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Impact of crop establishment methods and mineral nutrition on the productivity of rice (*Oryza sativa* L.) in North-West India

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Abstract

Due to scarcity of labour and declining underground water resources, there is a need to shift from the conventional transplanting method of rice to other methods which save on irrigation water and labour while maintaining similar productivity. Hence, studies to evaluate the comparative performances of different rice establishment methods under varied nutrition were conducted during *Kharif* 2017 and 2018 on Sandy Loam soil. The experiment was laid out in split plot design with three crop establishment methods (Manual transplanting, Mechanical transplanting and Direct seeding) in main plots, and five mineral nutrition (NPK) treatments {T_1-120:60:40- (Through chemical fertilizer), T_2-120:60:40- (75 % N through chemical fertilizer + 25 % N through farmyard manure), T_3-180:90:60 (Through chemical fertilizer), T_4-150:0:0 (Through chemical fertilizer) and T_5- Control (No fertilizer)} in subplots replicated thrice. Direct seeding recorded the highest panicles/m^2 but panicle weight was the highest under manual transplanting leading to similar grain and straw yields under all the establishment methods. Among mineral nutrition treatments, N: P: K 150:0:0 applied through chemical fertilizer recorded the highest grain and straw yields with respective increase of 56.4 and 59.0% than no fertilizer treatment (control), but former treatment was statistically similar to all other nutrition treatments. Interactive effects reveal statistical parity among all the establishment methods under different mineral nutrition treatments except control (no fertilizer), where manual transplanting treatment out yielded mechanical transplanting and direct seeding. Correlation studies revealed significant positive correlation of seed yield with plant height, panicle weight, filled grains, 1000 grain weight, SPAD and dry matter accumulation by crop, whereas, grain yield and unfilled grains were found to be negatively correlated.

Keywords: crop establishment methods, grain yield, mineral nutrition, rice, SPAD

Introduction

Paddy is cultivated in Punjab on a large area for more than half century due to the availability of plenty of groundwater as well as surface water resources (Srivastava *et al.,* 2014). The conventional system of rice production i.e., manual transplanting of rice in puddled fields is water and energy intensive, thereby, leading to increased pumping cost and water scarcity (Kaur and Vatta, 2015; Dhillon and Mangat, 2018; Vijaya kumar *et al*., 2018, 2019).

Repeated puddling destroys soil structure and creates shallow hard pan, affecting the performance of rice as well as the succeeding wheat crop. It also makes the conditions favorable for emission of methane (Bhardwaj and Sidana, 2019). Rice transplanting requires 150-200 man-hr ha^{-1}, which forms the major labour requirement for rice crop production. Moreover, the non-availability of sufficient labour at an appropriate time delays the transplanting of rice, causing yield reduction (Rakesh *et al.,* 2017). Hence, the productivity and sustainability of rice production systems are threatened because of increasing resource scarcity (Nayak *et al*., 2020, Vijayakumar *et al*., 2021b). To sustain the production of rice, alternative methods of rice production needed to be explored. Punjab, a state with a geographical area of 1.53 % of India contributed 30-48 % to the national buffer stock and played a key role in the food security of India (Chauhan *et al.,* 2012). Therefore, the sustainability of the rice production system in Punjab is important for ensuring the food security of India. Among the rice production systems, puddled transplanted rice (PTR) is the most widely adopted system while globally; about 23% of rice is direct-seeded rice (Rao *et al.,* 2007). To check the fall in ground water and diminishing labour availability, technological intervention is needed. Direct seeding of rice claims to reduce water footprints by 10-20% and labour requirements by 80% besides increasing water recharge (Anonymous, 2022, Chakraborty *et al.,* 2017; Vijayakumar *et al*., 2019a, 2022). Pathak *et al.,* (2009) reported that there was negligible methane emission in aerobic rice fields as compared to that in the transplanted rice. Similarly, the mechanical transplanting technique also addresses labour problem along with shortening of transplanting window on account of higher field efficiency of mechanical transplanters as compared to manual labour (Manes *et al.,* 2013; Vijayakumar *et al*., 2021). Changing the rice ecosystem from stagnated water (reducing conditions) to aerobic system as in case of DSR, even within two transplanting methods, where row spacing automatically got varied as in recommended practice of manual transplanting row spacing of 20 cm but paddy transplanter plants seedlings at the spacing of 30 cm. Under variable ecosystems and planting geometries, plant nutrition acquired our attention (Subramanian *et al*., 2020). Changes in crop establishment methods have some variations for farm operations like tillage, seedbed preparation, sowing or planting method, weed, water and nutrient management, that cause a major effect on the growth and development of rice (Dhillon and Mangat, 2018; Pooja *et al*., 2021, 2021a, Saravanane *et al*., 2021). Meagre information on the nutrition requirements of rice under different rice establishment methods is available for north-western India. Keeping these facts in mind, present studies were planned to evaluate the effect of different doses and sources (organic or inorganic) of mineral nutrition in relation to crop establishment methods of rice.

Materials and Methods

A field experiment was conducted at the research farm of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana located at 30° 54’ N and 75° 48’ E and 247.0 m above mean sea level with subtropical climatic conditions during summer (*Kharif*) seasons of 2017 and 2018. The monthly average maximum, minimum temperature and rainfall during the *Kharif* seasons of both years (2017 and 2018) has been given in **Figure 1**. The soil of the experimental field was sandy-loamy in texture, high in available–P (27.0 kg ha^{-1}), medium in available–K (167 kg ha^{-1}) and soil organic carbon (0.42%) but low in available N (270 kg ha^{-1}) status. The electrical conductivity and pH of the soil were within the normal range.

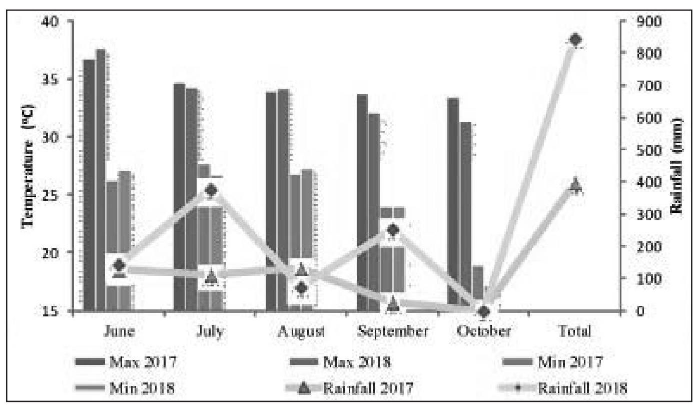

Figure 1: Maximum, minimum temperature and rainfall received during crop seasons of 2017 and 2018

The field trial was laid out in split plot design with three crop establishment methods (Manual transplanting, Mechanical transplanting and Direct seeding) in main plots, and five mineral nutrition (NPK) treatments {T_1: 120:60:40- (through chemical fertilizer), T_2: 120:60:40- (75% N through chemical fertilizer + 25% through farmyard manure), T_3: 180:90:60 (through chemical fertilizer), T_4: 150:0:0 (through chemical fertilizer) and T_5: control (no nutrients)}in sub plots replicated thrice. The farmyard manure (FYM) applied under T_2 treatment was analyzed for nitrogen, phosphorus and potassium content. It was found that FYM contained 0.5 N, 0.21 P_2O_5 and 0.36% K_2O. Hence, out of 120 kg N ha^{-1}, 25% i.e., 30 kg was applied through FYM @ 6 t/ha, which also supplied about 12.6 kg/ha of P_2O_5 and 21.6 kg/ha of K_2O. So, remaining 47.4 kg/ha P_2O_5 and 18.4 kg/ha K_2O was applied through chemical fertilizers. The sowing of rice nursery for manual and machine transplanting as well as direct sowing of rice in the field was done on the same day (June 5, 2017 and June 8, 2018) and was transplanted 25 days after sowing. The nursery of rice for manual and mechanical transplanting was sown as per the recommendations of Punjab Agricultural University, Ludhiana (Anonymous, 2022). For direct seeded rice, 25 kg seed ha^{-1} was sown in lines spaced at 20 cm. Irrigation was applied immediately after sowing. Manual transplanting of rice seedlings was done at 20 cm x 15 cm spacing and machine transplanting was carried out using a self-propelled paddy transplanter at 30 cm x 12 cm spacing. Crop was raised as per the recommendations of Punjab Agricultural University given in the package of practice for *kharif* crops (Annonymous, 2022). Urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) were used as sources of NPK, respectively and were applied as per treatment. The plant height, tillers m^{-2}, days to 50 percent flowering, panicles m^{-2}, panicle weight, filled and unfilled grain $panicle^{-1}$, 1000 grain weight were recorded as per the standard procedures in all the treatments. SPAD was estimated from five randomly selected leaves of different plants with a portable chlorophyll meter (SPAD-502). For estimating grain yield, a net area of 8.0 m^2 [4.0 m X 2.0 m] was harvested from each plot and then threshed, sun dried, winnowed, cleaned, and weighed on an electronic balance. For valid comparison of different treatments, moisture in grains was estimated using a digital moisture meter (Kett's RICETER J Handheld grain moisture meter). Grain yield was adjusted at 14% moisture and expressed as q ha^{-1}. The weight of the straw from each net plot was also recorded three days after harvest for estimation of straw yield, which was expressed as q ha^{-1}. Data were subjected to the analysis of variance (ANOVA) using the Proc GLM procedure of SAS software (SAS 9.3.). Least significant difference (LSD) at 5% level of probability was computed to compare the statistical significance of different treatments.

Results and Discussion

Planting methods

The pooled analysis of two *Kharif* seasons indicated that plant height at harvest, number of tillers per metre square, days taken to attain 50 % flowering stage, panicle per square metre, panicle weight and grain number per panicle differed significantly among various establishment methods of rice (**Table 1 and 2**). Crop attained significantly the highest plant height (97 cm) under manual transplanting whereas, machine transplanting (88.4 cm) and direct seeding (87.4 cm) attained statistically similar plant height. A similar trend was observed for tillers per square metre. Direct seeding had significantly the highest density of tillers (406.1) per meter square followed by machine transplanting, however, manual transplanting had the lowest density of tillers (290.3) per meter square. Machine transplanted crop took significantly the highest number of days (97.9) to attain 50% flowering followed by manual transplanting (91 days), whereas, the direct seeded crop took the least number of days for attaining 50% flowering stage, which was about 15 days earlier than machine transplanting of rice seedlings (**Table 1**). Data presented in **Figure 2** indicate that manually transplanted crops recorded significantly the highest SPAD value (37.8) whereas, direct seeded crop recorded the least, although differences between direct seeding (33.9) and mechanical transplanting (33.9) were not significant. Dry matter accumulation by crop and weed did not vary under the influence of establishment method.

Manual transplanting recorded the highest panicle weight (3.31g) and number of filled grains per panicle (149.5), which were 32.4 and 30.7% higher than that obtained under direct seeding. Direct seeding and machine transplanting of rice remained statistically similar w.r.t. panicle weight and number of filled grains per panicle (**Table 2**). The differences in 1000 grain weight among different establishment methods were not significant. Similar results were also reported by Gill and Walia (2013). It is further evident that

Table 1. Effect of establishment method and mineral nutrition on plant height, tiller count and days to 50% flowering of rice

Treatments	Plant height (cm) (at harvest)			Tillers/ m^2 (at harvest)			Days to 50 percent flowering		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Planting method									
M_1: Manual transplanting	99.8	94.2	97.0	299.4	281.2	290.3	92.7	89.3	91.0
M_2: Mechanical transplanting	92.4	84.3	88.4	387.7	349.4	368.6	96.3	99.5	97.9
M_3: Direct seeding	83.1	91.7	87.4	340.0	472.1	406.1	85.3	80.3	82.8
LSD (p=0.05)	9.4	7.3	6.1	31.9	49.6	29.6	2.5	1.3	2.0
Mineral nutrition									
T_1: 120:60:40- (Through chemical fertilizer)	94.6	91.6	93.1	337.3	386.0	361.7	90.2	89.2	89.7
T_2: 120:60:40- (75% N through chemical fertilizer + 25 % N through FYM)	89.0	92.8	90.9	329.9	367.0	348.5	90.8	89.1	90.0
T_3: 180:90:60 (Through chemical fertilizer)	95.9	93.8	94.9	367.7	408.0	387.9	92.4	88.4	90.4
T_4: 150:0:0 (Through chemical fertilizer)	94.8	91.0	92.9	373.9	376.0	375.0	90.3	90.1	90.2
T_5: Control (No nutrient)	84.3	81.0	82.7	287.9	296.1	292.0	93.3	91.7	92.5
LSD (p=0.05)	3.2	4.4	3.0	22.8	19.3	18.2	1.3	1.5	1.2

panicles per square meter showed the reverse trend with direct seeding recoding the highest (377 per square meter), whereas, manually transplanted cop recording the least (265 per square meter). Hence the superiority of panicle weight and the number of filled grains per panicle under manual transplanting over direct seeding was superseded by significantly the highest number of panicles per square meter under direct seeding, resulting into statistically similar grain yield under all establishment methods (**Table 3**). Similar grain yield under different establishment methods has also been reported by Dhillon *et al.,* (2020). The differences in the data were found to be non-significant for straw yield and harvest index among various crop establishment methods **(Table 3).** Our results are in contradiction to the findings of Kumar *et al.,* (2018) who reported more grain yield of rice under manual transplanting in puddled conditions than in direct seeded rice.

Mineral Nutrition

Mineral nutrition plays an important role in the growth and development of crop plants. The various mineral nutrition treatments had a significant effect on the growth, yield attributes and yield of rice crop as is indicated in pooled data of 2 years **(Table 1, 2, 3).** Data reveal that the control (no nutrition) treatment recorded the least plant height, tiller density, SPAD

Table 2. Effect of establishment method and mineral nutrition on yield attributes of rice

Treatments	Panicles/ m^2			Panicle weight (g)			Filled grain/ panicle			Un filled grains/ panicle			1000 grain weight (g)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Planting method															
M_1: Manual transplanting	260	269	265	3.35	3.26	3.31	163	135.9	149.5	15.7	22.4	19.1	22.1	20.0	21.1
M_2: Mechanical transplanting	300	310	305	2.89	2.66	2.78	141.5	98.2	119.9	13.1	21.1	17.1	21.9	20.2	21.1
M_3: Direct seeding	323	431	377	2.52	2.48	2.50	123.5	105.2	114.4	22.1	22.4	22.3	21.4	20.1	20.8
LSD (p=0.05)	35	48	31	0.42	0.32	0.30	14.9	7.3	8.9	5.2	NS	NS	NS	NS	NS
Mineral nutrition															
T_1: 120:60:40- (Through chemical fertilizer)	292	366	329	3.12	2.90	3.01	151.8	120.8	136.3	15.0	18.8	16.9	22.0	20.8	21.4
T_2: 120:60:40- (75% N through chemical fertilizer + 25 % N through FYM)	289	353	321	3.03	2.86	2.95	148.6	124.4	136.5	16.3	18.5	17.4	22.2	20.6	21.4
T_3: 180:90:60 (Through chemical fertilizer)	325	388	357	3.05	2.96	3.01	153.2	115.8	134.5	19.6	19.3	19.5	21.5	20.6	21.1
T_4: 150:0:0 (Through chemical fertilizer)	325	355	340	3.12	2.98	3.05	149.6	120.2	134.9	15.5	20.1	17.8	21.9	20.8	21.4
T_5: Control (No nutrient)	242	222	232	2.29	2.32	2.31	110	84.1	97.1	18.4	33.1	25.8	21.4	17.9	19.7
LSD (p=0.05)	30	36	28	0.24	0.22	0.19	13.0	4.4	7.4	NS	9.6	6.6	NS	NS	NS

value, dry matter accumulation by crop, panicles per square meter, panicle weight and filled grains per panicle but under the same treatment (i.e., control) crop took the significantly highest number of days to attain 50% flowering stage along with the highest dry matter accumulation by weeds. All other nutrition treatments recorded similar growth and yield attributes of rice but significant improvement in tiller density along with the concurrent reduction in dry matter accumulation by weeds was noted under higher levels of nutrition i.e., T_3 and T_4 (**Figure 2**). Although there was an improvement in tiller density under higher nutrition the panicles per square meter did not improve on account of the higher level of fertilizer application.

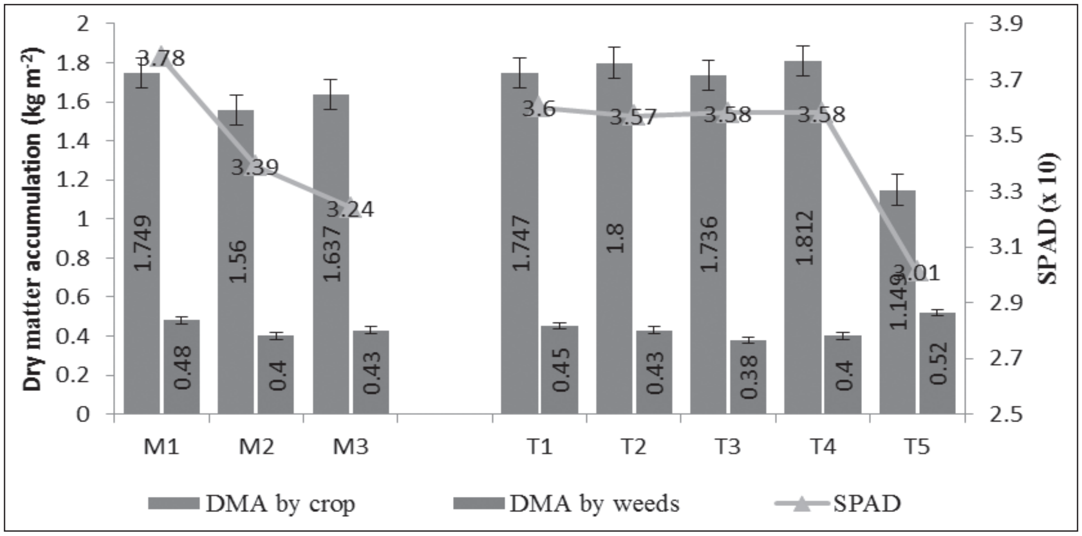

Figure 2: Effect of crop establishment methods and mineral nutrition on SPAD value at 50% floweing stage; dry matter accumulation by crop and weeds at active tillering stage (pooled data)

All the treatments irrespective of the source and amount of nutrition had a significantly higher number of filled grains and lower unfilled grains per panicle than the control treatment (no fertilizer) (**Table 3**). In pooled data differences for 1000 grain weight and harvest index were found to be non-significant. All the nutrition treatments had significantly higher grain and straw yields than the control. Increase in grain and straw yield with different sources of nutrition might be due to better growth attributes of rice like plant height, tillers, dry matter accumulation and higher chlorophyll content in leaves by the vigorous plants of rice with nutrients in comparison to control (no fertilizer). It is interesting to note that in the foregoing studies, even non-use of phosphatic and potassic fertilizers (T_4) did not affect the growth and yield of rice crop, which can probably be ascribed to the sufficient status of available phosphorus and potassium in the soil of the experimental field. Similar results have been reported by Tripathi *et al.,* (2019) and Dai *et al.,* (2010.)

Planting Methods x Mineral Nutrition

The interactive effects of planting methods x mineral nutrition on grain and straw yields have been presented in **Figures 3 and 4**. Data revealed that all the nutrition treatments performed significantly better than the control (no nutrient) under all methods of crop establishment. Data revealed statistical parity among all the establishment methods under different mineral nutrition treatments except control (no fertilizer), where manual transplanting treatment out yielded mechanical transplanting and direct seeding. Manual transplanting treatment having NPK 150:0:0 (through chemical fertilizer) gave significantly higher grain yields and statistically on par with all other treatments combination except for the control of all planting methods and machine transplanting with NPK 120:60:40- (75% N through chemical fertilizer) + (25 % N through FYM). Mitali *et al*., (2019) reported that the grain yield of rice increased with increasing N dose under manual transplanting and direct seeding of rice. Similarly, Ranjan and Yadav, (2019) also found that the establishment methods and appropriate doses of N fertilizer are needed to improve the nitrogen use efficiency in rice. The various crop establishment methods also performed significantly different at the different levels of nutrition for straw yields. In general, machine transplanting gave more straw yield than direct seeding and manual transplanting. Significantly higher straw yields were obtained under machine transplanting with NPK 180:90:60 (through chemical fertilizer) than the control of all planting methods

Table 3. Effect of establishment method and mineral nutrition on grain, straw yield and harvest index of rice

Treatments	Grain yield (q/ha)			Straw yield (q/ha)			Harvest index (%)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Planting method									
M_1: Manual transplanting	65.5	69.7	67.6	80.1	87.3	83.7	45.0	44.4	44.7
M_2: Mechanical transplanting	62.0	59.8	60.9	81.5	81.1	81.3	43.2	44.3	43.8
M_3: Direct seeding	60.9	64.0	62.5	78.9	80.8	79.9	43.6	44.5	44.0
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mineral nutrition									
T_1: 120:60:40- (Through chemical fertilizer)	65.2	69.4	67.3	84.4	91.5	88.0	43.6	43.2	43.4
T_2: 120:60:40- (75% N through chemical fertilizer + 25 % N through FYM)	63.7	68.3	66.0	82.5	90.5	86.5	43.5	43.0	43.3
T_3: 180:90:60 (Through chemical fertilizer)	67.2	71.8	69.5	86.6	96.2	91.4	43.7	42.7	43.2
T_4: 150:0:0 (Through chemical fertilizer)	68.3	72.5	70.4	85.4	89.3	87.3	44.4	44.9	44.7
T_5: Control (No nutrient)	49.7	40.3	45.0	61.8	48.0	54.9	44.6	47.9	46.3
LSD (p=0.05)	6.2	5.3	5.0	8.5	8.4	8.1	NS	3.3	NS

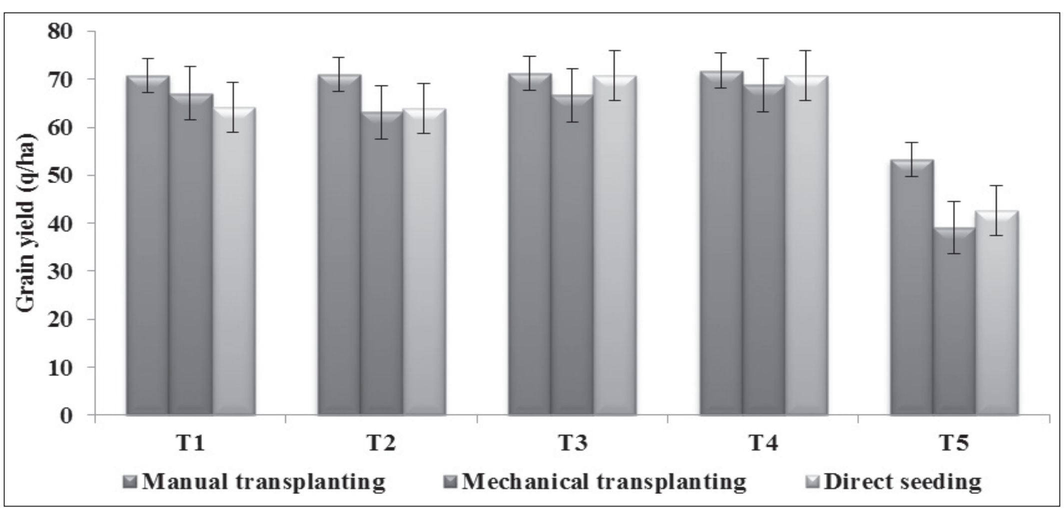

Figure 3: Interactive effect of crop establishment methods and mineral nutrition on grain yield of rice (pooled data)

but were statistically at par with all other treatment combinations for varied planting methods (**Figure 4**).

Correlation studies

Correlation studies revealed significant positive correlation of seed yield with plant height, panicle weight, filled grains, 1000 grain weight, SPAD and dry matter accumulation by crop at active tillering stage, whereas, grain yield and unfilled grains were found to be negatively correlated (**Table 4**). Cursory look at the data also reveal that panicles m^{-2} and tiller density had significant negative correlation with dry matter accumulation by weed at active tillering stage thereby indicating the smothering potential of more tiller density on weeds. It is also evident that DMA by crop and SPAD had significant positive correlation with panicle weight and filled grains, ultimately with grain yield.

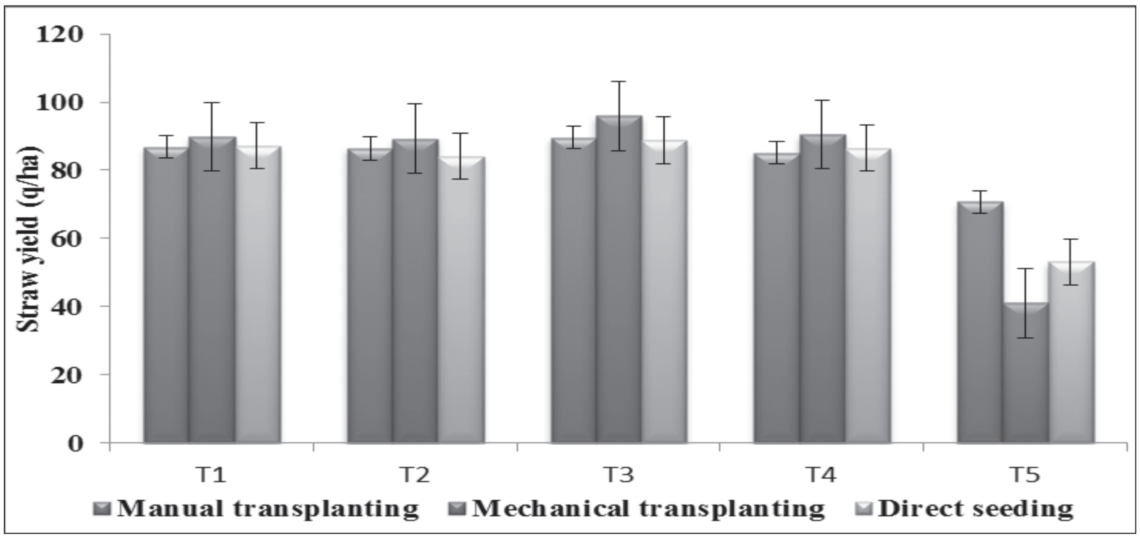

Figure 4: Interactive effects of crop establishment methods and mineral nutrition on straw yield of rice (pooled data)

Conclusions

It is concluded that all the methods of crop establishment performed statistically similar and one can practice any method of crop establishment method depending upon the local situations like availability of labour, groundwater, energy, sowing window and other resources. Rice crop responds more to nitrogen fertilizer in sandy loam soil having sufficient phosphorus and potash status. Hence, one can omit addition of phosphorus and potassium fertilizers to rice if soil status for these nutrients is sufficient.

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Table 4. Correlation matrix between growth, yield attributes and yield of rice (on the basis of pooled data)

Parameters	PH	TD	DTF	Pm^{-2}	PW	FG	UFG	1000GW	SPAD	DM-crop	DM-weeds	GY
PH	1.000											
TD	0.070^{NS}	1.000										
DTF	-0.058^{NS}	-0.378^{NS}	1.000									
Pm^{-2}	0.282^{NS}	0.952^{**}	-0.557^{NS}	1.000								
PW	0.965^{**}	-0.050^{NS}	0.114^{NS}	0.142^{NS}	1.000							
FG	0.964^{**}	0.021^{NS}	-0.042^{NS}	0.244^{NS}	0.981^{**}	1.000						
UFG	-0.671^{NS}	-0.325^{NS}	-0.259^{NS}	-0.382^{NS}	-0.764^{*}	-0.763^{*}	1.000					
1000GW	0.758^{*}	0.466^{NS}	-0.056^{NS}	0.591^{NS}	0.791^{*}	0.834^{*}	-0.942^{**}	1.000				
SPAD	0.969^{**}	0.029^{NS}	0.031^{NS}	0.233^{NS}	0.991^{**}	0.996^{**}	-0.792^{*}	0.841^{**}	1.000			
DM-crop	0.835^{**}	0.451^{NS}	-0.277^{NS}	0.642^{NS}	0.816^{*}	0.883^{**}	-0.810^{*}	0.954^{**}	0.872^{**}	1.000		
DM-weed	-0.386^{NS}	-0.830^{*}	-0.017^{NS}	-0.794^{*}	-0.335^{NS}	-0.342^{NS}	0.615^{NS}	-0.677^{NS}	-0.374^{NS}	-0.630^{NS}	1.000	
GY	0.883^{**}	0.478^{NS}	-0.226^{NS}	0.652^{NS}	0.841^{**}	0.882^{**}	-0.794^{*}	0.932^{**}	0.883^{**}	0.980^{**}	-0.685^{NS}	1.000

PH: plant height; TD: tiller density; DTF: days to flowering; Pm^{-2}:Panicles m^{-2}; PW: Panicle weight; FG: filled grains; UFG: Un filled grains; 1000GW: 1000 grain weight; SPAD: SPAD value; DM-crop: Dry matter accumulation by crop at active tillering stage; DM-weed: Dry matter accumulation by weed at active tillering stage; GY: Grain yield.

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