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Impact of different rice Establishment Methods and Conservation Tillage on Leaf Chlorophyll Status of Rice and Succeeding *rabi* Crops

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ABSTRACT: This research investigated the effects of different rice establishment methods and tillage practices on SPAD readings of rice, chickpea, blackgram, and mustard. The study was conducted over two years (2021-2022 and 2022-23) and evaluated machine transplanting (M_1), wet direct seeding (M_2) and dry direct seeded rice (M_3), as rice establishment methods, along with conventional tillage and zero tillage as tillage practices. With respect to rice dry direct seeding reported significantly higher SPAD values at 30 days after sowing (DAS) but in succeeding stages (60. 90 DAS and harvest) machine transplanting recorded significantly higher SPAD readings over wet and dry direct seeding. SPAD readings of succeeding *rabi* crops were taken at 30, 60 DAS and harvest for each crop. The results demonstrated that dry direct seeded rice consistently exhibited significantly higher SPAD values compared to the other methods for all three crops in *rabi*. Conventional tillage also reported higher SPAD readings than zero tillage. The interaction effect between rice establishment methods and tillage practices was found to be significant for SPAD readings in chickpea, blackgram and mustard. Specifically, the combination of dry direct seeded rice with conventional tillage (M_3S_2) consistently reported the highest SPAD readings in both years for chickpea, blackgram and mustard indicating the significance of dry direct seeding method of rice establishment and conventional tillage practice on succeeding crops.

Keywords: Blackgram, Chickpea, Mustard, Rice establishment methods, SPAD readings and Tillage practices.

INTRODUCTION

Studying nutrient dynamics in different rice establishment methods is of paramount importance in ensuring sustainable and efficient agricultural practices. Rice, being a staple food for a significant portion of the global population, requires optimal nutrient management for high yields and nutritional value (Shikha *et al*., 2017). Various rice establishment methods, such as dry direct seeding, wet direct seeding and transplanting, have unique effects on nutrient availability, uptake, and utilization in paddy fields. By understanding the crop behaviour in terms of nutrient dynamics associated with each method, farmers and researchers can make informed decisions regarding fertilization strategies, water management, and crop rotation, leading to improved resource-use efficiency, reduced environmental impacts, and enhanced food security. Furthermore, impact of rice establishment methods on succeeding I.D crops also assumes importance under crop diversification.

nitrogen is a critical nutrient required for plant growth and development. It plays a vital role in various physiological processes, including protein synthesis, chlorophyll formation, and overall crop productivity. Different rice establishment methods, such as dry direct seeding, wet direct seeding and transplanting, can have varying effects on soil nitrogen availability and distribution. Understanding how these methods influence nitrogen dynamics is crucial for optimizing nitrogen management strategies and ensuring efficient nutrient uptake by succeeding crops.

Secondly, efficient nitrogen uptake by succeeding crops is essential for sustainable agricultural systems. Excessive or inadequate nitrogen levels can have adverse effects on crop growth, yield and quality (Praveen *et al*., 2007). By studying the impact of different rice establishment methods on nitrogen status of succeeding crops through SPAD meter, most suitable method that promotes optimal nitrogen utilization by succeeding crops can be identified. This knowledge can help farmers make informed decisions regarding crop management practices and nitrogen fertilizer application, thereby minimizing nitrogen losses and reducing environmental impacts, such as nitrogen leaching and greenhouse gas emissions.

Furthermore, studying the nutrient uptake of succeeding crops in relation to different rice establishment methods provides insights into the overall sustainability of cropping systems (Stoop *et al*., 2002). Sustainable agriculture aims to maximize resource use efficiency while minimizing environmental degradation (Shrestha *et al*., 2021). Assessing the impact of rice establishment methods on nutrient uptake helps evaluate the potential for resource conservation and improved nitrogen-use efficiency in rice-based cropping systems. This knowledge can guide the development of integrated nutrient management practices that promote sustainable intensification and resilience in agricultural systems.

The leaf chlorophyll status of crops is a vital indicator of plant health, photosynthetic efficiency and overall crop productivity (Bussotti *et al*., 2020). The establishment method of rice, along with the tillage practices employed, can significantly influence the leaf chlorophyll content and subsequently impact the growth and performance of both rice and subsequent *rabi* crops. Understanding the effects of different rice establishment methods, such as dry direct seeding, wet direct seeding and transplanting, in conjunction with various tillage techniques, is crucial for optimizing crop management strategies and ensuring sustainable agricultural practices. With the aim to study how different rice establishment methods influence SPAD reading of succeeding crops, present experiment was designed and executed as per given details below.

MATERIALS AND METHODS

Present experiment was initiated in *kharif* 2021-22 at Regional Sugarcane and Rice Research Station (RS&RRS), Rudrur, Telangana. Geographical positioning system (GPS) co-ordinates of experimental site was 18°33′55.01″ N latitude and 77°52′20.12″E longitudes with an altitude of 401 m above mean sea level. Total rainfall received during the period of experiment was 765.5 mm and 1247 mm, mean maximum temperature was 30.4 and 31.3°C and minimum temperatures were 20.5 and 19.6 °C for 2021-22 and 2022-23, respectively. Soil of the experimental site belongs to silty clay type based on its particle size distribution and moderately alkaline in reaction with pH of 8.1, EC 1.94 dSm^{-1}, OC of 0.42 percent and Initial nitrogen status of soil was low with 231.1 kg N ha^{-1}.

The experiment was carried out in *kharif* followed by *rabi* for two successive years *i.e*., 2021-22 and 2022-23 in split-split plot design with three establishment methods of rice as main plots *viz*., Machine Transplanting (M_1), Wet Direct Seeding (M_2) and Dry Direct Seeding (M_3) followed by two tillage systems {Zero tillage with rice residue mulch (S_1) & Conventional tillage (S_2)} as sub plots and three I.D crops (Chickpea, Blackgram & Mustard) were taken in the succeeding *rabi* season into sub-sub plots.

Popular rice variety of Telangana, JGL-24423 (Jagtial Rice 1) with short duration and high yield potential was selected in the present experiment. Chickpea, blackgram and mustard were selected as test crops in succeeding *rabi* and varieties namely, NBeG-47, LBG-787 and Pusa Mustard-25, respectively were chosen. Rice crop was sown in the month of July in both the years of study as per treatments and succeeding *rabi* crops were sown as per treatment allotted. Under zero tillage, succeeding I.D crops were sown immediately after the harvest of rice and under conventional tillage, a series of tillage operations were carried till the soil attained fine tilth before sowing I.D crop. Fertilizer dose (N:P:K) of 120:50:40, 20:50:0, 60:40:40 and 20:50:20 was applied to rice, chickpea, blackgram and mustard respectively. Entire phosphorus and potassium was applied as basal and nitrogen in splits to all crops except in chickpea and blackgram where entire dose of nitrogen also applied as basal.

Chlorophyll content of leaf is the indirect measure of leaf nitrogen status and chlorophyll meter (Model SPAD 502 from Minotta Company, Japan) was used in the present experiment to record SPAD values of both rice and I.D crops. SPAD reading of rice was recorded at 30, 60, 90 Days After Sowing (DAS) and harvest from the demarcated plants in net plot. Whereas, in I.D crops it was measured at 30, 60 DAS and harvest.

Results of *rabi* I.D crops were compared statistically using ANOVA technique of split plot design for individual crop separately. Though the experiment was laid out in split-split plot design, three crops were compared in different establishment and tillage systems separately as these are biologically different entities using ANOVA of split plot design in OP stat software and critical difference was used to distinguish the results. Treatment wise mean SPAD values of *kharif* rice was also presented separately for better understanding and interpretation of the results.

RESULTS AND DISCUSSION

A. SPAD readings of kharif rice

The SPAD meter readings of rice were collected over two consecutive years, and the results were presented in Table 1 and Fig 1. There is a comparable variation in SPAD values among the establishment methods, with dry direct seeded rice (M_3) initially exhibiting the highest SPAD values in both the years of study. However, as the growth progressed, machine transplanting (M_1) consistently recorded higher SPAD values compared to wet direct seeding (M_2), while dry direct seeded rice showed the lowest SPAD meter readings. The results demonstrated distinct variation in

SPAD values among the establishment methods. Dry direct seeded rice exhibited the highest SPAD values of 33.40 and 33.83 at 30 DAS in 2021-22 and 2022-23, respectively which is due to early establishment due to direct seeding. Conversely, machine transplanting recorded the highest SPAD values at 60 (40.56), 90 DAS (44.06) and at harvest (29.16) in 2021-22. A similar trend was observed in the second year (2022-23), with machine transplanting displaying the highest SPAD values at 60 DAS (40.73), 90 DAS (44.93) and harvest (30.16). Wet direct seeding consistently followed machine transplanting in terms of SPAD values, while dry direct seeding consistently showed the lowest SPAD values at later growth stage (60, 90 DAS and harvest) in both the years. The findings suggest the establishment method significantly affects the leaf nitrogen content in rice plants. Machine transplanting consistently resulted in higher SPAD values compared to wet direct seeding and dry direct seeding. This could be attributed to the enhanced availability and efficient uptake of nitrogen in machine transplanted rice from puddling and continuous submergence of soil (Kadiyala *et al*., 2012). In contrast, dry direct seeded rice displayed the lowest SPAD values, possibly due to reduced nutrient availability (Mohanty *et al*., 2021).

A. SPAD readings of chickpea

Though Machine transplanting in rice exhibited higher SPAD reading in preceeding season, the SPAD readings of chickpea grown after rice displayed a different trend. Of the three systems dry direct seeded rice consistently showed significantly higher SPAD values of chickpea at 30, 60 and harvest, with readings of 43.05, 50.34 and 25.22, respectively (Table 2). In the subsequent year, dry direct seeded rice remained superior, displaying SPAD values of 40.67, 48.08 and 23.55 at the same respective stages (Table 2). Tillage practices included in the post *kharif* also had a considerable influence on SPAD readings of chickpea where, conventional tillage resulted in considerably higher SPAD readings compared to zero tillage, with values of 42.78, 50.51 and 25.90 in the first year and 40.16, 47.46 and 23.90 in the second year at 30, 60 DAS and harvest, respectively. The interaction effect between rice establishment methods and tillage practices significantly influenced the SPAD readings of chickpea at 30 and 60 DAS in both years. The combination of dry direct seeded rice with conventional tillage (M_3S_2) proved as best with highest SPAD readings of 46.30 and 54.03 at 30 and 60 DAS in the first year and 43.80 and 51.23 at the same stages in the second year (Table 2a). These findings highlight the suitability of dry direct seeding method of rice establishment on post *kharif* I.D crops over puddled systems in terms of nutrient uptake expressed as leaf chlorophyll content. This effect is further aggravated when combined with conventional tillage.

B. SPAD readings of blackgram

Blackgram grown in dry direct seeded rice exhibited significantly higher SPAD values compared to that grown in machine transplanting (M_1) and wet direct seeding (M_2). At 30, 60 DAS and harvest, dry direct seeded rice recorded SPAD values of 44.68, 53.02 and 20.25, respectively in 2021-2022 (Table 3). This pattern persisted in the second year, with SPAD values of 42.25, 48.08 and 18.90 for the same stages. There was no significant difference in SPAD readings between machine transplanting and wet direct seeding across both years. Conventional tillage in the succeeding *rabi* season resulted in significantly higher SPAD readings compared to zero tillage, with values of 44.16, 52.15, and 20.74 in the first year, and 41.93, 47.33, and 19.26 in the second year for 30, 60 DAS, and harvest, respectively. The interaction effect between rice establishment methods and tillage practices had a significant influence on SPAD readings for blackgram at only 30 and 60 DAS in both years. The combination of dry direct seeded rice with conventional tillage (M_3S_2) exhibited the highest SPAD readings, reaching 48.20 and 57.19 at 30 and 60 DAS, respectively, in the first year, and 46.10 and 52.75 at the same stages in the second year highlighting the suitability of combination for blackgram intended to grow post *kharif* rice (Table 3a).

C. SPAD readings of mustard

In the year 2021-2022 of experiment, dry direct seeded rice demonstrated significantly higher SPAD values compared to machine transplanting (M_1) and wet direct seeding (M_2) for mustard. At 30, 60 DAS and harvest, dry direct seeded rice recorded SPAD values of 35.93, 42.00, and 16.43, respectively (Table 4). Similar results were observed in the second year, with SPAD values of 32.48, 37.67 and 14.50 for the same stages. There was no significant difference in SPAD readings between machine transplanting and wet direct seeding over the two years. Conventional tillage in the succeeding *rabi* season resulted in significantly higher SPAD readings compared to zero tillage, with values of 35.69, 41.92, and 16.16 in the first year and 32.26, 37.34 and 14.64 in the second year for 30, 60 DAS and harvest, respectively. The interaction effect between rice establishment methods and tillage practices had a significant influence on SPAD readings for mustard at 30 and 60 DAS in both years. The combination of dry direct seeded rice with conventional tillage (M_3S_2) exhibited the highest SPAD readings, reaching 39.77 and 45.40 at 30 and 60 DAS, respectively, in the first year, and 36.53 and 40.80 at the same stages in the second year (Table 4a). These findings highlight the positive impact of dry direct seeding of rice with conventional tillage on the chlorophyll content of succeeding crops (mustard).

Nutrient availability of soil and its uptake in crops grown in succession to *kharif* rice faces a different challenge since growing of rice in traditional way involve several soil destructive operations like puddling and continuous submergence (Virender and Ladha 2011).

Puddling destroys the soil structure and makes the surface hard and compact while continuous submergence alters the soil microbial demography. Though these operations were considered destructive to soil, they have positive influence on rice crop with congenial conditions like improved nutrient availability and uptake. In spite of higher nitrogen uptake and availability in puddled transplanted rice, I.D crops grown in succession to it did not find similar results

(Kadiyala *et al*., 2012). Dry direct seeded rice with neither puddling nor submergence recorded significantly higher chlorophyll content over both puddled systems. Absence of puddling and prevalence of aerobic conditions in dry direct seeded rice from the beginning might have supported nitrifying and mineralizing bacteria with rapid mineralization of organic matter and improved nutrient availability and uptake over wet direct seeding and machine transplanting since there is a considerable influence of earlier nutrient management practices on succeeding crops (Haung *et al*., 2022). Conventional tillage on the other side improved nutrient access to plant by supporting voluminous root growth in succeeding crops over zero tillage through porous seed bed. In three crops tested, SPAD readings were lower initially at 30 DAS which later it reached peak by 60 DAS and reduced gradually till harvest due to maturity and senescence of leaf. Lower values of SPAD at 30 DAS in all three crops even with application of nitrogen fertilizer as basal can be attributed for poor activity of microbes due to transition from anaerobic to aerobic environments of soil. Zero tillage with rice residue retention with greater soil moisture retention on surface layers, did not favour crops which may be due to greater soil resistance over conventional tillage.

Across the crops, two legumes (chickpea & blackgram) have superior SPAD readings over mustard at the stages and in all the treatments imposed. Nodulation in these crops is one reason for higher nitrogen status of crops over mustard. Of the three test crops, blackgram recorded superiorly higher SPAD values indicating its adoptability and suitability in three rice establishment methods.

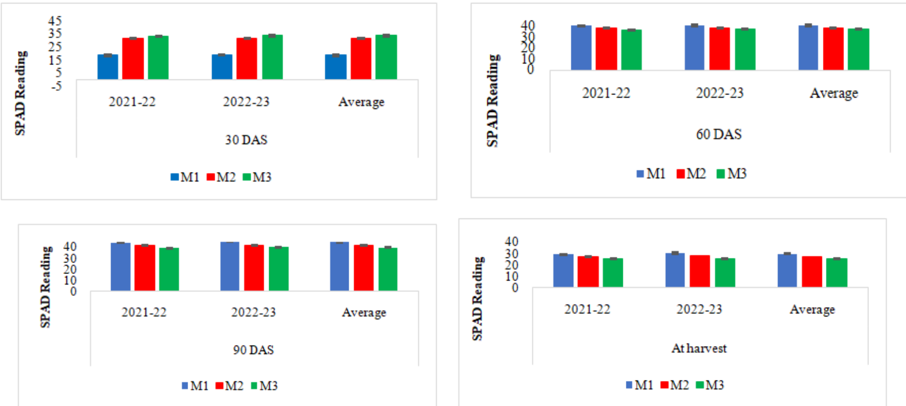

Fig. 1. SPAD readings of rice at different growth stages as influenced by different rice establishment methods. Vertical bars are ± standard error of the means. (M_1: Machine transplanting; M_2: Wet direct seeding through drum seeder; M_3: Dry direct seeding through seed drill, DAS: Days after sowing)

Table 1: SPAD readings (Chlorophyll status) of *kharif* rice under different establishment methods

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2021-22	2022-23	Average	2021-22	2022-23	Average	2021-22	2022-23	Average	2021-22	2022-23	Average
M_1	18.53	18.90	18.71	40.56	40.73	40.79	44.06	44.93	44.49	29.16	30.16	29.66
M_2	31.56	31.66	31.61	38.30	38.73	38.51	41.30	41.63	41.46	27.26	27.60	27.43
M_3	33.40	33.83	33.61	36.93	37.10	37.01	39.16	40.06	39.61	25.23	25.43	25.33

Table 2: SPAD readings of chickpea as influenced by different rice establishment methods and tillage systems

Treatment	30 DAS			60 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Main plots: Rice establishment methods									
M_1: Machine transplanting	39.67	37.00	38.335	47.00	44.43	45.715	22.45	20.13	21.29
M_2: Wet direct seeding through drum seeder	38.43	36.22	37.325	46.08	43.05	44.565	21.72	19.58	20.65
M_3: Dry direct seeding through seed drill	43.05	40.67	41.86	50.34	48.08	49.21	25.22	23.55	24.38
S.Em±	0.78	0.84	-	0.79	0.88	-	0.64	0.77	-
CD (P=0.05)	3.05	3.30	-	3.08	3.47	-	2.51	3.02	-
Sub plots: Tillage practices									
S_1: Zero tillage with rice residue mulch	37.99	35.77	36.88	45.10	42.92	44.01	20.36	18.28	19.32
S_2: Conventional tillage	42.78	40.16	41.47	50.51	47.46	48.985	25.90	23.90	24.90
S.Em±	0.17	0.28	-	0.23	0.28	-	0.48	0.60	-
CD (P=0.05)	0.58	0.97	-	0.80	0.96	-	1.67	2.08	-
Interaction (M × S)	S	S	-	S	S	-	NS	NS	-

DAS: Days after sowing

Table 2a: Interaction effect of rice establishment methods and tillage systems on SPAD readings of succeeding chickpea.

SPAD readings of chickpea at 30 DAS								
M × S	2021-22				2022-23			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	37.63	36.53	39.80	37.99	35.43	34.33	37.53	35.77
S_2	41.70	40.33	46.30	42.78	38.57	38.10	43.80	40.16
Mean	39.67	38.43	43.05	40.38	37.00	36.22	40.67	37.96
	S.Em±		CD (P=0.05)		S.Em±		CD (P=0.05)	
S at same M	0.29		1.01		0.49		1.68	
M at same S	0.80		3.13		0.91		3.51	
SPAD readings of chickpea at 60 DAS								
M × S	2021-22				2022-23			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	44.23	44.44	46.64	45.10	42.19	41.64	44.93	42.92
S_2	49.77	47.72	54.03	50.51	46.67	44.47	51.23	47.46
Mean	47.00	46.08	50.34	47.80	44.43	43.05	48.08	45.19
	S.Em±		CD (P=0.05)		S.Em±		CD (P=0.05)	
S at same M	0.40		1.39		0.48		1.67	
M at same S	0.84		3.24		0.95		3.66	

M_1: Machine transplanting; M_2: Wet direct seeding through drum seeder; M_3: Dry direct seeding through seed drill; S_1: Zero tillage with rice residue mulch; S_2: Conventional tillage; DAS: Days After Sowing

Table 3: SPAD readings of blackgram as influenced by different rice establishment methods and tillage systems.

Treatment	30 DAS			60 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Main plots: Rice establishment methods									
M_1: Machine transplanting	40.78	38.50	39.64	48.54	43.41	45.975	18.15	16.53	17.34
M_2: Wet direct seeding through drum seeder	39.68	37.43	38.555	46.93	42.47	44.7	17.52	16.20	16.86
M_3: Dry direct seeding through seed drill	44.68	42.25	43.465	53.02	48.08	50.55	20.25	18.90	19.575
S.Em±	0.79	0.89	-	1.08	1.08	-	0.52	0.54	-
CD (P=0.05)	3.11	3.50	-	4.22	4.25	-	2.02	2.11	-
Sub plots: Tillage practices									
S_1: Zero tillage with rice residue mulch	39.12	36.86	37.99	46.84	41.98	44.41	16.53	15.17	15.85
S_2: Conventional tillage	44.16	41.93	43.045	52.15	47.33	49.74	20.74	19.26	20
S.Em±	0.30	0.41	-	0.41	0.60	-	0.41	0.44	-
CD (P=0.05)	1.04	1.41	-	1.44	2.06	-	1.43	1.51	-
Interaction (M × S)	S	S	-	S	S	-	NS	NS	-

DAS: Days after sowing

Table 3a: Interaction effect of rice establishment methods and tillage systems on SPAD readings of succeeding blackgram.

SPAD readings of blackgram at 30 DAS								
M × S	2021-22				2022-23			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	39.17	37.50	40.70	39.12	36.87	35.30	38.40	36.86
S_2	42.40	41.87	48.20	44.16	40.13	39.57	46.10	41.93
Mean	40.78	39.68	44.45	41.64	38.50	37.43	42.25	39.39
	S.Em±		CD (P=0.05)		S.Em±		CD (P=0.05)	
S at same M	0.52		1.80		0.71		2.45	
M at same S	0.87		3.36		1.02		3.90	
SPAD readings of blackgram at 60 DAS								
M × S	2021-22				2022-23			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	47.00	44.69	48.84	46.84	41.66	40.87	43.40	41.98
S_2	50.08	49.18	57.19	52.15	45.16	44.06	52.75	47.33
Mean	48.54	46.93	53.02	49.50	43.41	42.47	48.08	44.65
	S.Em±		CD (P=0.05)		S.Em±		CD (P=0.05)	
S at same M	0.72		2.49		1.03		3.57	
M at same S	1.19		4.57		1.31		4.94	

M_1: Machine transplanting; M_2: Wet direct seeding through drum seeder; M_3: Dry direct seeding through seed drill; S_1: Zero tillage with rice residue mulch; S_2: Conventional tillage; DAS: Days After Sowing

Table 4: SPAD readings of mustard as influenced by different rice establishment methods and tillage systems.

Treatment	30 DAS			60 DAS			At harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
Main plots: Rice establishment methods									
M_1: Machine transplanting	32.03	28.73	30.38	38.08	34.12	36.1	15.15	13.22	14.185
M_2: Wet direct seeding through drum seeder	30.94	27.17	29.055	37.48	32.92	35.2	14.92	13.12	14.02
M_3: Dry direct seeding through seed drill	35.93	32.48	34.205	42.00	37.67	39.835	16.43	14.50	15.465
S.Em±	0.76	0.75	-	0.89	0.77	-	0.30	0.29	-
CD (P=0.05)	2.97	2.93	-	3.51	3.04	-	1.20	1.13	-
Sub plots: Tillage practices									
S_1: Zero tillage with rice residue mulch	30.25	26.67	28.46	36.46	32.46	34.46	14.39	12.58	13.485
S_2: Conventional tillage	35.69	32.26	33.975	41.92	37.34	39.63	16.61	14.64	15.625
S.Em±	.035	0.45	-	0.31	0.15	-	0.19	0.19	-
CD (P=0.05)	1.20	1.55	-	1.07	0.50	-	0.66	0.65	-
Interaction (M × S)	S	S	-	S	S	-	NS	NS	-

DAS: Days after sowing

Table 4a: Interaction effect of rice establishment methods and tillage systems on SPAD readings of succeeding mustard.

SPAD readings of mustard at 30 DAS								
M × S	**2021-22**				**2022-23**			
	M_1	**M_2**	**M_3**	**Mean**	**M_1**	**M_2**	**M_3**	**Mean**
S_1	30.47	28.17	32.10	30.25	27.20	24.37	28.43	26.67
S_2	33.60	33.70	39.77	35.69	30.27	29.97	36.53	32.26
Mean	32.03	30.94	35.93	32.97	28.73	27.17	32.48	29.46
	S.Em±		**CD (P=0.05)**		**S.Em±**		**CD (P=0.05)**	
S at same M	0.60		2.08		0.78		2.69	
M at same S	0.87		3.31		0.93		3.49	
SPAD readings of mustard at 60 DAS								
M × S	**2021-22**				**2022-23**			
	M_1	**M_2**	**M_3**	**Mean**	**M_1**	**M_2**	**M_3**	**Mean**
S_1	36.40	34.37	38.60	36.46	32.77	30.07	34.53	32.46
S_2	39.77	40.60	45.40	41.92	35.47	35.77	40.80	37.34
Mean	38.08	37.48	42.00	39.19	34.12	32.92	37.67	34.90
	S.Em±		**CD (P=0.05)**		**S.Em±**		**CD (P=0.05)**	
S at same M	0.53		1.84		0.25		0.87	
M at same S	0.97		3.74		0.79		3.10	

M_1: Machine transplanting; M_2: Wet direct seeding through drum seeder; M_3: Dry direct seeding through seed drill; S_1: Zero tillage with rice residue mulch; S_2: Conventional tillage; DAS: Days After Sowing

CONCLUSIONS

The findings suggest that machine transplanting among three rice establishment methods, promotes better leaf chlorophyll content in rice plants, possibly due to enhanced nutrient availability from puddling and continuous submergence of soil. Conversely, dry direct seeded rice displayed lower SPAD values, potentially indicating reduced nutrient availability. These results emphasize the importance of puddled transplanting method of rice. The availability and uptake of nutrients in crops grown after *kharif* rice are influenced by soil conditions, especially puddling and submergence. While SPAD meter readings were higher in puddled transplanting of rice, subsequent crops did not show similar results. *Rabi* crops grown in dry direct seeded rice had significantly higher nitrogen content compared (SPAD reading) to puddled systems which is likely due to aerobic conditions prevailed in dry direct seeded rice from the beginning of system supporting soil bacteria and improved nutrient availability. Conventional tillage and legume crops, such as chickpea and blackgram also played a crucial role in enhancing nutrient access.

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