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Physiological parameters and nutrient uptake in unpuddled machine transplanted rice (*Oryza sativa*) in combination with alternate wetting and drying

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ABSTRACT

A field study was carried out during *rabi* (winter) seasons of 2018–19 and 2019–20 at Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu to study the effect of four different crop establishment methods, viz. manual transplanting; transplanting of rice seedling in puddled soil using machine; transplanting of rice seedling in non-puddled soil using machine; and direct sowing combined with four different irrigation treatments, viz. farmers practice; irrigation following the development of a hairline crack; irrigation when water level descents 5 cm; and 10 cm below soil surface on physiology of rice (*Oryza sativa* L.). Experiment was conducted in a strip plot design replicated thrice. The study revealed that nutrient uptake and physiological parameters were found to be maximum with seedlings of rice crop transplanted in non-puddled soil using machine combined with irrigation following the development of a hairline crack. Seedlings of rice crop transplanted in non-puddled soil using machine combined with irrigation once the water level descends to 5 cm beneath the soil surface, had a significant positive influence on rice yield during both the years. It also recorded higher photosynthetic rate and improved physiological parameters, and yield even with minimum use of water. So, it may be recommended as the best alternate method of rice cultivation compared to conventional method where the rainfall is deficit.

Key words: Irrigation management practices, Physiological parameters, Seed drill sowing, Yield

In India, most popular technique for establishing rice (*Oryza sativa* L.) is manual transplanting into puddled soil. These days, there is a shortage of labour, which impacts the availability of competent labour during the busiest agricultural season (Sravanthi *et al.* 2022). Mechanized transplanting can be the best alternative for manual transplanting. Water scarcity is one of the implications of climate change, which directly affects the rice production. Unpuddled transplanting requires less water and formation of hard pan (Selvakumar and Sivakumar 2021), and also seedlings of rice crop transplanted in non-puddled soil using machine resulted in transplanting of seedlings at uniform depth. Direct drum sowing of rice emerges as a potentially effective method for rice establishment when compared to transplanting, as it involves only two individuals to sow seeds across a hectare of land (McDonald *et al.* 2022).

In conventional method of rice cultivation, 5 cm of continuous standing water is maintained throughout the crop growing period, for which relatively higher input of water is required. Appropriate irrigation management practices can save huge quantity of water and saves the life of crop where there are limited water resources. Several studies revealed that water input could be significantly reduced with safe alternate wetting and drying (AWD) irrigation without penalty in grain yield (Norton *et al.* 2017). The relationship between physiological characteristics and the availability of water is crucial in determining crop output and the crop's capacity to withstand stress. Studying the physiological changes of crop when it was cultivated by transplanting in non-puddled soil combined with various irrigation management practices gives first-hand information about reason for changes in yield. Keeping these aspects in view, the current work was undertaken to evaluate the effect of transplanting of rice seedlings in non-puddled soil using machine combined with alternate wetting and drying on nutrient uptake and physiological parameters of *rabi* rice to achieve maximum yield even under moisture stress.

MATERIALS AND METHODS

The field study was carried out during *rabi* (winter) seasons of 2018–19 and 2019–20 at Agricultural College

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and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu. Source of irrigation for this region was Periyar-vaigai canal. The experimental site's soil type was sandy clay loam having *p*H of 7.2 and organic matter 0.29%. Rainfall received during cropping period of *rabi* 2018–19 and 2019–20 was 678.4 mm received in 30 rainy days and 597.6 mm received in 28 rainy days respectively. The experiment was laid out with strip plot design and replicated thrice. The main plot treatments consisted of four crop establishment, viz. Conventional transplanting (M_1); Transplanting of rice seedling under puddled soil using machine (M_2); Transplanting of rice seedling under non-puddled soil using machine (M_3); Seed drill sowing (wet sowing) (M_4) and sub-plot included four irrigation management practices, viz. Farmer practice (5 cm of continuous flooding) (I_1); Irrigation following the development of a hairline cracks in soil (I_2); Irrigation once the water level descends to 5 cm beneath the soil surface (I_3); and Irrigation once the water level descends to 10 cm beneath the soil surface (I_4). The calculation of total water consumption involved combining the applied irrigation water with the effective rainfall. The amount of rain water received and the amount of rainwater drained during the field experiment were used to determine the effective rainfall.

Plant samples were collected for dry matter estimation, which were oven dried, ground in Willey mill and used for estimating nitrogen, phosphorous and potassium content and uptake of nutrients was calculated by multiplying the nutrient content and dry matter.

Crop physiological parameters observed during cropping period were; leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), days to emergence of 50% panicles, chlorophyll index, proline content in leaves, net photosynthetic rate and relative water content (RWC).

According to the formula suggested by Barrs and Weatherley (1962), RWC was estimated at panicle initiation stage and results were expressed in per cent.

Water use efficiency (WUE) was calculated based on the formula given by Viets (1962):

$$\text{WUE} = \frac{\text{Y}}{\text{W}} \text{ (kg ha/mm)}$$

where Y, Grain yield (kg/ha); W, Total water used (I + Re) to produce the yield (mm) [I, Irrigation water applied (mm); Re, Effective rainfall (mm)].

In accordance with the guidelines provided by Gomez and Gomez (1984), the analytical data from soil samples, plant samples and the computed data were statistically examined.

RESULTS AND DISCUSSION

Nutrient uptake: Seedlings of rice crop transplanted in non-puddled soil using machine (M_3) registered higher N, P and K uptake (10.91, 10.17 and 6.03% increased N, P, K uptake respectively during 2018–19 and 6.93, 5.76 and 6.31% increased N, P, K uptake respectively during 2019–20) (Table 1) compared to conventional transplanting. Fertilizer leaching and increased soil reduction were observed with intensive puddling (Kumar *et al.* 2021), whereas unpuddled soil recorded increased organic matter in soil (Kumar *et al.* 2016) and machine transplanting produced uniform spacing and depth of planting, so the plants have less competitive environment both above and below the soil that promotes root growth and canopy development, which in turn improved the nutrient (N, P and K) uptake, grain filling, grain weight and yield. Sheeja *et al.* (2012) reported that machine transplanting provides more room for both canopy and root growth that give rise to increased nutrient uptake. Synergetic effect of unpuddled soil condition and machine transplanting recorded improved nutrient uptake in rice crop.

Irrigation following the development of a hairline crack (I_2) and irrigation once the water level descends to 5 cm beneath the soil surface (I_3) recorded higher uptake of N, P and K (Table 1). Nutrient uptake and translocation from the soil is mainly done by well-developed and healthy root system (Kumar *et al.* 2013). Aeration and optimum moisture availability improved root growth with those best treatments. Increased dry matter production (DMP) was the index for enhanced nutrient availability, which ultimately recorded higher nutrient uptake (Liu *et al.* 2022).

Leaf area index (LAI) and leaf area duration (LAD): LAI and LAD can be used as an effective tool to measure photosynthetic efficiency of the crop and ultimately the yield of crop. Crop productivity hinged on the variability in LAI, a crucial biophysical parameter that directly impacted the crop canopy's ability to intercept light and facilitate transpiration (Ghadirnezhad *et al.* 2023). Improved LAI (4.63 and 4.67 respectively during *rabi* 2018–19 and *rabi* 2019–20) at flowering was observed with seedlings of rice crop transplanted in non-puddled soil using machine (M_3). The LAD (110.36 and 110.33 respectively during 2018–19 and 2019–20) was also higher with seedlings of rice crop transplanted in non-puddled soil using machine (M_3) (Table 2). Machine for transplanting under unpuddled soil condition produced uniform spacing, better root growth, improved nutrient uptake, increased cell division and cell enlargement that ultimately increased the photosynthetic rate, and subsequently increased LAI (Zhou *et al.* 2022).

Within the various alternate wetting and drying treatments, irrigation following the development of a hairline crack (I_2) and irrigation when water level reaches 5 cm below soil surface (I_3) documented higher LAI (4.61 and 4.61 during 2018–19 and 2019–20 respectively) at flowering stage and higher LAD at active tillering to flowering stages (Table 2). Water saving irrigation improved soil aeration, which facilitated the production of more number of tillers and subsequently improved the photosynthetic rate and LAI (Kanimozhi 2015). Prolonging the intervals between irrigations in rice led to adjustments in the transpiring leaf area by triggering earlier senescence in lower leaves and the drying of leaf tips. This was the reason for lower LAI and LAD under irrigation when water level reaches 10 cm below soil surface (I_4). Zhang *et al.* (2021) documented that enhanced leaf area index in rice was achieved through optimal irrigation practices.

Table 1 Effect of transplanting of rice seedling in non-puddled soil using machine and irrigation practices on nutrient uptake of *rabi* rice

Treatment	Nitrogen uptake (kg/ha)		Phosphorous uptake (kg/ha)		Potash uptake (kg/ha)	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Main plot						
M_1	116.53	114.11	31.95	31.2	91.51	91.29
M_2	119.37	115.92	33.5	32.36	92.30	91.80
M_3	130.8	122.61	35.57	33.11	97.38	97.35
M_4	107.14	107.03	29.74	28.77	82.86	83.03
SEd	2.766	2.529	1.057	0.644	1.940	2.344
CD (*P*=0.05)	6.767	6.188	2.587	1.577	4.748	5.735
Sub plot						
I_1	118.04	116.81	33.13	32.57	92.54	91.98
I_2	127.53	125.36	35.31	34.26	99.50	98.96
I_3	122.32	122.07	33.59	33.67	97.47	97.52
I_4	105.95	95.43	28.73	24.94	74.54	75.01
SEd	2.436	2.435	0.869	0.718	1.869	1.881
CD (*P*=0.05)	5.960	5.959	2.126	1.758	4.572	4.602
M×I						
SEd	3.584	3.615	1.448	0.786	2.760	2.999
CD (*P*=0.05)	8.268	8.206	3.310	1.833	6.270	6.935
I×M						
SEd	3.336	3.550	1.317	0.847	2.710	2.653
CD (*P*=0.05)	7.624	8.036	2.966	1.991	6.139	6.036

Treatment details are given under Materials and Methods.

Chlorophyll index: Seedlings of rice crop transplanted in non-puddled soil using machine registered higher SPAD value reading (39.20 and 39.23 during 2018–19 and 2019–20, respectively) (Table 2), owing to hassle free root growth, which aided in increased nutrient uptake especially nitrogen. Result of this study confirmed that nitrogen uptake and SPAD value showed positive correlation with each other. SPAD value increased with increasing chlorophyll content that enhanced photosynthesis and yield (El-Mageed *et al.* 2022).

Chlorophyll index (38.29 and 38.50 respectively during 2018–19 and 2019–20) was higher with irrigation following the development of a hairline crack (I_2), which was on par with irrigation once the water level descends to 5 cm beneath the soil surface (I_3) (Table 2). When compared to traditional irrigation, the higher chlorophyll content was observed in AWD irrigation due to enhanced nitrate availability. On the other hand, lesser chlorophyll index was observed with irrigation once the water level descends to 10 cm beneath the soil surface (I_4) (Table 2). Leaf chlorophyll content was highly reduced with water stress and controlled crop productivity through reduction of CO_2 assimilation (Jahan *et al.* 2014 and Khairi *et al.* 2015).

Leaf gas exchange parameters: In flag leaf, significant difference was observed with photosynthesis during both the years. Seedlings of rice crop transplanted in non-puddled soil using machine (M_3) combined with irrigation following the development of a hairline crack (I_2) recorded higher net photosynthetic rate (Table 3).

Crop growth rate (CGR): Photosynthetic efficiency of a plant is represented by CGR, which depends upon the DMP of the crop. Increased nutrient uptake improved CGR, which enhanced the grain yield.

Higher CGR was recorded with seedlings of rice crop transplanted in non-puddled soil using machine (M_3) at tillering to flowering (20.01 and 19.64 g/m^2/day during *rabi* 2018–19 and *rabi* 2019–20, respectively) (Table 2). Seedlings of rice crop transplanted in non-puddled soil using machine (M_3) achieved consistent spacing, facilitating the development of efficient photosynthetic structures. This, enabled the plants to intercept a greater quantity of radiant energy, leading to higher dry matter production and ultimately an increased yield (Dwiningsih and Alkahtani 2022)

Among irrigation management practices, higher CGR was observed with irrigation following the development of a hairline crack (I_2) and irrigation once the water level descends to 5 cm beneath the soil surface (I_3). Increased root growth positively influenced the growth of above ground parts, due to that leaf area and CGR were also increased (Archana *et al.* 2017).

Relative water content (RWC): Higher RWC was observed with control [farmers practice of irrigation i.e.

Table 2 Effect of transplanting of rice seedling in non-puddled soil using machine and irrigation practices on physiological parameters of *rabi* rice

Treatment	Leaf area index		Leaf area duration		Chlorophyll index		Crop growth rate ($g/m^2/day$)	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Main plot								
M_1	4.52	4.30	106.16	102.04	35.92	36.00	18.67	18.51
M_2	4.57	4.64	108.08	108.11	38.00	37.43	19.45	18.14
M_3	4.63	4.67	110.36	110.33	39.20	39.23	20.01	19.64
M_4	3.75	3.87	92.89	93.86	33.94	33.55	18.67	14.36
SEd	0.095	0.136	1.178	2.705	1.042	0.827	0.377	0.558
CD (P=0.05)	0.233	0.332	2.882	6.619	2.549	2.023	0.922	1.365
Sub plot								
I_1	4.46	4.37	105.34	103.43	36.20	36.25	19.55	18.29
I_2	4.61	4.61	109.88	108.45	38.29	38.50	20.86	18.74
I_3	4.44	4.45	105.68	105.19	37.19	36.98	19.82	18.92
I_4	3.97	4.05	96.60	97.28	35.38	34.48	16.57	14.71
SEd	0.118	0.114	1.849	2.080	0.755	0.731	0.329	0.359
CD (P=0.05)	0.289	0.279	4.525	5.089	1.847	1.789	0.806	0.879
M×I								
SEd	0.202	0.208	3.205	3.666	2.167	1.089	1.187	1.117
CD (P=0.05)	NS	NS	NS	NS	4.726	2.504	NS	NS
I×M								
SEd	0.214	0.195	3.508	3.233	2.044	1.018	1.173	1.033
CD (P=0.05)	NS	NS	NS	NS	4.392	2.320	NS	NS

Treatment details are given under Materials and Methods.

5 cm continuous flooding (I_1)], which was on par with irrigation once the water level descends to 5 cm beneath the soil surface (I_3) (Fig. 1). Decrease in soil water content resulted in increased soil water tension thus in turn reduced the plant water content (Khairi *et al.* 2015).

Proline estimation: The experimental results revealed that the increasing water stress increased the proline content (Fig. 1), so the rice variety TKM 13 can be a stress tolerant and suitable for deficit irrigation. Growing proline content during moisture stress enhanced the plant's ability to withstand drought, according to research by Ghosh *et al.* (2022).

Higher rice grain yield was recorded with seedlings of rice crop transplanted in non-puddled soil using machine combined with irrigation following the development of a hairline crack (M_3I_2), which was on par with seedlings of rice crop transplanted in non-puddled soil using machine combined with irrigation once the water level descends to 5 cm beneath the soil surface (M_3I_3) (Fig. 1). Stronger

Table 3 Effect of transplanting of rice seedling in non-puddled soil using machine and irrigation practices on net photosynthetic rate (µmol $CO_2/m^2/s$) of *rabi* rice

Treatment	*Rabi* 2018						*Rabi* 2019				
	M_1	M_2	M_3	M_4	Mean		M_1	M_2	M_3	M_4	Mean
I_1	27.27	27.41	29.35	26.38	27.60	I_1	27.80	29.18	29.97	25.61	28.14
I_2	29.98	30.61	32.56	29.24	30.60	I_2	30.05	31.21	33.14	28.24	30.66
I_3	29.15	29.50	32.31	28.40	29.84	I_3	28.31	30.26	32.98	24.43	29.00
I_4	24.75	25.11	27.96	23.61	25.36	I_4	26.54	28.14	29.01	24.35	27.01
Mean	27.79	28.16	30.55	26.91			28.18	29.70	31.28	25.66	
	M	I	M at I	I at M			M	I	M at I	I at M	
SEd	0.299	0.294	0.646	0.643			0.445	0.303	0.853	0.789	
CD (P=0.05)	0.732	0.719	NS	NS			1.089	0.743	NS	NS	

Treatment details are given under Materials and Methods.

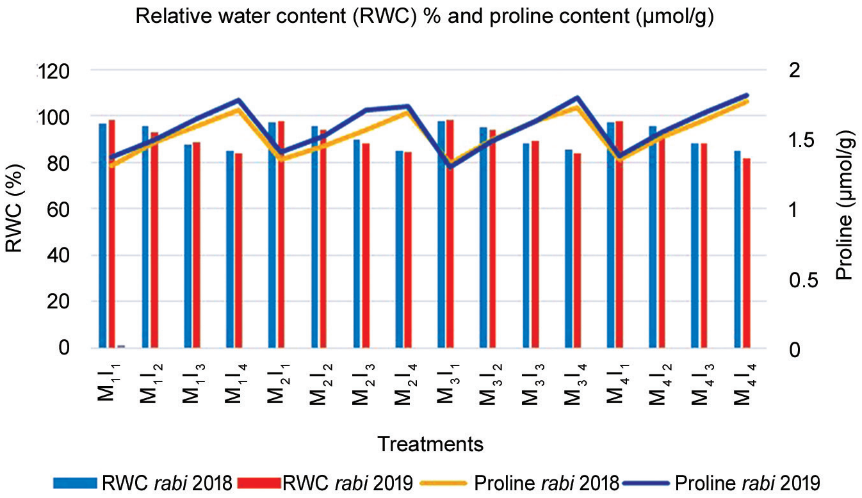

Fig. 1 Effect of transplanting of rice seedling in non-puddled soil using machine and irrigation practices on RWC and proline content of leaves of *rabi* rice.
RWC, Relative water content.

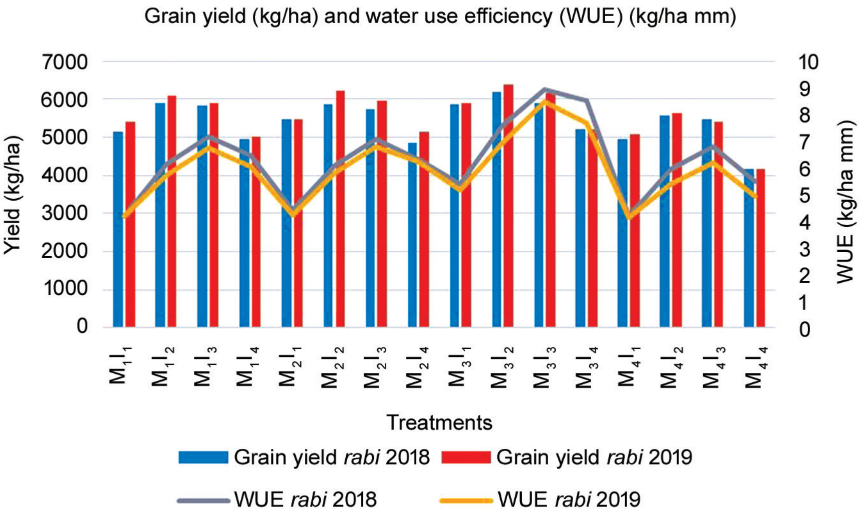

Fig. 2 Effect of transplanting of rice seedling in non-puddled soil using machine and irrigation practices on WUE of *rabi* rice.
WUE, Water-use efficiency.

correlations were observed between nutrient uptake and yield (Thakur *et al.* 2020).

Water use efficiency (WUE): Increasing yield of rice or maintaining the yield with reduced quantity of water use can increases the water use efficiency (WUE). Present study found that water use efficiency and water productivity were higher with seedlings of rice crop transplanted in non-puddled soil using machine (M_3). Rashid *et al.* (2018) also discovered that unpuddled rice transplanting recorded improved water productivity compared to puddled transplanting.

Among the alternate wetting and drying irrigation management practices, irrigation once the water level descends to 5 cm beneath the soil surface (I_3) observed higher WUE (Fig. 2). Increasing the frequency irrigations increased the consumptive use of water without corresponding increase in grain yields that led to diminished WUE under farmers' practice of 5 cm continuous flooding (I_1). Compared to other irrigation management practices, field water tube irrigation practice was found to be the superior and recorded the highest water use efficiency (Santheepan and Ramanathan 2016). Ultimately seedlings of rice crop transplanted under non-puddled soil using machine combined with irrigation once the water level descends to 5 cm beneath the soil surface recorded higher WUE.

From this study it is concluded that seedlings of rice crop transplanted in non-puddled soil using machine, combined with alternate wetting and drying irrigation treatments like irrigation following the development of a hairline crack and irrigation once the water level descends to 5 cm beneath the soil surface recorded higher nutrient uptake. Physiological parameters like higher crop growth rate, leaf area index, leaf area duration, SPAD value were observed with seedlings of rice that were transplanted in non-puddled soil using machine combined with irrigation following the development of a hairline crack and irrigation once the water level descends to 5 cm beneath the soil surface. Improved physiological parameters, increased the nutrient uptake and photosynthetic rate ultimately increased the yield. Among the two best irrigation methods (I_2 and I_3), irrigation once the water level descends to 5 cm beneath the soil surface (I_3) recorded 19% lesser water consumption compared to irrigation following the development of a hairline crack (I_2). Based on this study, water saving technology of transplanting rice seedlings in non-puddled soil using machine combined with irrigation once the water level descends to 5 cm beneath the soil surface can be recommended as the best alternate rice cultivation method compared to conventional rice cultivation in the rainfall deficit areas.

REFERENCES

Archana Rajput, Sujit Singh Rajput and Girish Jha. 2017. Physiological parameters leaf area index, crop growth rate, relative growth rate and net assimilation rate of different varieties of rice grown under different planting geometries and depths in SRI. *International Journal of Pure and Applied Bioscience* **5**(1): 362–67.

Barrs H D and Weatherley P E. 1962. A re-examination of relative turgidity for estimating water deficits in leaves. *Australian Journal of Biological Science* **15**: 413–28.

Dwiningsih Y and Alkahtani J. 2022. Agronomics, genomics, breeding and intensive cultivation of ciherang rice variety. *Preprints* 2022110489.

El-Mageed A, Taia A, El-Mageed A, Shimaa A, El-Saadony M T, Abdelaziz S and Abdou N M. 2022. Plant growth-promoting rhizobacteria improve growth, morph-physiological responses, water productivity, and yield of rice plants under full and deficit drip irrigation. *Rice* **15**(1): 1–15.

Ghadirnezhad Shiade S R, Fathi A, Taghavi Ghasemkheili F, Amiri E and Pessarakli M. 2023. Plants' responses under drought stress conditions: Effects of strategic management approaches–A review. *Journal of Plant Nutrition* **46**(9): 2198–230.

Ghosh U K, Islam M N, Siddiqui M N, Cao X and Khan M A R. 2022. Proline, a multifaceted signalling molecule in plant responses to abiotic stress: Understanding the physiological mechanisms. *Plant Biology* **24**(2): 227–39.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, 2nd edn. Wiley India Pvt Ltd., India.

Jahan M S, Nozulaidi M B N, Moneruzzaman M K, Ainun A and Husna N. 2014. Control of plant growth and water loss by a lack of light-harvesting complexes in photosystem-II in Arabidopsis thaliana ch1-1 mutant. *Acta Physiologiae Plantarum* **36**: 1627–35.

Kanimozhi N. 2015. 'Evaluation of safe depth of alternate wetting and drying irrigation practices and nitrogen management for transplanted rice'. MSc Thesis, Agricultural College and Research Institute, Killikulam, Tamil Nadu Agricultural University, Tamil Nadu, India.

Khairi M, Nozulaidi M, Afifah A and Jahan M S. 2015. Effect of various water regimes on rice production in low-land irrigation. *Australian Journal of Crop Science* **9**(2): 153–59.

Kumar N, Chhokar R S, Meena R P, Kharub A S, Gill S C, Tripathi S C, Gupta O P, Mangrauthia S K, Sundaram R M, Sawant C P and Gupta A. 2021. Challenges and opportunities in productivity and sustainability of rice cultivation system: A critical review in Indian perspective. *Cereal Research Communications* 1–29.

Kumar S, Singh R S, Yadav L and Kumar K. 2013. Effect of moisture regime and integrated nutrient supply on growth, yield and economics of transplanted rice. *Oryza* **50**(2): 189–91.

Kumar Y, Dhyani B P, Kumar V and Raj R. 2016. Influence of fertility levels on nutrient uptake and productivity of rice under puddled and unpuddled conditions. *Annals of Agricultural Research* **37**(2): 147–53.

Liu Q, Li M, Ji X, Liu J, Wang F and Wei Y. 2022. Characteristics of grain yield, dry matter production and nitrogen uptake and transport of rice varieties with different grain protein content. *Agronomy* **12**(11): 1–13.

McDonald A J, Keil A, Srivastava A, Craufurd P, Kishore A, Kumar V, Paudel G, Singh S, Singh A K, Sohane R K and Malik R K. 2022. Time management governs climate resilience and productivity in the coupled rice-wheat cropping systems of eastern India. *Nature Food* **3**(7): 542–51.

Norton G J, Shafaei M, Travis A J, Deacon C M, Danku J, Pond D, Cochrane N, Lockhart K, Salt D, Zhang H and Dodd I C. 2017. Impact of alternate wetting and drying on rice physiology, grain production, and grain quality. *Field Crops Research* **205**: 1–13.

Rashid M H, Goswami P C, Hossain M F, Mahalder D, Rony M K I, Shirazy B J and Russell T D. 2018. Mechanised non-puddled transplanting of boro rice following mustard conserves resources and enhances productivity. *Field Crops Research* **225**: 83–91.

Santheepan S and Ramanathan S P. 2016. Investigation on AWDI method with field watertube for rice production under SRI. *International Journal of Agricultural Science Research* **6**(3): 117–24.

Selvakuma S and Sivakumar K. 2021. Conservation agriculture: A way for soil water conservation. *Agricultural Reviews* **42**(4): 474–77.

Sheeja K R, Reena Mathew, Nimmy Jose and Leenakumary S. 2012. Enhancing the productivity and profitability in rice cultivation by planting methods. *Madras Agricultural Journal* **99**(10-12): 759–61.

Sravanthi D, Ramanjaneyulu A V, Reddy P R R, Jagan P and Rao M. 2022. Mechanized transplanting and harvesting in rice: An on-farm study. *The Pharma Innovation* **11**(12): 3815–20.

Thakur A K, Mandal K G and Raychaudhuri S. 2020. Impact of crop and nutrient management on crop growth and yield, nutrient uptake and content in rice. *Paddy and Water Environment* **18**: 139–51.

Viets F G. 1962. Fertilizers and the efficient use of water. *Advances in Agronomy* **14**: 223–64.

Zhang G, Ming B, Shen D, Xie R, Hou P, Xue J, Wang K and Li S. 2021. Optimizing grain yield and water use efficiency based on the relationship between leaf area index and evapotranspiration. *Agriculture* **11**(4): 313.

Zhou C, Gong Y, Fang S, Yang K, Peng Y, Wu X and Zhu R. 2022. Combining spectral and wavelet texture features for unmanned aerial vehicles remote estimation of rice leaf area index. *Frontiers in Plant Science* **13**: 957870. doi: 10.3389/fpls.2022.957870