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Interactive effect of nutrient and weed management in transplanted rice (*Oryza sativa* L.) for enhancing the productivity in Eastern India

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Abstract

A field experiment comprising three nutrient and six weed management practices was conducted in strip plot design with three replications during 2019 and 2020 at Odisha University of Agriculture & Technology (OUAT), Bhubaneswar, India to assess the effect of the treatments on weed dynamics, productivity and nutrient uptake by crop and weed. Averaged over both years, among nutrient management practices, the soil test based dose (STD: 100-40-40 N-P_2O_5-K_2O kg ha^{-1}) + green manuring (GM) of *dhaincha* recorded the minimum weed density of 45.3 and 64.2 number m^{-2} and weed biomass of 19.2 and 37.6 g m^{-2} at 30 and 60 days after transplanting (DAT), respectively and the minimum N, P and K uptake of 6.4, 2.0 and 6.8 kg ha^{-1} by weed and the maximum N, P and K uptake of 113.6, 23.2 and 122.6 kg ha^{-1} by the crop, respectively. Among weed management practices, bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT produced the minimum weed density of 25.15 and 20.66 number m^{-2}, the minimum weed biomass of 7.70 and 8.08 g m^{-2} at 30 and 60 DAT, respectively and the minimum N, P and K uptake of 2.4, 0.5 and 2.6 kg ha^{-1} by weed and the maximum N, P and K of 117.9, 25.3 and 263.7 kg ha^{-1} by crop, respectively. Among nutrient management practices, the STD + GM proved to be the best with the maximum grain yield of 5562 kg ha^{-1}. whereas the application of bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT excelled over other weed management practices with the maximum grain yield of 5907 kg ha^{-1} registering 17.71 and 47.64% higher grain yield compared to the STD and the weedy check, respectively.

Keywords

bensulfuronmethyl; pretilachlor; green manure; fym; rice; weed dynamics

Introduction

Rice (*Oryza sativa*) is consumed by more than half of the World's population (1). India is the second leading producer of rice, contributing 24% of global rice production (2). In eastern Indian states, rice-based cropping systems are the most dominant system, covering 43% of the country's rice growing area. Moreover, rice productivity in the wet season has also been stagnant for the past two decades in Eastern India (3). In India, rice is mainly grown using a system known as puddling transplanting (PT), which offers numerous benefits including weed suppression, optimum plant population and nutrient availability (4) and still the yield losses due to weeds were about 16.0% (5). With more reliability on agrochemicals and imbalanced nutrient management practices, rice soils are getting deprived of their inherent fertility and factor productivity in many Asian countries (6). Compared to the national average, the average rice yield in this region is low due to improper nutrients and weed management (7). So, improving the profitability and resource use efficiency fitting to the local agro ecological situation is the present need. The significance of leguminous green manure crops *Sesbania bispinosa* (Jacq.) W.Wight (*dhaincha*) in improving soil health and productivity has received increasing attention in recent times (8). Organic sources (FYM and green manure), apart from improving innate properties of soil, enhance the nutrient use efficiency (9). The addition of green manure increases the nitrogen uptake rates by rice, indicating a better synchrony between green manure nitrogen availability and nitrogen uptake. Nitrogen-use efficiency increases with the application of urea in combination with farm yard manure (FYM) (10). The application of organic manures may upgrade the soil health for harnessing better rice yield in this region. The incorporation of *Sesbania bispinosa in situ* at the age of 42 days helped in suppressing weed population in rice through allelopathic weed interference and reducing weed seed bank in soil, as well as by covering the ground extensively to prevent the weeds growth beneath them (11). Proper nutrient management can improve the competitiveness of crops, decrease weed density and alter the species composition of the weed community (12). Again, it was observed that weeds absorb more than 60% of applied fertilizers, resulting in poorer nutrient availability for crops (13). Weed nutrient uptake depends on the duration of their growth, but due to labour shortage and increased wages, controlling weeds at critical stages by manual weeding alone is very difficult and unprofitable as well. Herbicides with a single mechanism of action will not be effective against a wide range of weeds. Persistence of the herbicides in the field is only up to 30 DAT (14). So, to control these broad-spectrum weeds, herbicide formulations with various modes of action combined with hand weeding will result in effective weed control, lesser nutrient loss via weeds, accompanied by more crop nutrient uptake (15). The basic research hypothesis is that integration of rational fertilisation and effective weed management practices can enhance the competitive advantage of rice by suppressing the weed growth and reducing the loss of nutrients due to weed, thereby making it available for crop to achieve a higher yield in a sustainable manner.

Materials and Methods

Experimental site and soil characteristics

The experiment on transplanted rice (*Oryza sativa* L.) was established in 2019 at Instructional Farm, Odisha University of Agriculture and Technology, Bhubaneswar, India. The field study was carried out during *kharif* season 2019 and 2020. The experimental location is positioned in Odisha's East and South Eastern Coastal Plain agro-climatic zone with moist hot type climate. Rainfall totaled 1125 mm with 79 rainy days during the growth cycle of rice in 2020, compared to 1233 mm with 86 rainy days in 2019. At the time of initiation of the experiment, the soil (0-15 cm) was sandy loam (71.9% sand, 10.7% silt and 17.1% clay) and had 5.02 g kg^{-1} oxidizable soil organic carbon (16), 218.6 kg ha^{-1} alkali hydrolyzable N (17), 19.7 kg ha^{-1} NH_4FþHCl-extractable P (18) and182.6 kg ha^{-1} NH_4OAc-exchangeable K (19).

Experimental design and treatment details

The experiment was carried out in a strip plot design with three horizontal and six vertical plots replicated thrice. Three nutrient management practices, *viz*. N_1: Soil Test based Dose (STD:100-40-40 N-P_2O_5-K_2O kg ha^{-1}), N_2:N_1+ FYM @5t ha^{-1} and N_3:N_1+ green manuring of *dhaincha* and six weed management practices, *viz*. W_1:pre-emergence (PE) application of bensulfuron methyl (0.6%) + pretilachlor (6%) GR @0.66 kg ha^{-1}, W_2:W_1+ one hand weeding (HW) at 35 days after transplanting (DAT), W_3:Pyrazosulfuron ethyl (10% WP) @ 0.02 kg ha^{-1} (PE), W_4:W_3+ one HW at 35 DAT, W_5:Two HW at 25 and 40 DAT and W_6:Weedy check were allocated to horizontal and vertical plots of strip plot design, respectively, in *kharif* rice with each cross-section plot size of 5.4 m x 5.0 m in both years.

Crop and nutrient management

The non-lodging rice cultivar "Maudamani (CR-307)" (135 days duration) was sown in nursery on 4^{th} and 6^{th} July of 2019 and 2020, respectively. Field preparation for transplanting was done as per treatment details. With the onset of monsoon, a green manuring crop (*Sesbania bispinosa*) @ 25 kg ha^{-1} was sown in plots as per treatment specifications and incorporated after 42 DAS. The FYM was incorporated before final puddling. Out of soil test-based dose of fertilizer, $1/3^{rd}$ N as urea, full P_2O_5 as DAP and full K_2O as MOP were applied as basal. Rest $2/3^{rd}$ N was applied at tillering and panicle initiation stages in equal splits. Before incorporation, total NPK content of *Sesbania* and FYM was analyzed using the Kjeldahl method (20) and the di-acid digestion method (21) and nutrients added by organic sources were estimated (Table 1). During both years, healthy rice seedlings 25-30 days old were transplanted at 20 cm x 15 cm spacing.

Table 1. Nutrient added through organic manures utilized in the investigation.

Organic Source	Year	Quantity Added (kg ha^{-1})	Nutrient Content (g kg^{-1})			Nutrient Added (kg ha^{-1})		
			N	P	K	N added	P added	K added
FYM	2019	5000	6.4	3.6	6.8	32.0	18.0	34.5
	2020	5000	6.7	3.8	7.1	33.5	19.0	36.0
Sesbania bispinosa	2019	2814	28.7	5.6	1.28	80.8	15.8	36.4
	2020	2970	29.8	5.8	1.32	88.5	17.2	39.2

(FYM: Farm yard manure; N:Nitrogen; P:Phosphorus; K:Potassium)

Collection and analysis of plant samples

Following rice harvesting, grain and straw samples were collected and dried until they reached a constant weight in a hot air oven at 70°C. The straw and grain samples were ground using an electric grinder to ensure uniform and complete digestion for nutrient analysis. The N was estimated using the micro-Kjeldahl distillation method with boric acid after digesting grain and straw samples in 400°C concentrated H_2SO_4 (22). The total P and K concentration of straw and grain was determined by diacid digestion with a 3:1 ratio of conc. HNO_3:$HClO_4$. The P content was determined by the spectrophotometer method (23), whereas the K content was determined by the flame photometer method (22). The N, P and K uptake was calculated by multiplying grain yield and straw yield by the respective nutrient concentrations. The crop N, P and K uptake was calculated by adding the nutrient uptake by grain and straw.

Collection and analysis of weed samples

The uniform representative samples of weeds were randomly collected using quadrate of 0.25 m^2 (0.5 m × 0.5 m) from each plot at 30 and 60 DAT. The individual weed species and their densities were computed. The collected weeds were sundried, followed by oven drying (70°C) until they reached a constant weight. The weeds falling in the quadrate randomly at two points from each plot in all replications were identified and grouped. The data on weed density and biomass were recorded and subjected to square root of $\sqrt{x+0.5}$ transformations for statistical analysis.

Soil analysis

At the commencement of the experiment, 10 soil samples were collected from 0-15 cm soil layer and analyzed for different physical, chemical and biological parameters. Soil samples were collected from different sites in the field in zig-zag manner and blended for acquiring one composite soil sample. Grinding and processing of soil samples were done in a 2 mm sieve for analysis of different chemical parameters except soil organic carbon (SOC). Sieving of soil sample was done through 0.5 mm sieve for oxidizable soil organic carbon analysis by the Walkley-Black method (16). Standard methods for soil chemical analysis like alkaline $KMNO_4$ method for available nitrogen (17), Bray's extractant-NH_4FþHCl method for available phosphorus (18), 1N NH4OAc extractant for available potassium (25).

Nutrient indices

The formula mentioned below was adopted to calculate partial factor productivity of applied nutrient (PFPN) (26).

$$\text{PFPN (kg/kg)} = \frac{\text{Grain Yield (kg)}}{\text{Amount of N applied (kg)}} \qquad \text{(Eqn.01)}$$

Nitrogen utilization efficiency (NUtE) is defined physiologically as seed yield per unit N taken by the plant (27).

$$\text{NUtE (kg/kg)} = \frac{\text{Grain Yield}}{\text{Total nitrogen uptake by above ground dry matter}} \qquad \text{(Eqn.02)}$$

Nitrogen harvest index (NHI) is the ratio of nitrogen uptake by grain to total nitrogen uptake (27).

$$\text{NHI} = \frac{\text{Nitrogen uptake by grain}}{\text{Total nitrogen uptake in grain and}} \qquad \text{(Eqn.03)}$$

Statistical analysis

Data collected over 2 years was analysed statistically. The statistical analysis was conducted using Felipe de Mendiburu (2021), Agricolae: statistical procedures for Agricultural research, R package version 1.3-5. A 5% significance level was used to assess the statistical differences among various treatment means. Additionally, Duncan's Multiple Range Test (DMRT) was utilized in post-hoc analysis to classify the means of the treatment groups, as per the methodology of Gomez and Gomez (1984). The regression analysis of yield with crop and weed dry matter and nutrient uptake by crop and weeds was computed by using the SPSS 18.0 software package (SPSS Inc., Chicago, USA) and regression equations were fitted to estimate the response of yield explained by dry matter and nutrient uptake. The coefficient of determination (R^2) and adjusted R^2 were determined for testing the ability of the used mathematical models.

Results and Discussion

Weed density and weed biomass

The pre-dominant weeds of the experimental site in weedy check included grasses like *Dinebra chinensis* (L.) P.M.Peterson & N.Snow, *Echinochloa crus-galli* (L.) P.Beauv. and *Digitaria ciliaris* (Retz.) Koeler; sedges *viz. Cyperus iria* L. and broad-leaved weeds like *Ammannia baccifera* L., *Marselia quadrifolia* L., *Alternanthera philoxeroides* (Mart.) Griseb, *Ludwigia octovalvis* (Jacq.) P.H.Raven, *Eclipta prostrata* (L.) L., *Commelina diffusa* Burm.f., *Hygrophila* spp. and *Spilanthes acmella* (L.) Murray. The W_2 treated plots controlled almost all of the weeds except a negligible count of *Commelina diffusa* and *Spilanthes acmella*. Bensulfuronmethyl + pretilachlor suppressed annual grasses and BLW weeds effectively (*Dinebra chinensis* and *Marselia quadrifolia*) (28). Whereas W_3 could not suppress the weed species like *Ludwigia octovalvis*, *Ammannia baccifera.*, *Alternanthera philoxeroides* and *Spilanthes acmella*. The manual weeding recorded negligible later flushes comprising *Commelina diffusa*, *Alternanthera philoxeroides*, *Hygrophila* spp. and *Ammannia baccifera.* Most of the weeds were suppressed in the second year in herbicide treated plots due to continuous herbicide application as well as an integrated nutrient and weed management approach.

Both nutrient and weed management practices affected the weed density and biomass significantly (p<0.01) irrespective of growth stage and year (Table 2a). The application of soil test-based fertilizer alone registered higher values of weed density and biomass, whereas the integrated management of STD + GM produced the minimum values. Considering the average over both years, the STD + GM treatment recorded the minimum weed density of 45.3 and 64.3 numbers m^{-2} and the minimum weed biomass of 19.2 and 37.6 g m^{-2} at 30 and 60 DAT, respectively. The incorporation of GM along with STD reduced the weed density by 29.9 and 30.7% as compared to STD alone and by 21.4 and 28.5% as compared to STD + FYM at 30 and 60 DAT, respectively. Similarly, the STD + GM lowered the weed biomass by 37.7 and 35.3% as compared to STD and by 24.3 and 23.9% as compared to STD + FYM at 30 and 60 DAT, respectively. The suppression of weeds by organic manures and the increase in rice yield were more pronounced in the second year of study. Lower weed density due to green manuring might be attributed firstly to the emergence of weeds during *Sesbania* in the field, which were ploughed down before transplanting of rice and secondly to the probability of some effects of allelochemicals like sterols, saponins, phenols and tannins, etc., released from green manured crops (29, 30). Generally, organic sources release nutrients more slowly than conventional nutrient management, whereas the instant release from conventional management with minerals often favours the accumulation of biomass in weeds. Furthermore, the organic manures, which were added as a supplement in INM, may have released allelopathic phytochemicals that have the potential to reduce weed emergence and increase weed seed mortality (31).

Irrespective of year and growth stage, the treatment with bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT produced the minimum weed density and biomass and was statistically at par with manual weeding twice. The weedy check recorded the maximum values of weed density and biomass due to uncontrolled weed growth throughout the growth stages. The pooled data suggested that the application of bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT registered the minimum weed density of 25.1 and 20.7 number m^{-2} and the minimum weed biomass of 7.7 and 8.1 g m^{-2} at 30 and 60 DAT, respectively. The bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT treated plots reduced the weed density by 83.4 and 90.8% and weed biomass by 91.6 and 95.4% as compared to weedy check at 30 and 60 DAT, respectively. At 60 DAT, the bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT recorded significantly 69.9% lower weed dry matter than bensulfuronmethyl + pretilachlor without HW treatment. This proved the necessity of one extra hand weeding in addition to the application of bensulfuron-methyl + pretilachlor to kill the late flushes of weeds (32, 33). There are some carbon sources, like sodium lactate, which causes rapid degradation of bensulfuronmethyl, making it less effective at later stages (34). Its rapid degradation may be due to repeated application owing to adaptation of soil bacteria, which can utilize bensulfuronmethyl as a source of carbon and energy (35). Application of pyrazosulfuron-ethyl alone offered moderate control on weed growth because it became less effective for late germinating weeds (36). This suggested that a single weed management approach is not sufficient for the effective management of the diverse weed flora of a crop. The integration of two or more approaches results in better weed control efficiency than a

Table 2a. Effect of integrated nutrient and weed management on total weed density and biomass at 30 and 60 DAT.

Treatment	Weed Density (number m^{-2})				Weed Biomass (g m^{-2})			
	30 DAT		60 DAT		30 DAT		60 DAT	
	2019	2020	2019	2020	2019	2020	2019	2020
Horizontal-Nutrient Management Practices								
N_1	7.7 (64.8) a	7.5 (64.5) a	8.9 (90.4) a	8.9 (94.9) a	4.9 (29.2) a	5.0(32.4) a	6.6 (55.1) a	6.7 (61.2) a
N_2	7.2 (57.7) a	7.0 (57.6) a	8.4 (81.6) a	8.3 (83.5) b	4.4 (24.1) b	4.5(26.6)b	6.1 (47.6) b	6.1 (51.2) b
N_3	6.4 (46.0) b	6.2 (44.6) b	7.4 (63.6) c	7.3 (64.9) c	3.8 (17.9) c	3.9(20.5) c	5.3 (36.6) c	5.3 (38.5) c
SE(m)±	0.13	0.14	0.91	0.12	0.05	0.03	0.11	0.08
CD (0.05)	0.5	0.6	0.4	0.5	0.2	0.1	0.4	0.3
Vertical-Weed Management Practices								
W_1	5.4 (28.6) c	4.8 (23.2) c	7.6 (59.0) c	7.1 (51.2) c	3.0 (8.7) c	2.9 (8.2) c	5.2 (27.1) c	5.2 (26.8) c
W_2	5.3 (28.2) c	4.7 (22.0) c	4.8 (23.4) d	4.2 (17.9) d	2.9 (8.5) c	2.6 (6.9) c	3.0 (8.6) d	2.8 (7.6) e
W_3	7.0 (48.5) b	7.5 (56.3) b	9.6 (92.9) b	10.1 (103.0) b	4.1 (16.5) b	4.6 (20.6) b	7.0 (48.8) b	7.1 (50.7) b
W_4	7.6 (57.6) b	7.0 (48.9) b	7.4 (54.9) c	6.9 (48.9) c	4.3 (18.7) b	4.1 (17.0) b	4.7 (21.3) c	4.2 (17.6) d
W_5	5.6 (31.3) c	4.9 (23.6) c	5.6 (30.9) d	5.0 (24.9) d	2.6 (6.5) c	2.8 (7.1) c	3.5 (11.9) d	3.3 (10.53) e
W_6	11.9 (142.6) a	12.6 (159.6) a	14.5 (210.3) a	15.5 (240.5) a	9.1 (83.3) a	9.9 (99.3) a	12.7 (160.9) a	13.7 (188.6) a
SE(m)±	0.35	0.27	0.36	0.44	0.16	0.23	0.18	0.17
CD (0.05)	1.1	0.9	1.1	1.4	0.5	0.7	0.6	0.5

Figures in parentheses are the original value. The data was transformed to SQRT $\sqrt{(x+0.5)}$ before analysis

(Means followed by a similar lower-case letter within a for a management practice are not significantly different at p<0.05)

(N1: STD (100-40-40 N-P2O5-K2O kg ha^{-1}), N2:N1 + FYM @5t ha^{-1}, N3:N1 + green manuring of *dhaincha,* W1: bensulfuron methyl (0.6%) + pretilachlor (6%) GR @0.66 kg ha^{-1} (PE), W2:W1 + one hand weeding (HW) at 35 DAT, W3: pyrazosulfuron ethyl (10% WP) @ 0.02 kg ha^{-1} (PE), W4:W3 + one HW at 35 DAT, W5:Two HW at 25 and 40 DAT and W6:Weedy check) (CD: critical difference at 5% level of significance) single one.

The interaction effects of nutrient and weed management practices were significant for weed density and biomass both at 30 and 60 DAT (Table 2b to 2e). The pooled analysis revealed that the N_3W_2 interaction recorded ($p<0.01$) the minimum weed density of 18.0 and 16.6 number m^{-2} and weed biomass of 4.6 and 6.0 g m^{-2} at 30 and 60 DAT, respectively. The N_3W_2 interaction lowered the weed density by 89.5 and 93.5% and weed biomass by 95.8 and 97.1% as compared to N_1W_6 interaction at 30 and 60 DAT, respectively. The application of N fertilisers and manures can significantly decrease the weed density, as rice had higher nitrogen requirements associated wth a higher nitrogen uptake rate than the weed species (37).

Plant growth parameters

Data pertaining to growth parameters like leaf area index (LAI), crop biomass and crop growth rate (CGR) as affected nutrient and weed management practices were presented in Table 3. Both nutrient and weed management practices affected LAI significantly ($p<0.01$) at 60 and 90 DAT. Based on average value over both years, among nutrient management practices, the inclusion of GM to STD documented the maximum LAI value of 5.17 at 60 DAT, which were significantly 19.6 and 9.1% higher compared to STD and STD + FYM, respectively. A similar trend also followed at 90 DAT, where STD + GM produced 26.2 and 11.8% higher LAI over STD and STD + FYM, respectively. The reduction of LAI during the reproductive stage might be due to a decline in leaf nitrogen content for grain filling, which might have reduced the capacity of leaf to accumulate carbon (38). But the rate of decline in LAI was less under green manure treated plots, as green manuring helped in supplying a considerable amount of nitrogen due to synchronized release of nutrients through decomposition and augmented the growth of rice (39). Among weed management practices, bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT gave a significantly higher LAI value of 5.21 at 60 DAT and was on par with both bensulfuronmethyl + pretilachlor and manual weeding twice. The bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT increased LAI significantly by 37.5 and 21.5% as compared to weedy check at 60 and 90 DAT, respectively. The incorporation of GM along with STD accumulated significantly ($p<0.01$) the maximum mean crop dry matter of 518 and 1131 g m^{-2} at 60 and 90 DAT, respectively, whereas STD produced the least values. Similarly, the application of bensulfuronmethyl + pretilachlor (PE) *fb* HW

Table 2b. Interaction effects of integrated nutrient and weed management practices on weed density (number m^{-2}) at 30 DAT.

N × W	W_1		W_2		W_3		W_4		W_5		W_6	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
N_1	34.3 h	27.9 gh	32.6 hi	27.5 ghi	56.9 e	63.5 c	66.7 d	57.3 cd	39.4 g	28.8 g	158.9 a	182.3 a
N_2	29.5 i	23.1 hij	32.0 hi	22.9 hij	47.2 f	57.5 cd	63.5 d	52.0 de	29.6 i	21.8 ij	144.2 b	168.4 a
N_3	22.0 jk	18.7 jk	20.2 k	15.8 k	41.5 g	47.8 e	42.8 fg	37.4 f	25.0 j	20.1 jk	124.8 c	128.0 b

The data presented in the table are the original values which were analysed after SQRT $\sqrt{(x+0.5)}$ transformation

(Means followed by a similar lower-case letter for the interaction between two management practices are not significantly different at $p<0.05$)

Table 2c. Interaction effects of integrated nutrient and weed management practices on weed density (number m^{-2}) at 60 DAT.

N × W	W_1		W_2		W_3		W_4		W_5		W_6	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
N_1	72.2 ef	62.6 g	27.3 kl	21.9 mn	106.3 d	119.8 d	64.6 fg	59.9 gh	36.1 ij	29.1 kl	236.3 a	275.8 a
N_2	59.8 g	50.7 i	22.9 lm	18.8 n	96.4 d	104.2 e	59.6 g	51.9 hi	31.5 jk	25.2 lm	219.5 b	250.1 b
N_3	45.1 h	40.4 j	19.9 m	13.2 0	75.9 e	84.9 f	40.4 hi	34.8 jk	25.2 l	20.4 mn	175.1 c	195.5 c

The data presented in the table are the original values which were analysed after SQRT $\sqrt{(x+0.5)}$ transformation

(Means followed by a similar lower-case letter for the interaction between two management practices are not significantly different at $p<0.05$)

Table 2d. Interaction effects of integrated nutrient and weed management practices on weed biomass (g m^{-2}) at 30 DAT.

N × W	W_1		W_2		W_3		W_4		W_5		W_6	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
N_1	11.3 gh	10.2 gh	10.9 gh	9.6 ghi	20.9 de	24.9 d	23.7 d	21.0 de	7.7 jk	7.6 hij	100.6 a	121.0 a
N_2	8.1 ij	7.8 hij	9.0 hi	7.4 ij	15.9 f	20.8 de	19.6 e	17.8 ef	6.7 jk	7.3 ij	85.0 b	98.5 b
N_3	6.8 jk	6.4 j	5.5k	3.7 k	12.8 g	16.0 f	12.9 g	12.1 g	4.9 k	6.5 j	64.5 c	78.5 c

The data presented in the table are the original values which were analysed after SQRT $\sqrt{(x+0.5)}$ transformation

(Means followed by a similar lower-case letter for the interaction between two management practices are not significantly different at $p<0.05$)

Table 2e. Interaction effects of integrated nutrient and weed management practices on weed biomass (g m^{-2}) at 60 DAT.

N× W	W_1		W_2		W_3		W_4		W_5		W_6	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
N_1	33.0 e	32.5 f	11.3 i	9.9 ijk	56.9 d	67.4 d	23.7 g	20.1 g	14.6 h	12.2 hi	191.3 a	225.2 a
N_2	27.9 f	27.9 f	8.1 jk	7.2 kl	52.6 d	51.2 e	23.6 g	16.7 g	11.6 i	10.8 ij	161.7b	193.2 b
N_3	20.5 g	20.0 g	6.4 k	5.6 l	36.7 e	33.5 f	16.5 h	15.9 gh	9.6 ij	8.6 jk	129.9c	147.6 c

The data presented in the table are the original values which were analysed after SQRT $\sqrt{(x+0.5)}$ transformation

(Means followed by a similar lower-case letter for the interaction between two management practices are not significantly different at $p<0.05$)

Table 3. Effect of integrated nutrient and weed management on growth parameters at different stages.

Treatment	LAI (60 DAT)		LAI (90 DAT)		Biomass (g m^{-2}) (60 DAT)		Biomass (g m^{-2}) (90 DAT)		CGR (g m^{-2} day^{-1}) (60-90 DAT)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Horizontal-Nutrient Management Practices										
N_1	4.23 c	4.40 c	2.13 c	2.22 c	417 c	450 c	929 c	1032 b	17.1 b	19.4 b
N_2	4.68 b	4.80 b	2.38 b	2.53 b	457 b	491 b	1029 b	1138 a	19.1 a	21.6 a
N_3	5.12 a	5.21 a	2.71 a	2.78 a	504 a	532 a	1084 a	1178 a	19.3 a	21.5 a
SE(m)±	0.024	0.077	0.035	0.032	3.5	6.7	7.7	13.2	0.32	0.38
CD (0.05)	0.09	0.30	0.14	0.12	14	26	30	52	1.6	1.5
Vertical-Weed Management Practices										
W_1	4.93 ab	5.04 ab	2.47 abc	2.59 ab	464 b	502 ab	1049 b	1169 bc	19.5 a	22.2 ab
W_2	5.13 a	5.28 a	2.59 a	2.68 a	505 a	535 a	1106 a	1219 a	20.5 a	23.1 a
W_3	4.44 c	4.54 c	2.34 c	2.42 b	422 cd	453 bc	935 c	1031 d	17.1b	19.3 c
W_4	4.73 bc	4.88 bc	2.38 bc	2.54 ab	458 bc	495 ab	1024 b	1140 c	18.9 a	21.5 b
W_5	5.12 a	5.21 ab	2.56 ab	2.65 a	490 ab	525 a	1099 a	1199 ab	19.8 a	22.1 ab
W_6	3.72 d	3.85 d	2.11 d	2.19 c	415 d	435 c	870 d	938 e	15.2 c	16.7 d
SE(m)±	0.115	0.118	0.065	0.070	11.5	15.8	13.3	14.3	0.56	0.46
CD (0.05)	0.36	0.37	0.21	0.22	36	50	42	45	1.8	1.5

(Means followed by a similar lower-case letter within a column for a management practice are not significantly different at p<0.05)

on 35 DAT accumulated the maximum average crop biomass of 520 and 1162 g m^{-2} at 60 and 90 DAT, respectively and was on par with two hand weeded plots. With respect to crop growth rate from 60 to 90 DAT, the STD + GM treatment reported the maximum average value of 20.4 gm^{-2} day^{-1}, which was significantly ($p<0.01$) 11.8% higher over STD and was statistically at par with STD+FYM. The utilization of *Sesbania* as a green manure prior to transplanting had a significant positive impact on various aspects of rice, including LAI, dry matter and productivity, due to balanced supply of nutrients (40). Similarly, considering the mean values, the bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT treatment registered a maximum CGR of 21.8 gm^{-2} day $^{-1}$, which were significantly ($p<0.05$) higher over pyrazosulfuron ethyl *fb* HW on 35 DAT and weedy check by 7.9 and 36.7%, respectively. The weed suppression in herbicide treated plots favoured crop growth by decreasing the competition for resources.

Yield attributes and grain yield

The number of effective tillers m^{-2} and filled grains panicle^{-1} were significantly ($p<0.01$) influenced by both nutrient and weed management practices (Table 4a). Considering the average data, the STD+GM and bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT plots recorded the maximum effective tillers m^{-2} of 340.1 and 348.0 and filled grains panicle^{-1} of 134.6 and 139.3, respectively whereas STD and weedy check registered the minimum values. The STD+GM treatment significantly increased the effective tillers m^{-2} and filled grains panicle^{-1} by 20.9 and 18.5% as compared to STD, respectively. The weed management by application of bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT produced 39.3 and 38.0% higher effective tillers m^{-2} and filled grains panicle^{-1} than weedy check and was at par with two HW treated plots. The test weight ($p<0.05$) and grain yield ($p<0.01$) were also significantly affected due to nutrient and weed management practices (Table 4a). Among nutrient management practices, the STD+GM

Table 4a. Effect of integrated nutrient and weed management on yield attributes and grain yield.

Treatment	Effective tillers m^{-2}		Filled grains panicle^{-1}		1000 grain weight (g)		Grain yield (kg ha^{-1})	
	2019	2020	2019	2020	2019	2020	2019	2020
Horizontal-Nutrient Management Practices								
N1	273.2 b	289.5 b	110.6 b	116.5 b	21.1 b	21.5 b	4559 b	4890 b
N2	312.6 a	323.7 a	125.9 a	129.8 a	21.5 ab	22.1 ab	5189 a	5583 a
N3	332.9 a	347.2 a	132.5 a	136.7 a	22.5 a	23.2 a	5361 a	5763 a
SE(m)±	9.61	6.88	3.50	1.93	0.25	0.27	58.4	62.2
CD (0.05)	37.7	27.0	13.7	7.6	1.0	1.1	229	244
Vertical-Weed Management Practices								
W1	322.8 ab	335.4 bc	129.2 a	134.9 ab	21.6 abc	22.3 abc	5254 ab	5700 ab
W2	344 a	352 a	135.4 a	143.1 a	22.5 a	23.1 a	5749 a	6202 a
W3	287.3 c	305.8 d	113.4 b	117.7 c	21.1 bc	21.8 bc	4545 c	4810 c
W4	307.4 bc	322.6 c	126.5 a	129.2 bc	21.8 ab	22.4 ab	5122 b	5491 b
W5	338 a	343.4 ab	134.3 a	139.6 ab	22.5 a	23.0 a	5678 a	6136 a
W6	238.4 d	261.6 e	99.3 c	101.7 d	20.6 c	21.4 c	3870 d	4132 d
SE(m)±	8.74	5.17	3.81	4.25	0.34	0.32	169.0	187.3
CD (0.05)	27.5	16.3	12.0	13.4	1.2	1.0	532	590

and STD and weed management treatments, bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT and weedy check registered the maximum and minimum values of the test weight and grain yield, respectively. The STD+GM treatment recorded a mean test weight of 22.9 g and a grain yield of 5562 kg ha^{-1}, which were 7.5 and 17.7% higher than STD, respectively. There was no significant difference between STD + GM and STD + FYM treatment for yield attributing characters as well as for grain yield. An increasing trend was seen with respect to grain yield from first year to second year. Grain yield varied from 3870 to 5749 kg ha^{-1} and 4132 to 6202 kg ha^{-1} in 2019 and 2020, respectively. The addition of GM to STD resulted in a mean maximum grain yield of 5562 kg ha^{-1}, a significantly 17.7% higher yield over STD and was statistically similar to STD + FYM. It might be due to the balanced supply of nutrients and efficient weed suppression, which enhanced plant growth and dry matter partitioning towards panicle (11). Higher magnitude of shoot and root growth parameters under INM practice may be attributed to good early vigorous plant growth, thereby reducing the weed growth with better LAI and photosynthesis, resulting superior yield attributes and rice yield (41). In addition to rapid decomposition of *Sesbania,* it released nutrients quickly and increased their availability to the plants, which increased the growth parameters and yield subsequently. It might also improve the soil's physicochemical and biological characteristics, along with more recycling of NPK nutrients that lead to an increase in the grain yield (42).

Considering the weed management practices, the grain yield varied from 3870 to 5749 kg ha^{-1} and 4132 to 6202 kg ha^{-1} during 2019 and 2020, respectively. As per pooled data, among weed management practices, the application of bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT (5975 kg ha^{-1}) produced significantly 49.7% more grain yield compared to weedy check. There were no significant differences among two HW and bensulfuronmethyl + pretilachlor treated plots with respect to grain yield. This might be due to the combined result of higher yield attributing characters and the lowest crop weed competition. The better weed suppression that favoured the crop for effective utilization of resources throughout the crop growth stages helped in more production and assimilation of photosynthates (4). The reduction of yield in weedy check and other treatments was possibly due to severe weed infestation and compete with the crop throughout the growing season.

Significant interaction effects between weed and nutrient management treatments were observed with respect to grain yield (Table 4b). Being on par with the N_2W_5, N_3W_5, N_2W_2 and N_3W_1 interactions, the interaction N_3W_2 registered significantly higher grain yields of 6073 and 6458 kg ha^{-1} in 2019 and 2020, respectively. The pooled value of N_3W_2 (6265 kg ha^{-1}) resulted in a significantly 73.35% higher yield over the N_1W_6 interaction.

Table 4b. Interaction effects of integrated nutrient and weed management practices on grain yield (kg ha^{-1}).

N × W	2019	2020
SE(m)±	119.0	128.1
CD (0.05)	351	378

(Means followed by a similar lower-case letter for the interaction between two management practices are not significantly different at p<0.05)

Nutrient uptake by crop

The N, P and K uptake by rice crop was significantly ($p<0.01$) increased owing to integrative application of inorganic and organic sources of nutrients and integrative weed management practices during both years of the experiment (Table 5). The STD and weedy check removed the least amount of nutrient from soil, whereas STD + GM and bensulfuronmethyl + pretilachlor (PE) *fb* HW treatment accumulated the most. Based on average data, The STD + GM treated plots removed the maximum values of 113.6, 23.2 and 122.6 kg ha^{-1} N, P and K, which were 31.5, 40.2 22.8% more than STD, respectively. Similarly, the bensulfuronmethyl + pretilachlor (PE) *fb* HW removed the maximum value of 117.9, 25.3 and 131.3 kg ha^{-1} N, P and K, respectively and was on par with two HW treatments. Both nutrient and weed management practices significantly ($p<0.01$) influenced PFPN, where STD + GM and bensulfuronmethyl + pretilachlor (PE) fb HW registered the maximum values. The average value proved that the integration of green manure into STD increased PFPNby 17.54% over STD and was statistically at par with STD + FYM. Similarly, the STD + GM recorded the maximum NHI value of 0.69 and the minimum NUtE value of 49.1 kg kg^{-1}. Averaged over years, the application of bensulfuron-methyl+ pretilachlor *fb* HW on 35 DAT resulted in the maximum PFPN and NHI values of 59.8 kg kg^{-1} and 0.69, respectively and the minimum NUtE value of 50.9 kg kg^{-1} which was on par with two HW plots. Green manure improves soil fertility and ecology, thereby stimulating soil microbial activity, which avails more nutrients and results in higher productivity of rice with more nutrient use efficiency (43-45). The different mineralization rates and nutrient content of organic fertilizers also affect the differential rate of nutrient uptake (46).

Nutrient uptake by weeds

Both nutrient and weed management treatments significantly ($p<0.01$) influenced the nutrient uptake by weeds (Table 6). The inclusion of GM in STD reduced the weed N, P and K uptake on average by 35.5, 35.1 and 36.5% as compared to STD, respectively. The application of bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT reduced the weed N, P and K uptake by 85.78, 90.85 and 84.98% as compared to weedy check in 2019. A similar trend was also followed in 2020. There was no significant difference among the W_1, W_2 and W_5 treatments with respect to N and K uptake, whereas for P uptake, both W_2 and W_5 were statistically at par with each other. There was a negative linear relationship between the nutrient uptake by weeds and the grain yield of the crop which is due to the presence of weed flora affecting crop growth via competition with the crop for resource allocation (Fig. 3).

Table 5. Effect of integrated nutrient and weed management on crop nutrient uptake (kg ha^{-1}) and nutrient indices at harvest.

N × W	W1		W2		W3		W4		W5		W6	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
N1	4394f g	4690 ef	5224 cd	5784 c	4095gh	4403fg	4883de	5046 de	5273 c	5670 c	3483 i	3745 h
N2	5477 bc	6021 bc	5949 a	6365 ab	4728ef	4923de	5221 cd	5663 c	5810 ab	6296 ab	3950 h	4232 g
N3	5891 a	6390 ab	6073 a	6458 a	4814e	5105d	5261 c	5765 c	5951 a	6443 a	4176 gh	4419 fg

Treatment	N		P		K		PFPN (kg kg^{-1})		NUtE (kg kg^{-1})		NHI	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Horizontal-Nutrient Management Practices												
N1	83.7 c	89.1 b	15.9 b	17.2 b	97.9 b	101.8 b	45.6 b	48.9 b	54.5 a	55.0 a	0.67 b	0.69 a
N2	101.9 b	110.2 a	21.2 a	23.6 a	118.2 a	125.6 a	51.9 a	55.8 a	51.1 b	50.8 b	0.69 a	0.69 a
N3	110.0 a	117.2 a	21.7 a	24.6 a	120.3 a	124.8 a	53.6 a	57.6 a	48.9 c	49.3 b	0.68 ab	0.69a
SE(m)±	1.95	1.98	0.78	0.53	3.21	1.01	0.58	0.62	0.36	0.62	0.004	0.003
CD	7.6	7.8	3.1	2.1	12.6	4.0	2.3	2.4	1.4	2.4	0.02	0.01
Vertical-Weed Management Practices												
W1	102.8 b	111.9 ab	20.7 b	23.7 b	116.4 ab	122.9 ab	52.5 ab	57.0 ab	51.6 ab	51.3 b	0.68 a	0.69 ab
W2	113.4 a	122.4 a	23.6 a	26.9 a	128.4 a	134.2 a	57.5 a	62.0 a	50.9 bc	51.0 b	0.68a	0.70 a
W3	87.8 c	93.5 c	16.6 c	17.9 c	101.2 c	107.2 c	45.5 c	48.1 c	52.0 a	51.7 b	0.68 a	0.68 b
W4	99.4 b	106.0 b	19.3 b	21.9 b	112.3 bc	119.0 b	51.2 b	54.9 b	51.7 a	52.1 ab	0.68 a	0.69a
W5	113.1 a	120.8 a	23.7 a	26.1a	129.5 a	133.6 a	56.8 a	61.4 a	50.6 c	51.1 b	0.68a	0.69 a
W6	74.7 d	78.4 d	13.9 d	14.4 d	85.2 d	87.5 d	38.7d	41.3 d	52.2 a	53.0 a	0.68 a	0.69a
SE(m)±	3.29	3.45	0.52	0.69	4.18	3.60	1.69	1.87	0.24	0.37	0.003	0.004
CD	10.4	10.9	1.6	2.2	13.18	11.4	5.3	5.9	0.8	1.2	0.01	0.01

(Means followed by a similar lower-case letter within a column for a management practice are not significantly different at $p<0.05$)

Table 6. Effect of integrated nutrient and weed management on weed nutrient uptake (kg ha^{-1}).

Treatment	N		P		K	
	2019	2020	2019	2020	2019	2020
Horizontal-Nutrient Management Practices						
N1	6.0 b	6.8 b	1.9 b	2.1 b	6.4 b	7.3 b
N2	7.0 a	7.9 a	2.2 a	2.5 a	7.7 a	8.7 a
N3	4.5 c	5.1 c	1.4 c	1.6 c	4.9 c	5.6 c
SE(m)±	0.11	0.09	0.04	0.03	0.12	0.11
CD (0.05)	0.4	0.4	0.1	0.1	0.5	0.4
Vertical-Weed Management Practices						
W1	2.6 d	2.5 c	0.9 d	0.9 d	2.7 d	2.8 c
W2	2.4 d	2.3 c	0.5 e	0.5 e	2.7 d	2.5 c
W3	6.0 b	6.0 b	1.8 b	2.1 b	6.7 b	6.7 b
W4	5.2 c	5.9 b	1.3 c	1.3 c	5.5 c	6.3 b
W5	2.4d	2.3 c	0.6 e	0.6 e	2.6 d	2.5 c
W6	16.6 a	20.5 a	5.8 a	7.2 a	17.8 a	22.2 a
SE(m)±	0.31	0.48	0.11	0.17	0.34	0.49
CD (0.05)	1.0	1.5	0.4	0.5	1.1	1.5

(Means followed by a similar lower-case letter within a column for a management practice are not significantly different at $p<0.05$)

The crop accounted for the maximum share of 96, 94 and 96%, whereas weeds accounted for the minimum share of 4, 6 and 4% of total (crop + weed) N, P and K uptake under STD + GM treatment (Fig. 4). Similarly, the crop accounted for the maximum share of 98% each of N, P and K, while weeds accounted for the minimum share of 2% each of N, P and K total (crop + weed) nutrient uptake, respectively, under bensulfuronmethyl + pretilachlor (PE) *fb* HW on 35 DAT (Fig. 5).

Regression and correlation studies

The weed biomass at 30 DAT, weed biomass at 60 DAT, N uptake by crop, P uptake by crop, K uptake by crop, N uptake by weed, P uptake by weed and K uptake by weed accounted for 53.0 and 52.6%, 61.5 and 57.7%, 94.9 and 96.0%, 93.6 and 94.8%, 96.7 and 94.6%, 58.4 and 58.6%, 61.8 and 59.8% and 57.2 and 57.1% of variation in grain yield during 2019 and 2020 respectively, (Table 7). Significant linear regression relationships were observed between weeds biomass and grain yield of rice (Fig. 1). The grain yield of rice decreased significantly with increase in total weed biomass (R^2=0.557 and 0.554 at 30 DAT, R^2=0.637 and 0.602 at 60 DAT), respectively (Table 7). There was a positive linear regression between crop nutrient uptake and rice yield (Fig. 2). A Similar trend was reported from research conducted in Jammu and Kashmir, India (47). The linear regression relationship between rice yield and weed nutrient uptake indicated that the yield reduced significantly with increase in weed N (R^2=0.608 and 0.609), P (R^2=0.640 and 0.622) and K (R^2=0.598 and 0.596) uptake, respectively (Table 7, Fig. 3) (48). The higher grain yield was the combined result of the better growth parameters and yield attributing characters of the crop. The results were further confirmed with Pearson's correlation analysis (Fig. 6). There was a strong positive correlation between yield attributes and yield (p=0.001).

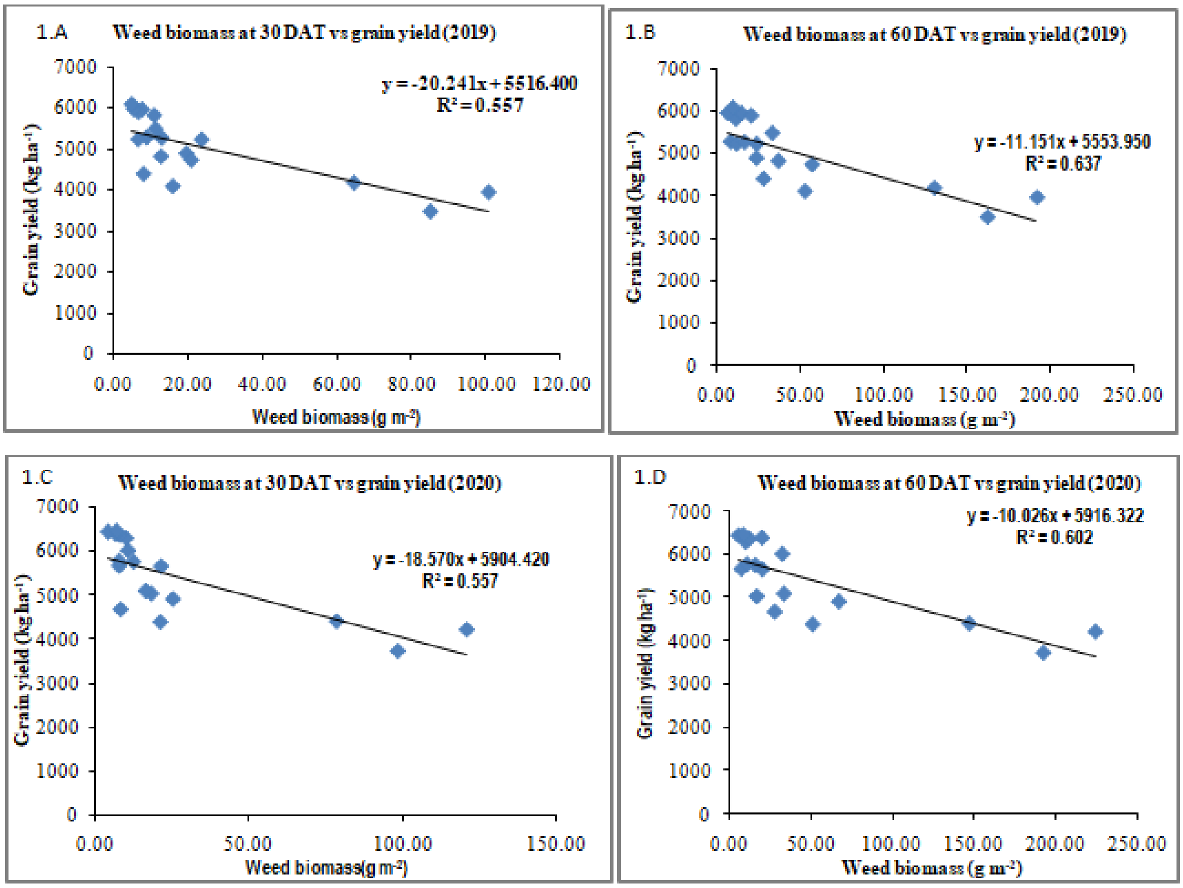

Fig. 1. Linear regression between weed biomass and grain yield of rice at 30 and 60 DAT during 2019 and 2020 (1.A to 1.D).

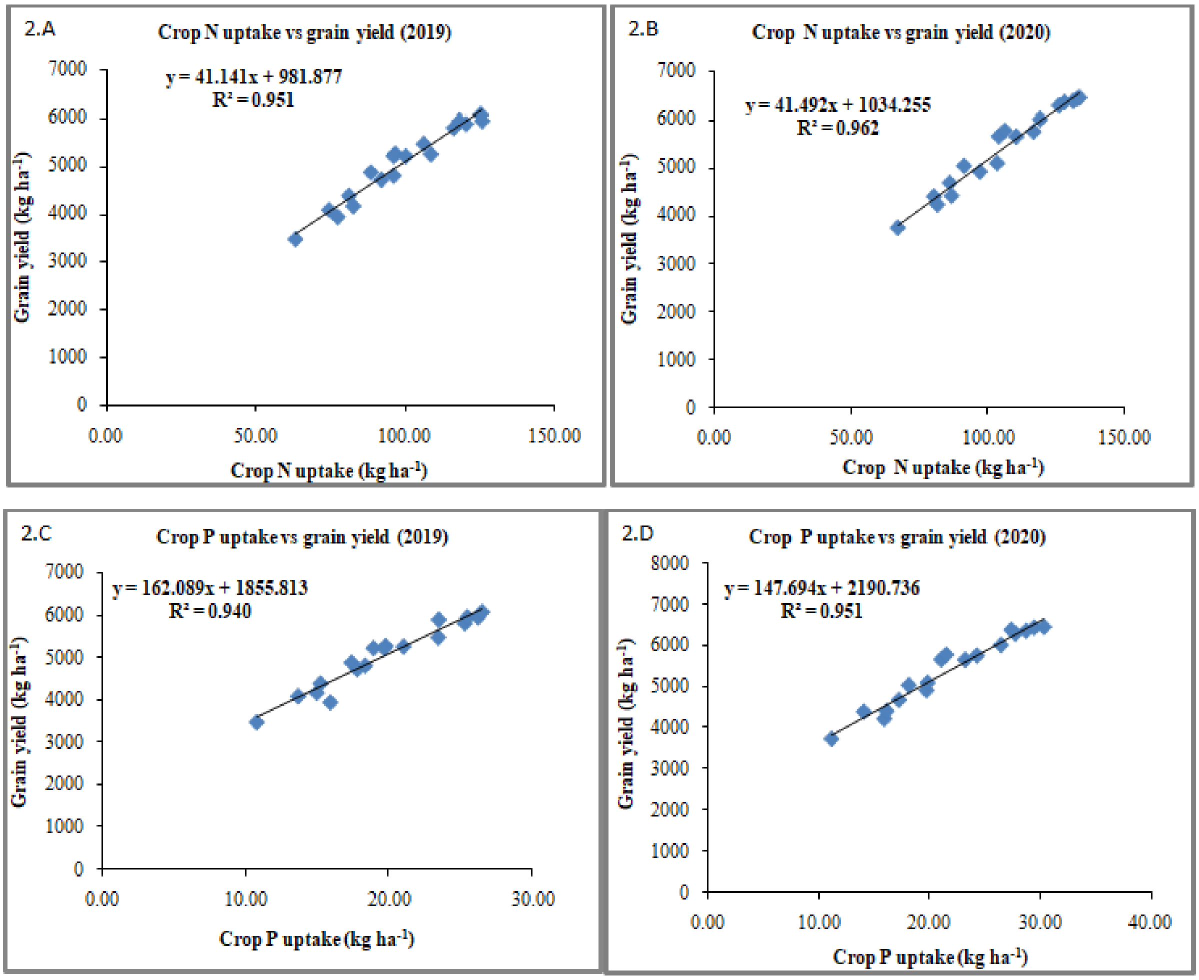

Fig. 2. Linear regression between crop nutrient uptake and grain yield of rice at 30 and 60 DAT during 2019 and 2020 (2.A to 2.F).

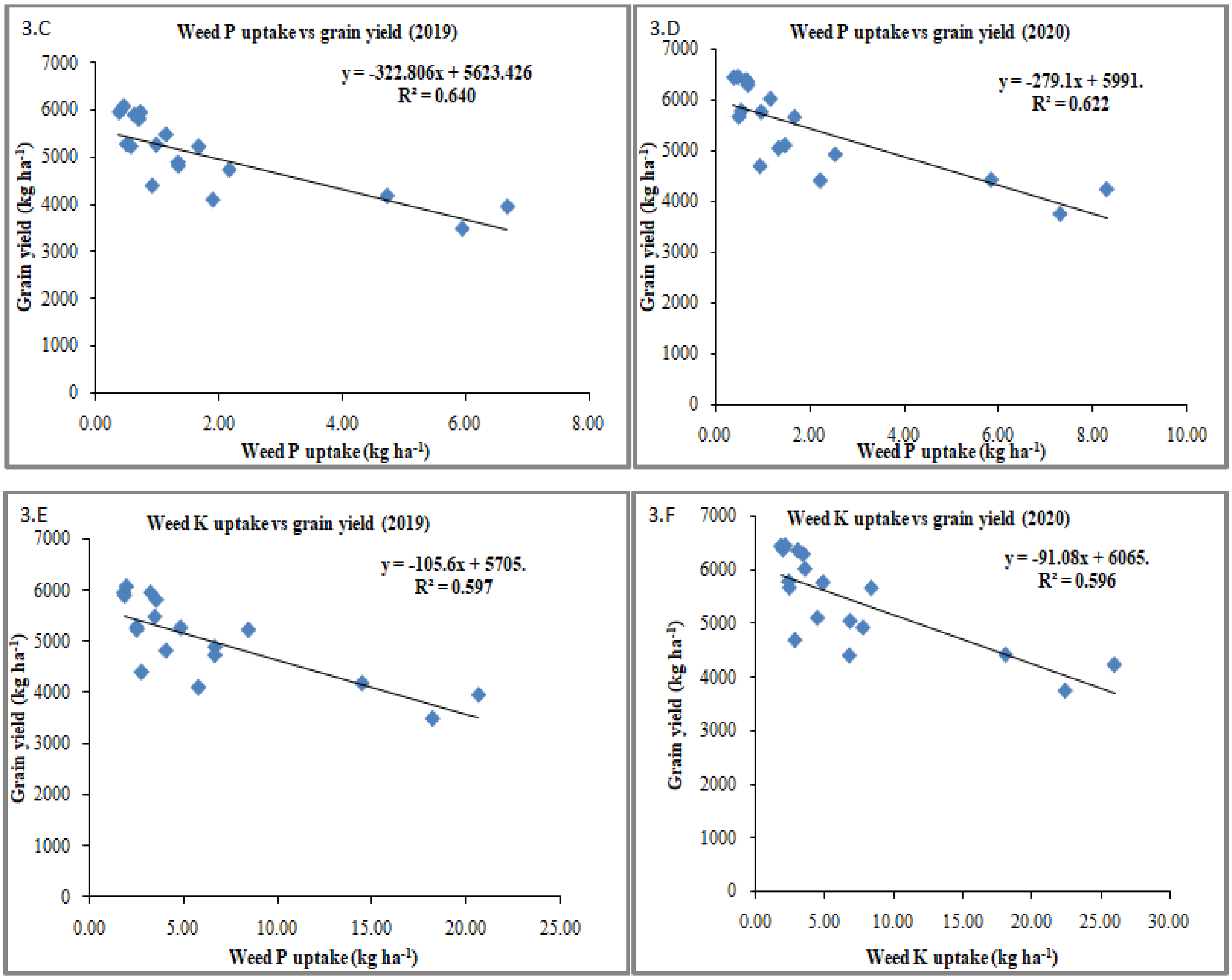

Fig. 3. Linear regression between weed nutrient uptake and grain yield of rice at 30 and 60 DAT during 2019 and 2020 (3.A to 3.F).

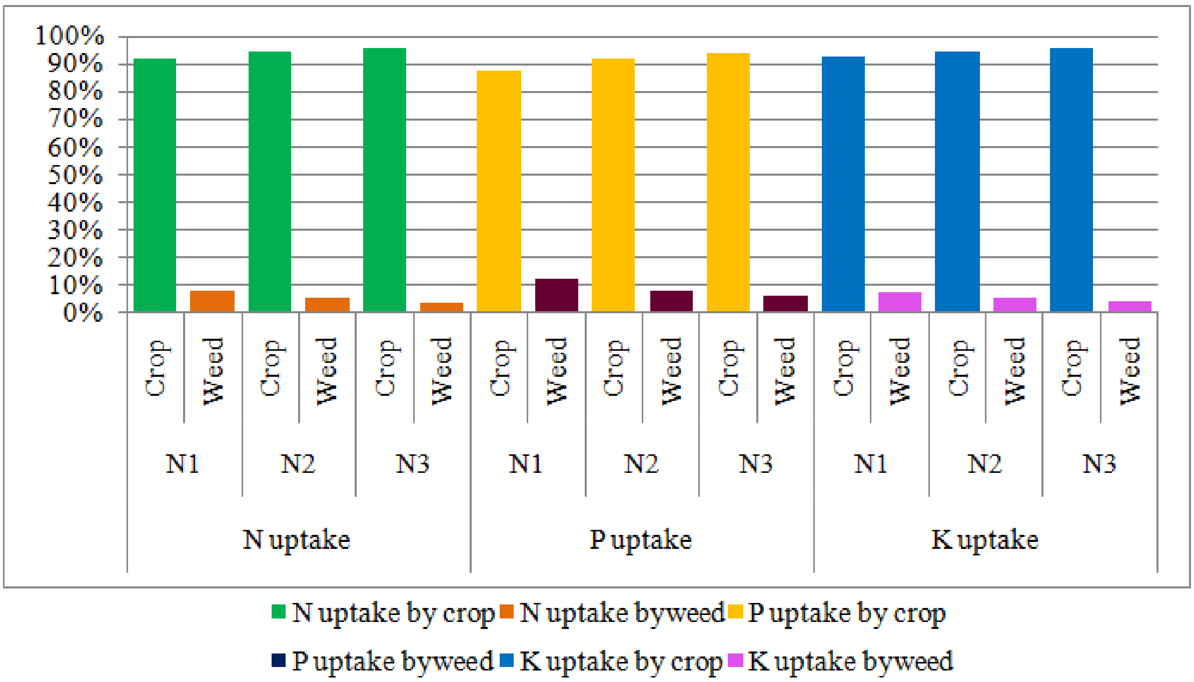

Fig. 4. Effect of nutrient management practices on percentage N, P and K uptake by crop and weed.

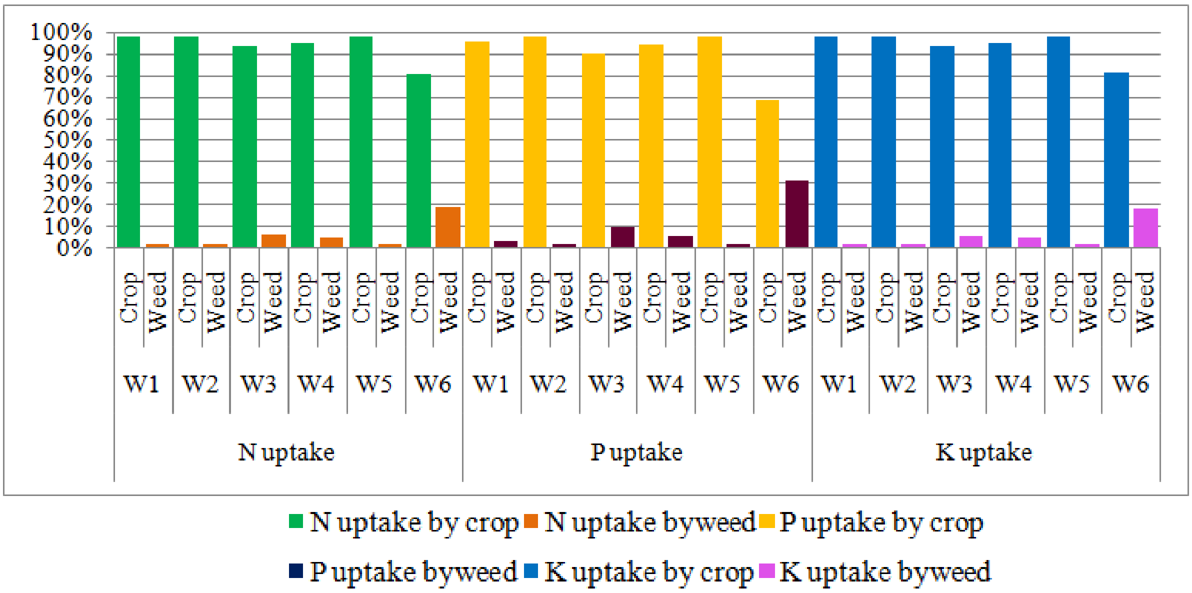

Fig. 5. Effect of weed management practices on percentage N, P and K uptake by crop and weed.

Table 7. Estimated R^2 and standard error of linear regression analysis between grain yield (kg ha^{-1}) and weed biomass (g m^{-2}), grain yield (kg ha^{-1}) and crop nutrient uptake (kg ha^{-1}), grain yield (kg ha^{-1}) and weed nutrient uptake (kg ha^{-1}).

Regression Comparison	R^2		Adjusted R^2		Std. Error of the Estimate	
	2019	2020	2019	2020	2019	2020
Grain yield vs Weed biomass at 30 DAT	0.557	0.554	0.530	0.526	532.226	593.326
Grain yield vs Weed biomass at 60 DAT	0.637	0.602	0.615	0.577	481.818	562.650
Grain yield vs N uptake by crop	0.952	0.963	0.949	0.960	175.823	173.675
Grain yield vs P uptake by crop	0.940	0.954	0.936	0.948	195.970	195.666
Grain yield vs K uptake by crop	0.968	0.951	0.967	0.946	142.059	194.752
Grain yield vs N uptake by weed	0.608	0.609	0.584	0.586	500.778	558.337
Grain yield vs P uptake by weed	0.640	0.622	0.618	0.598	479.998	548.408
Grain yield vs K uptake by weed	0.598	0.596	0.572	0.571	507.583	566.857

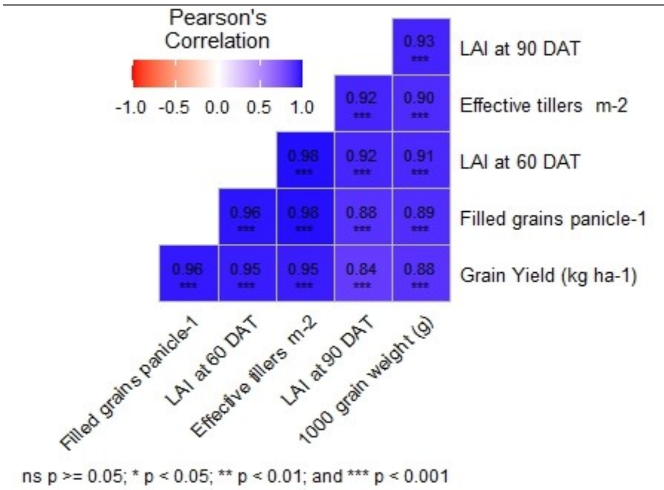

Fig. 6. Pearson's correlation coefficient between yield attributes and yield of rice.

Conclusion

Integration of green manuring of *dhaincha* and FYM with soil test-based dose of 100-40-40 N-P_2O_5-K_2O kg ha^{-1} increased grain yield by 17.7 and 14.0% over soil test-based fertilizer alone. This underscores the necessity of application of organic sources with chemical fertilizer for sustaining the productivity of rice under situation of declining factor productivity of nitrogen due to continuous application of the nutrients from chemical source. Similarly, among weed management practices, pre-emergence application of bensulfuronmethyl + pretilachlor *fb* hand weeding on 35 days after transplanting and manual weeding twice at 25 and 40 days after transplanting suppressed weed satisfactorily and recorded 49.4 and 47.6% higher grain yield of rice than weedy check respectively. Nutrient management through soil test-based fertilizer and green manuring along with weed management by bensulfuronmethyl + pretilachlor *fb* hand weeding on 35 days after transplanting gave the maximum productivity of rice (6265 kg ha^{-1}) being at par with the integrated nutrient management with green manure and manual weeding twice. The farmers should incorporate these integrated nutrients and weed management for maximization of rice productivity in eastern India.

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Authors' contributions

JKN was responsible for carrying out the lab and field research work, manuscript preparation and communication of the manuscript. The experiment was conceptualised, designed and monitored by MRS, BB and SKD. RKP contributed to laboratory analysis and data interpretation. The statistical analysis and designing of figures were carried out by RD and AD.

Compliance with ethical standards

Conflict of interest: There is no visible conflict of interests related to publication of this article.

Ethical issues: None.

References

1. Ciulu M, Cádiz-Gurrea MDLL, Segura-Carretero A. Extraction and analysis of phenolic compounds in rice: a review. Molecules. 2018; 23: 1-20. https://doi.org/10.3390/molecules23112890
2. USDA (United States of Department of Agriculture). Rice production by country-world agricultural production 2020/2021. World agricultural production. 2020:25.
3. Mohanty S, Yamano T. Rice food security in India: emerging challenges and opportunities. The Future Rice Strategy for India. 2017:1-13.. https://doi.org/10.1016/B978-0-12-805374-4.00001-4
4. Pattanayak S, Jena S, Das P, Maitra S, Shankar T, et al. Weed management and crop establishment methods in rice (*Oryza sativa* L.) influence the soil microbial and enzymatic activity in sub-tropical environment. Plants. 2022; 11(8):1071. https://doi.org/10.3390/plants11081071
5. Chhokar RS, Sharma RK, Gathala MK, Pundir AK. Effects of crop establishment techniques on weeds and rice yield. Crop Protection. 2014; 64:7-12. https://doi.org/10.1016/j.cropro.2014.05.016
6. Urmi TA, Rahman MM, Islam MM, Islam MA, et al. Integrated nutrient management for rice yield, soil fertility and carbon sequestration. Plants. 2022; 11(1):138. https://doi.org/10.3390/plants11010138
7. Panneerselvam P, Srivastava AK, Kumar V, Seelan LP, Banik NNC, et al. Crop establishment and diversification strategies for intensification of rice-based cropping systems in rice-fallow areas in Odisha. Field Crops Res.2023; 302: 109078. https://doi.org/10.1016/j.fcr.2023:109078
8. Islam M, Urmi TA, Rana Md S, Alam MS, Haque MM. Green manuring effects on crop morpho-physiological characters, rice yield and soil properties. Physiol Mol Biol Plants.2019; 25(1): 303-12. https://doi.org/10.1007/s12298-018-0624-2
9. Mangaraj S, Paikaray RK, Maitra S, Pradhan SR, et al. Integrated Nutrient Management Improves the Growth and Yield of Rice and Greengram in a Rice-Greengram Cropping System under the Coastal Plain Agro-Climatic Condition. Plants.2022; 11 (1): 142. https://doi.org/10.3390/plants11010142
10. Aulakh CS, Kaur P, Walia SS, Gill RS, et al: Productivity and quality of basmati rice (*Oryza sativa*) in relation to nitrogen management. Indian Journal of Agronomy.2016; 61 (4): 467-73. https://doi.org/10.59797/ija.v61i4.4394
11. Yadav DB, Yadav A, Punia SS. Long-term effects of green manuring and herbicides on weeds and productivity of the rice-wheat cropping system in North-Western India. Indian Journal of Weed Scienc.2019; 51(3): 240-45. https://doi.org/10.5958/0974-8164.2019.00051.0
12. Ferrero R, Lima M, Davis AS, Gonzalez-Andujar JL. Weed Diversity Affects Soybean and Maize Yield in a Long Term Experiment in Michigan, USA. 2017; Fornt Plant Sci.: 8, 236. https://doi.org/10.3389/fpls.2017.00236
13. Puniya R, Pandey PC, Bisht PS, Singh DK: Nutrient uptake by crop and weeds as influenced by trisulfuron, trisulfuron + pretilachlor and bensulfuron methyl in transplanted rice. Indian J. Weed Sci.; 39: 239-40.
14. Balasubramanian R, Veerabadran V, Devasagayam M, Krishnasamy S, Jayapaul P. Influence of herbicides on weed management in lowland rice. Pestology.1996; XX (12): 18-20.
15. Sreelaksmi K, Balasubramanian R, Babu R, Balakrishnan K. Herbicide combinations for weed management in transplanted rice. Indian Journal of Weed Science. 2016; 48(1): 60-63. https://doi.org/10.5958/0974-8164.2016.00013.7
16. Walkley A, Black JA. Estimation of soil organic carbon by chromic acid titration method. Soil Science. 1934; 37 (1): 29-38. https://doi.org/10.1097/00010694-193401000-00003
17. Subbiah BV, Asija GL. A rapid procedure for the determination of available nitrogen in soils. Current Science; 25: 259-60.
18. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Science.1945; 59 (1): 39-46. https://doi.org/10.1097/00010694-194501000-00006
19. Hanway JJ, Heidel H. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa Agriculture.1952; 57:1-31.
20. Jackson M L. Soil chemical analysis, New Delhi: Prentice Hall of India. 1967; 498
21. Prasad R, Shivay YS, Kumar D, Sharma SN. Learning by doing exercise in soil fertility - A practical manual for soil fertility. In Division of agronomy, 68. New Delhi, India: IARI. 2006.
22. Chapman HD, Pratt PF. Methods of analysis for soils, plants and waters. Soil Science.1962; 93 (1): 68. https://doi.org/10.1097/00010694-196201000-00015
23. Olsen SR, Sommers LE. Phosphorus. In Methods of soil analysis, ed. A. L. Page, R. H. Miller and D. R. Keeney, Madison Book Company (W.I): Soil Science Society of American Journal.1982; 2 (2): 403-27. https://doi.org/10.2134/agronmonogr9.2.2ed.c24
24. Jehangir IA, Hussain A, Sofi NR, Wani SHet al. Crop establishment methods and weed management practices affect grain yield and weed dynamics in Temperate rice. Agronomy. 2021; 11: 2137. https://doi.org/10.3390/agronomy11112137
25. Page AL, Miller RH, Keeney DR. Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy: Soil Science Society of America, 1982; 1159.
26. Huang GB, Zhang RZ, Li GD, Li LL, Chan KY, et al. Productivity and sustainability of a spring wheat-field pea rotation in a semi-arid environment under conventional and conservation tillage systems. Field Crops Research. 2008; 107 (1):43-55. https://doi.org/10.1016/j.fcr.2007.12.011
27. Moll RH, Kamprath EJ, Jackson WA: Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agronomy Journal.1982; 74 (3):562-4. https://doi.org/10.2134/agronj1982.00021962007400030037x

28. Kathiresan RM, Vishnudevi S, Sarathkumar M, Singh S, Singh US. Role of submergence tolerant rice cultivar and herbicides in managing invasive alien weeds. Indian Journal of Weed Science. 2019; 51 (4): 333-36. https://doi.org/10.5958/0974-8164.2019.00071.6

29. Jamwal S, Puniya R, Bazaya BR, Bochalya RS, et al. Effect of Green Manuring and Herbicides on weed dynamics in direct seeded rice under sub tropics of Jammu. Agricultural Mechanization in Asia, Africa & Latin America.2022; 53 (3):6792-97.

30. Wickramasinghe D, Devasinghe U, Suriyagoda LDB, Egodawatta C, Benaragama DI. Weed dynamics under diverse nutrient management and crop rotation practices in the dry zone of Sri Lanka. Front. Agron. 2023; 5:1211755. https://doi.org/10.3389/fagro.2023.1211755

31. Ghosh D, Brahmachari K, Skalicky M, Hossain A, Sarkar S, et al. Nutrients Supplementation through Organic Manures Influence the Growth of Weeds and Maize Productivity. Molecules.2020; 25:4924. https://doi.org/10.3390/molecules25214924

32. Kumar V, Mahajan G, Sheng Q, Chauhan BS: Weed management in wet direct-seeded rice (*Oryza sativa* L.): Issues and opportunities. Advances in Agronomy. 2023; 179: 91-133. https://doi.org/10.1016/bs.agron.2023.01.002

33. Saha S, Munda S, Singh S, Kumar V, Jangde HK, et al. Crop Establishment and Weed Control Options for Sustaining Dry Direct Seeded Rice Production in Eastern India. Agronomy.2021; 11: 389. https://doi.org/10.3390/agronomy11020389

34. Luo W, Y Zhao, H Ding, X Lin, Zheng H. Co-metabolic degradation of bensulfuron-methyl in laboratory conditions. J. Hazard. Mater.2008; 158: 208-14. https://doi.org/10.1016/j.jhazmat.2008.02.115

35. Beheshti TI, Keyhani A, Rafiee SH. Energy balance in Iran's agronomy (1990-2006). Renew. Sustain. Energy Rev.2010; 14: 849-55. https://doi.org/10.1016/j.rser.2009.10.024

36. Zahan T, Richard WB, Rahman M, Ahmed MM. Performance of pyrazosulfuron-ethyl in non-puddled transplanted rainy season rice and its residual effect on growth of the succeeding crop in rice-wheat cropping pattern. International Journal of Pest Management.2020; 66 (2): 122-30. https://doi.org/10.1080/09670874.2019.1575489

37. Jiang M, Liu T, Huang N, Shen X, Shen M, Dai Q. Effect of long-term fertilization on the weed community of a winter wheat field. Scientific Repor.2018; 8: 4017. https://doi.org/10.1038/s41598-018-22389-4

38. Islam M, Urmi TA, Rana Md. S, Alam MS, Haque MM. Green manuring effects on crop morpho-physiological characters, rice yield and soil properties. Physiol Mol Biol Plants.2019; 25(1): 303-12. https://doi.org/10.1007/s12298-018-0624-2

39. Meena BL, Fagodiy RK, Prajapat K, Dotaniya ML, et al. Legume green manuring: an option for soil sustainability in Legumes for soil health and sustainable management. Springer.2018; 387-08. https://doi.org/10.1007/978-981-13-0253-4_12

40. Barala K, Shivay YS, Prasanna R, Kumari D, et al. Optimising nitrogen use efficiency of prilled urea through integrated use of nano-ZnO and green manuring for better productivity, quality and nutritional status of Basmati rice crop. Front. Sustain. Food Syst. 2024; 8. https://doi.org/10.3389/fsufs.2024.1352924

41. Omran HA, Dass A, Rajanna GA, Dhar S, et al. Root-shoot characteristics, yield and economics of mungbean (*Vigna radiata* L.) under variable rates of phosphorus and nitrogen. Bangladesh J. Bot. 2020; 49: 13-19. https://doi.org/10.3329/bjb.v49i1.49086

42. Singh T, Bana RS, Satapathy BS, Lal B, et al. Energy Balance, Productivity and Resource-Use Efficiency of Diverse Sustainable Intensification Options of Rainfed Lowland Rice Systems under Different Fertility Scenarios. Sustainability.2022; 14 (6): 3657. https://doi.org/10.3390/su14063657

43. Zhou G, Gao S, Lu Y, Liao Y, et al. Co-incorporation of green manure and rice straw improves rice production, soil chemical, biochemical and microbiological properties in a typical paddy field in southern China. Soil Tillage Res.2019; 197. https://doi.org/10.1016/j.still.2019.104499

44. Meng X, Li Y, Zhang Y, Yao H. Green manure application improves rice growth and urea nitrogen use efficiency assessed using 15^N labeling. Soil Sci. Plant Nutr. 2019; 65: 511-18. https://doi.org/10.1080/00380768.2019.1635872

45. Bhardwaj AK, Malik K, Chejara S, Rajwar D, et al. Integration of organics in nutrient management for rice-wheat system improves nitrogen use efficiency via favorable soil biological and electrochemical responses. Front. Plant Sci.2023; 13. https://doi.org/10.3389/fpls.2022.1075011

46. Dhaliwal SS, Sharma V, Shukla AK, Verma V, et al. Effect of addition of organic manures on basmati yield, nutrient content and soil fertility status in north-western India. Heliyon. 2023; 9. https://doi.org/10.1016/j.heliyon.2023.e14514

47. Nzir A, Bhat MA, Bhat TA, Fayaz S, et al. Comparative analysis of Rice and Weeds and their nutrient partitioning under various Establishment methods and Weed Management Practices in Temperate Environment. Agronomy. 2022; 12:81. https://doi.org/10.3390/agronomy12040816

48. Ghosh D, Brahmachari K, Brestic M, Ondrisik P, 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