain production. Under PTR, better formation of yield-attributing characters was possible, which ultimately resulted in higher biomass production (30, 10). Among different weed management practices, W2 exhibited the maximum grain and straw yield, which might be attributed to better weed management resulting in the lower crop-weed competition being reflected through higher yield (31, 32). On the other hand, better NPK uptake of rice was found under PTR and W6 concerning establishment methods and weed management practices, respectively. There was a strong correlation between seed nutrient uptake and seed yield as observed in Fig. 4a-c. Such a strong relationship also justified our findings.

The succeeding crop, green gram, yielded the best result in the residual plot where NPTR was adopted in rice, matching the yield obtained in DSR. Better soil health, in terms of favorable soil structure, might be attributed to promoting better growth and yield in NPTR and DSR, which were not affected by puddling. There might be soil aggregate

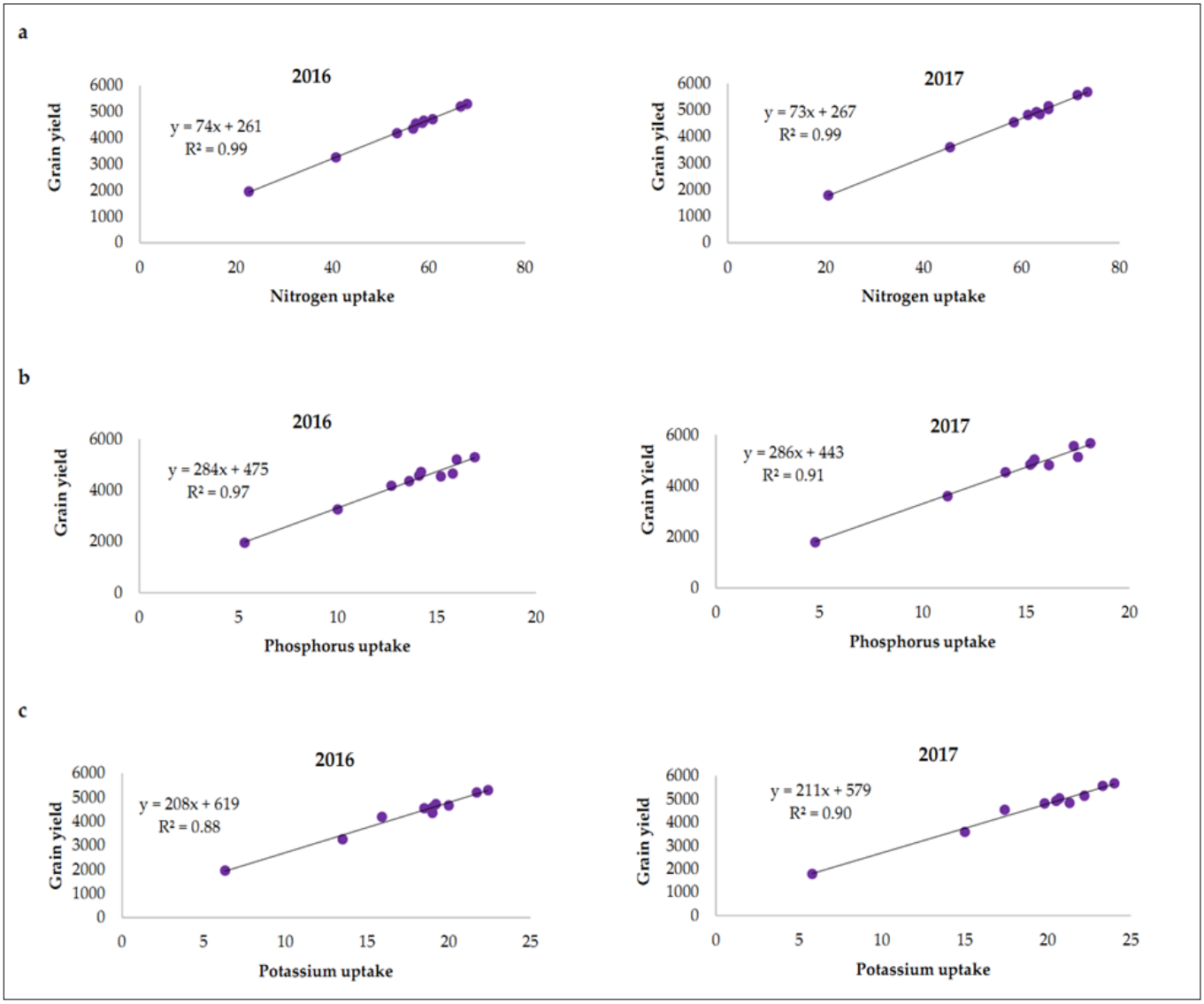

Fig. 4. Linear regression between rice grain yield (kg ha^{-1}) and a. nitrogen, b. phosphorus and c. potassium uptake (kg ha^{-1}) by rice grain.

destruction, capillary pore breakdown and soil dispersion due to continuous heavy soil disturbance with puddling operation, resulting in elevated bulk density of soil, which is not suitable for cultivation in the long run (33). On the contrary, (34) found that there was not much significant effect on green gram grown as a succeeding crop after varied rice establishments. Green gram grown in residual soil of green/brown manuring showed a higher value of yield, which might be the result of better soil health status and better nutrient availability (28).

Conclusion

The results of the current investigation showed that overall nutrient uptake in puddled transplanted rice was higher than in other establishment methods, followed by wet-seeded rice. In comparison, among different weed management methods, the application of bensulfuron methyl 0.6% + pretilachlor 6% (PE) at 0.660 kg ha$^{-1,}$ followed by manual HW after 1 month of sowing or transplanting, resulted in better nutrient uptake as well as crop yield in rice. In the succeeding green gram, there was the highest nutrient uptake in plots, which was followed by direct-seeded rice and green/brown manuring. Soil NPK balance was the best under brown manuring or green manuring plots concerning different weed management options, while the best N-balance was found under DSR concerning different establishments. The best attainments of P -balance and K-balance were found under PTR and NRTR, respectively. From this two-year study, it can be concluded that puddled transplanting was the best establishment method for rice ensuring better weed control and higher yield, while chemical weeding with the application of ready-mix pre-emergence herbicide bensulfuron methyl 0.6% + pretilachlor 6% at 0.660 kg ha^{-1} followed by one hand weeding at 30 DAS/T was found to be the most suitable concerning yield, nutrient balance and weed control.

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Authors' contributions

SP, SJ and PKR formulated the research. SP and SJ carried out the study. PD and DKS performed statistical analysis. SP, PD and SM drafted the manuscript. SJ, PKR and SBM reviewed the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

References

1. IFPRI. International Food Policy Research Institute; 2010
2. Das A, Chandra S. Irrigation, spacing and cultivar effects on net photosynthetic rate, dry matter partitioning and productivity of rice under system of rice intensification in mollisols of northern India. Exp Agric. 2013;49(4):504–23. https://doi.org/10.1017/S0014479713000252
3. Pattanayak S, Jena S, Das P, Maitra S, Shankar T, Praharaj S, et al. Weed management and crop establishment methods in rice (*Oryza sativa* L.) influence the soil microbial and enzymatic activity in subtropical environment. Plants. 2022;11(8):1071. https://doi.org/10.3390/plants11081071
4. Hongyan L, Hussain S, Zheng M, Peng S, Huang J, Cui K, Nie L. Dry direct seeded rice as an alternative to transplanted flooded rice in Central China. Agron Sustain Dev. 2015;35:285–94. https://doi.org/10.1007/s13593-014-0239-0
5. Farooq M, Siddique KHM, Rehman H, Aziz T, Dong-Jin L, Wahid A. Rice direct seeding: experiences, challenges and opportunities. Soil Tillage Res. 2011;111(2):87–98. https://doi.org/10.1016/j.still.2010.10.008
6. Singh R, Pramanick B, Singh AP, Kumar NS, Kumar A, Singh G. Bio-efficacy of fenoxaprop-p-ethyl for grassy weed control in onion and its residual effect on succeeding maize crop. Indian J Weed Sci. 2017;49(1):63–66. http://doi.org/10.5958/0974-8164.2017.00015.6
7. Kumar V, Mahajan G, Sheng Q, Chauhan BS. Weed management in wet direct-seeded rice (*Oryza sativa* L.): Issues and opportunities. Adv Agron. 2023;179:91–133. https://doi.org/10.1016/bs.agron.2023.01.002
8. Haque ME, Bell RW, Islam MA, Rahman MA. Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crop Res. 2016;185:31–39. https://doi.org/10.1016/j.fcr.2015.10.018
9. Adhikari U, Justice S, Tripathy J, Bhatta M, Khan S. Evaluation of non-puddled and zero till rice transplanting methods in monsoon rice. In: Proceedings of International Agricultural Engineering Conference; 2007. AIT Bangkok, Thailand.
10. Kaurk, Gill KK, Singh P, Sandhu SS. Crop establishment methods and management practices impact on rice yield parameters in central Punjab. Indian J Agron. 2024;69(2):122-29. https://doi.org/10.59797/ija.v69i2
11. Voase-Ringrose AJ, Kirby JM, Djoywasoito G, Sanidad WB, Serrano C, Lando TM. Changes to the physical properties of soils puddled for rice during drying. Soil Till Res. 2000;56(1-2):83–104. https://doi.org/10.1016/S0167-1987(00)00124-0
12. McDonald AJ, Riha SJ, Duxbury JM, Steenhuis TS, Lauren JG. Soil physical responses to novel rice cultural practices in the rice–wheat system: comparative evidence from a swelling soil in Nepal. Soil Till Res. 2006;86:163–75. https://doi.org/10.1016/j.still.2005.02.005
13. Rathod BGS, Somasundaram E. Nutrient uptake by weeds and rice under different organic weed management practices. Int J Chem Stud. 2017;5(4):2050–53.
14. Sankaran S, Mani VS. Comparative efficiency of physical, chemical and combination methods of weed control in grain sorghum. Madras Agric J.1974;61(4):244–52. https://doi.org/10.29321/MAJ.10.A03409
15. Revathi M, Prabhakaran, NK, Chinnusamy C, Meena S. Influence of establishment methods and weed management practices on nutrient removal by weeds and uptake by rice in puddled lowland. Madras Agric J. 2012;99(7-9):496–99. https://doi.org/10.29321/MAJ.10.100123
16. Reddy BGM, Ravishankar G, Balganvi S, Joshi VR, Negalur RK. Efficacy of bensulfuron methyl plus pretilachlor for controlling weeds in transplanted rice. Oryza. 2012;9(1):65–67.
17. Zahan T, Hossain MF, Chowdhury AK, Ali MO, Ali MA, Dessoky ES, et al. Herbicide in weed management of wheat (*Triticum aestivum* L.) and rainy season rice (*Oryza sativa* L.) under conservation agricultural system. Agronomy. 2021;11(9):1704. https://doi.org/10.3390/agronomy11091704
18. Kumar M, Mitra S, Mazumdar SP, Majumdar B, Saha AR, Singh SR, et al. Improvement of soil health and system productivity through crop diversification and residue incorporation under jute-based different cropping systems. Agronomy. 2021;11:1622. https://doi.org/10.3390/agronomy11081622
19. Pramanick B, Brahmachari K, Kar S, Mahapatra BS. Can foliar application of seaweed sap improve the quality of rice grown under rice–potato–green gram crop sequence with better efficiency of the system. J Appl Phyco. 2020;32:3377–86. https://doi.10.1007/s10811-020-02150-z
20. Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research, 2nd ed, New York, J Wiley & Sons; 1984
21. Cochran WG, Cox GM. Experimental Designs, 2nd ed, New York: J Wiley & Sons; 1992
22. Vineela K, Subramanyam D, Sagar GK, Madhuri KVN, Sudhakar P, Chandrika V. Nutrient uptake of rice as influenced by different systems of rice cultivation and organic nutrient management practices. J Res ANGRAU. 2024;52(1):30–38. https://doi.org/10.58537/jorangrau.2024.52.1.04
23. Shahane AA, Shivay YS, Prasanna R, Kumar D. Nitrogen nutrition and use efficiency in rice as influenced by crop establishment methods, cyanobacterial and phosphate solubilizing bacterial consortia and zinc fertilization. Commun Soil Sci Plant Anal. 2019;50(12):1487–99. https://doi.org/10.1080/00103624.2019.1626876
24. Deo M, Chaudhary M, Adhikari BB, Kandel BP. Study of the effect of tillage, seed priming and mulching on direct seeded rice variety sukhadhan-5 in mid hills of Nepal. Azarian J Agric. 2019;6(3):74–79. https://doi.org/10.29252/azarinj.010
25. Anbumani S, Chandrashekharan B, Kuppuswamy G. Evaluation of establishment methods and NPK levels in rice and their impact on succeeding crops. Agric Sci Digest. 2004;24(3):190–93.
26. Ghosh D, Brahmachari K, Brestic M, Ondrisik P, Hossain A, Skalicky M, et al. Integrated weed and nutrient management improve yield, nutrient uptake and economics of maize in the rice –maize cropping system of eastern India. Agronomy. 2020;10:1906. https://doi.org/10.3390/agronomy10121906
27. Manjunatha KB, Hanumanthappa M, Nagesh L, Kalyanmurthy KN, Kamanth SKV, Jayaprakash SM. Effect of new herbicide molecules on growth and yield of transplanted rice (*Oryza sativa*) in coastal Karnataka. The Mysore J Agric Sci. 2013;47(1):65–67.
28. Lliger MD, Sutar R, Chogatapur SV, Parameshwarareddy R. Effect of brown manuring on soil properties, weed density, grain yield and economics of different crops. Adv Res. 2017;12(6):1–11. https://doi.org/10.9734/AIR/2017/38527
29. Talla A, Jena SN. Nutrient composition, uptake by weeds and rice under different crop establishment and weed management practices. Int J Environ Agric Biotechnol. 2014;7(4):811–16. https://doi.org/10.5958/2230-732X.2014.01391.6

30. Awan TH, Ali RI, Manzoor Z, Ahmad M, Akhtar M. Effect of different nitrogen levels and row spacing on the performance of newly evolved medium grain rice variety, KSK-133. J Anim Sci. 2011;21 (2):231–34.

31. Sunil CM, Sekara BG, Murthy KN, Shankaralingappa BC. Growth and yield of aerobic rice as influenced by integrated weed management practices. Indian J Weed Sci. 2010;42(3 & 4):180–83. https://isws.org.in/IJWSn/File/2010_42_Issue-3&4_180-183.pdf

32. Kumar RS, Durairaj SN, Daisy M, Archana HA. Studies on weed management practices in transplanted rice. Trends Biosci. 2014;7 (23):3882–85.

33. Gupta RK, Hobbs PR, Harrington L, Ladha JK. Rice-wheat system: Problem analysis and strategic entry points. In: Mathur PN, Chacko E, Braganza M, Vijaykumar S, editors. Addressing resource conservation issues in rice-wheat systems of South Asia: A resource book, Rice Wheat Consortium for the Indo-Gangetic Plains-International Maize and Wheat Improvement New Delhi: RWC-CIMMYT; 2003. 16–23

34. Mohanty TR, Roul PK Maity SK. Energetics of green gram (*Vigna radiata* L.) production as affected by residual effect of rice establishment methods and nutrient management practices in rice-green gram cropping system. IOSR J Agric Vet Sci. 2014;7 (7):51–54. https://doi.org/10.9790/2380-07735154

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