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Green Seeker and chlorophyll meter-assisted nitrogen management increased the rice productivity in direct seeded dry rice

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ABSTRACT

Prediction of nutrient requirements is crucial for successful decision-making in crop production. The objective of this experiment was to study the real-time nitrogen management (RTNM) in dry direct-seeded with Green Seeker and SPAD meter in rainfed rice. The experiment was done in a randomized block design with seven treatments viz. T_1: N omission, T_2: N applied as basal and active tillering (AT), T_3: N as basal, AT and panicle initiation (PI), T_4: N as basal and top dressing at NDVI threshold of 0.75, T_5: N as basal and at NDVI threshold of 0.8, T_6: N as basal and $SPAD_{35}$, and T_7: N as basal and $SPAD_{37.5}$. An early maturing drought tolerant rice variety Sahbhagi Dhan was drill seeded (dry) for this study. The soil of the site of the experiment was sandy loam, acidic with medium organic carbon, available nitrogen, phosphorus, and potassium. Basal application of 30 kg N ha^{-1} followed by top dressing of 20 kg N ha^{-1} two times at 35 and 63 DAS directed by NDVI threshold level of 0.8 (T_5) was superior compared totherest of the treatment effects in terms of growth, productivity, profitability, nutrient, and energy use efficiency.

***Key words**: DSR, Energy use efficiency, NDVI, Nutrient use efficiency, SPAD meter*

Introduction

Rice is a staple food of over 2.4 billion people across the globe, and its demand is expected to rise to one billion ton to feed the ever-growing population of 4.6 billion by 2050 (Lampe, 1995). Feeding the teeming millions in this twenty-first century is one of the greatest challenges for the rice-growing countries in the world including India. Among the few major agronomic management constraints, nitrogen (N) is the most important limiting factor next to water budgeting for biomass production in the dry direct seeded rice (DDSR) ecosystem. Loss of N through volatilization, denitrification, leaching, and surface runoff is higher in DDSR than that of transplanted rice (TPR). When urea is applied to paddy soil, ammonia volatilization is a major N loss contributing 10-60 % of the total applied N (Tian *et al.*, 2001; Liang *et al*., 2007). Surface runoff comprises 1-13% of the total applied N loss (Blevins *et al.,* 1996). Nitrate leaching from rice fields is a major environmental challenge that leads to eutrophication (Bijay-Singh

([1]Research Scholar, [2]Professor, [3]Assistant Professor, [4]Scientists -Agronomy) and Craswell, 2021). Eutrophication is the process of nutrient enrichment of surface water bodies which is mostly caused by the run-off water and by the leaching process. Rather by leaching of N, there is nitrate contamination in ground water. Indiscriminate use of fertilizer and low fertilizer use efficiency is the main barrier to attaining higher productivity in rice-growing areas, mainly in coastal regions.

Excessive application of nitrogenous fertilizers causes lodging and disease-pest susceptibility that results in increased input cost and yield reduction. Thus, it is high time to manage N in such a way that the cost incurred owing to water and other input use is duly compensated with the efficient N fertilizer application. In this regard, real-time N management is a cost-effective and reliable approach where the timing of N fertilizer application is estimated via periodic monitoring of crop N status. Tools such as the SPAD meter and Green Seeker can be used for nitrogen management to get a high-yield level along with improved N-use efficiency compared to the blanket doses. With this backdrop, the present field experiment was designed to determine and establish the threshold limits of leaf greenness as measured by the Green Seeker (GS) and soil plant analysis development (SPAD) meter to meticulously plan for scheduling N management tactics in DDSR.

Materials and Methods

This replicated experiment was conducted in the *Kharif* 2020-21 at the Instructional farm of Odisha University of Agriculture and Technology, Bhubaneswar, India (20^{0}15′N, 85^{0}52′E, and 58 m above sea level) in the East and South Eastern Coastal Plain zone. The soil was sandy loam with the initial pH, organic carbon (OC), and available N, P_2O_5, and K_2O of 6.1 (1:2), 5.6 g kg^{-1}, and 286, 16, and 265 kg ha^{-1}, respectively.

The weather parameters represented by total rainfall, maximum and minimum air temperature (average), and day and night time RH during the crop growth period were 639.2 mm, 32.4 and 24. 9 ^{o}C, and 94% and 60%, respectively (Figure 1). The rice test variety used in this experiment was cv. Sahbhagi Dhan (110-115 d) was developed by the National Rice Research Institute, Cuttack (Odisha, India) with an optimum yield of 4-5 t ha^{-1}.

The field was prepared by two dry ploughings using a cultivator and rotavator followed by levelling. The seeds were treated with Carbendazimat

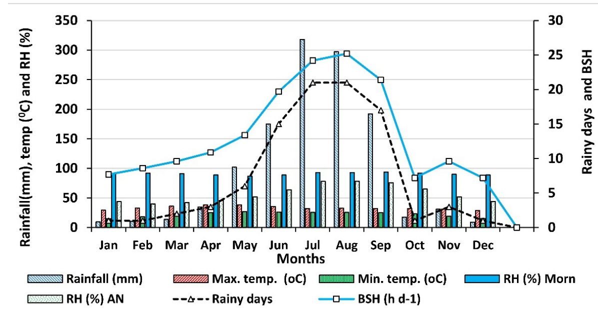

Fig. 1. Nitrogen application schedules

2gkg^{-1} of seeds and then dry-drilled at 50 kg ha^{-1} at a row spacing of 20cm. Fertilizers were applied as and when required as per the treatment needs. In DDSR, Pretilachlor at 1.5 kgha^{-1} was applied as a pre-emergence spray followed by Bispyribac sodium at 25 gha^{-1} at 20 days after sowing (DAS). At 47 DAS, manual weeding was done. At physiological maturity, the crop was harvested manually and then threshed by mechanical paddy threshers to record the yield data.

A dose of 30 kg of N ha^{-1} in the form of prilled urea (46% N) was applied as basal for all treatments except in the control and the remaining N was applied as per the treatments mentioned above. Spectral reflectance from the crop canopy was estimated by a portable optical sensor with the commercial name as Green Seeker Crop Sensor manufactured by NTech Industries, Inc., Ukiah, California, USA. It measures the normalized difference vegetation index (NDVI) based on the reflectance at red and near-infrared (NIR) regions (equation 1). NDVI is reported to have correlations with grain yield (Harrell *et al.*, 2011; Xue *et al*., 2014). Singh et al. (2015) have reported enhanced N recovery efficiency (6-22%) and agronomic efficiency (5-12 kg grain kg^{-1} N applied) over the conventional practice. In our experiment, two independent response indices of 0.75 and 0.8 were tested by GS as the threshold to schedule the time of N application in rice. The measurements were made by facing the scanner towards a height of about 0.3 m above the crop canopy and walking at a constant speed (Raun *et al.*, 2002). Shukla *et al.* (2004) and Singh (2008) considered two critical SPAD values *i.e.*, 35 and 37.5. SPAD values were measured by a handheld Minolta SPAD-502 by holding the middle portion of the topmost fully expanded and disease-free leaf in the SPAD meter frame. Ten readings were recorded per plot to average out the in-field variations. For N management using Green Seeker and SPAD meter, observations were recorded at seven days intervals starting from 28 DAS onwards and when the observed values fell below the threshold value then top dressing of N at 20 kg ha^{-1} was done. The details of the scheduling of N are presented in Table 1.

$$NDVI = \frac{NIR - red}{NIR + red} \quad ..(1)$$

Treatment details

This replicated experiment consisted of seven treatments *viz.* T_1 (N_0): N omission (control), T_2 (B + AT): N [basal and active tillering (AT)], T_3 (B + AT + PI): N [basal, AT and panicle initiation (PI)], T_4 (B + $NDVI_{0.75}$): N [basal + NDVI threshold level of 0.75], T_5 (B + $NDVI_{0.8}$): N [basal + NDVI threshold level of 0.8], T_6 (B + $SPAD_{35}$): N [basal and SPAD threshold level of 35], and T_7 (B + $SPAD_{37.5}$): N [basal and SPAD threshold level of 37.5].

Parameters recorded

The plant height from ground level to the tip of the main shoot of 10 tagged hills in the non-destructive row was estimatedwith a wooden scale. The leaf area from the destructive row, i.e. third row on the opposite side of the non-destructive row in each plot was measured by using the ImageJ application and wasexpressed as LAI by dividing the ground area under cover (equation 2). The above plants from the destructive row were air-dried and then oven-dried at 70 °C till constant weight and crop growth rate (CGR) was calculated as the increase in dry weight of the plant per unit area of land over unit time.

$$LAI = \frac{Leaf\ area}{Ground\ area} \quad ..(2)$$

At maturity, the number of ear-bearing tillers from 10 hills in the non-destructive row was counted and expressed per m^2 by multiplying with the average number of hills m^{-2}. Ten panicles from every plot were selected randomly to measure the yield attributing characters such as panicle length and weight, seed weight, and sterile and filled grains $panicle^{-1}$. Panicle length was measured from the neck node to the tip of the top most grain and averaged out to get the mean length of the panicle. The number of filled and unfilled grains of the panicles wascounted individuallyand summed up to obtain the total grains per panicle and expressed in numbers. Well-filled grains were randomly collected and 1000′ grains were counted by using the infrared grain counter.

The grain and straw yield was recorded by harvesting from the net plot area of the individual plot manually at the physiological maturity stage. The yield was then expressed in kg ha^{-1} after drying and cleaning, and by converting the fresh grain weight to 14% moisture content after measuring the grain moisture with handheld portable digital moisture meter (SKZ111B-2). Straw weight was finally expressed after oven-drying at 70 °C; the harvest index was calculated from grain and straw yields using equation 3.

$$Harvest\ index = \frac{Grain\ yield}{Grain\ yield + straw\ yield} \times 100 \quad ..(3)$$

The nutrient uptake was obtained by multiplying the grain and straw yield with their corresponding nutrient content values and finally, N, P, and K were added to get the total nutrient uptake. Apparent N recovery efficiency (ARE_N) was estimated by taking the ratio of the increase in plant N uptake to the amount of applied N to the soil and was expressed

Table 1. Effect of N application schedules on plant height and tiller number

Treatments	Plant height (cm)			Tillers m^{-2}		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
T_1: N omission (control)	55.6	81.0	83.0	243.3	226.1	222.7
T_2: N (B + AT)	75.1	88.9	90.9	345.2	330.9	318.3
T_3: N (B + AT + PI)	75.3	93.5	96.5	382.6	360.2	312.1
T_4: N (B + $NDVI_{0.75}$)	80.0	102.3	105.0	413.4	400.3	328.8
T_5: N (B + $NDVI_{0.8}$)	85.0	106.0	110.6	452.8	414.0	362.1
T_6: N (B + $SPAD_{35}$)	77.9	96.7	98.3	410.6	395.1	323.0
T_7: N (B + $SPAD_{37.5}$)	81.2	103.6	105.3	432.4	406.5	337.4
SEm	0.99	1.03	1.07	7.69	5.43	4.98
CD (0.05)	3.1	3.1	3.2	23.4	16.29	14.96

in per cent (equation 4). The ratio of increased yield to N applied was expressed as agronomic N use efficiency (A_{NUE}) expressed in terms of kg of grain per kg of N applied (equation 5). The ratio of the increase in yield to the increase in plant uptake is referred to as the physiological N use efficiency (PE_N) (equation 6). The partial factor productivity of N (PFP_N) (equation 7) was calculated as the ratio of grain yield to the quantity of N applied and is expressed as kg of grain per kg of N applied (Ladha *et al.,* 2005). The economic yield was expressed as a percent of its harvested biomass yield and was reported as the harvest index (equation 3). The treatment-wise detailed cost of production with their units and prices were calculated to get the cost of cultivation, gross and net returns, and benefit-cost ratio (BCR) (equation 8). Statistical analyses were done by using R-studio version 3.6.3 to elucidate the treatment effects.

$$\text{Apparent N recovery efficiency} = \frac{\text{Increase in N uptake over the control}}{\text{N fertilizer applied}} \quad (4)$$

$$\text{Agronomic N use efficiency (AN)} = \frac{\text{Grain yield advantage over the control}}{\text{N fertilizer applied}} \quad (5)$$

$$\text{Physiological N use efficiency (PEN)} = \frac{\text{Yield advantage over the control}}{\text{Increase in N uptake over the control}} \quad (6)$$

$$\text{Partial factor productivity of N (PFPN)} = \frac{\text{Grain yield}}{\text{N fertilizer applied}} \quad (7)$$

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Gross profit}}{\text{Cost of cultivation}} \quad (8)$$

Results and Discussion

Crop growth

N application significantly influenced plant height, tiller number, leaf area, and biomass of rice plants at all growth stages (Tables 2 and 3). At harvest, the tallest plants were in T_5 (110.6 cm) i.e. with a topdressing of N at NDVI threshold of 0.8 were 33.2% taller than the control (T_1) whereas T_7 (105.3 cm) was next best (N topdressing at SPAD threshold level of 37.5). The higher tiller number (452.8 m^{-2}) was recorded in T_5 (N as basal + $NDVI_{0.8}$) which was at par with T_7 (N as basal + $SPAD_{37.5}$) at 60 DAS. But at harvest, T_5 produced significantly more tillers (362.1 m^{-2}) than the rest of the treatments. The formerone produced 63% more tillers m^{-2} compared to no application of N (T_1). The highest LAI (4.06) at 90 DAS was estimated in T_5 where the top dressing of N was done at an NDVI threshold level of 0.8 which was statistically similar to T_7 (4.04) (Table 3). The maximum plant drymatter at harvest was produced (867.8 g m^{-2}) in T_5 (N as basal + $NDVI_{0.8}$) which was ensued by T_7 (N as basal + $SPAD_{37.5}$) (822 g m^{-2}). The maximum crop growth rate (CGR) was observed in T_5 at 60 to 90 DAS(14.9 g m^{-2} day^{-1}) which was 23.1% higher than T_4 (N as basal + $NDVI_{0.75}$) (Table 4). The increase in plant height with the increase in N application could be attributed to

Table 3. Effect of N application schedules on crop growth rate (CGR)

Treatments	CGR (g m^{-2} day^{-1})		
	30 to 60 DAS	60 to 90 DAS	90 DAS to harvest
T_1: N omission (control)	8.0	9.7	3.5
T_2: N (B + AT)	8.7	11.2	4.2
T_3: N (B + AT + PI)	9.7	11.3	4.3
T_4: N (B + $NDVI_{0.75}$)	10.7	12.1	6.2
T_5: N (B + $NDVI_{0.8}$)	13.4	14.9	8.7
T_6: N (B + $SPAD_{35}$)	10.2	13.0	5.2
T_7: N (B + $SPAD_{37.5}$)	11.6	13.9	7.6
SEm	0.20	0.26	0.21
CD (0.05)	0.6	0.8	0.7

Table 2. Effect of N application schedules on leaf area index (LAI) and dry matter production (DMP)

Treatments	LAI		DMP (g m^{-2})		
	60 DAS	90 DAS	60 DAS	90 DAS	At harvest
T_1: N omission (control)	1.50	1.01	236.7	280.9	319.8
T_2: N (B + AT)	3.36	1.12	398.7	436.9	560.6
T_3: N (B + AT + PI)	3.47	3.01	509.8	578.8	652.2
T_4: N (B + $NDVI_{0.75}$)	4.53	3.88	459.8	645.9	739.1
T_5: N (B + $NDVI_{0.8}$)	5.13	4.06	602.4	700.4	867.8
T_6: N (B + $SPAD_{35}$)	4.40	3.91	515.8	638.9	698.0
T_7: N (B + $SPAD_{37.5}$)	5.01	4.04	588.2	690.4	822.0
SEm	0.082	0.052	4.10	11.72	12.31
CD (0.05)	0.26	0.20	12.9	35.8	37.1

various physiological processes including cell division and elongation of the rice plant that enhanced vegetative growth (Mahajan *et al.*, 2011). Significantly superior utilization of production factors with N application as basal + $NDVI_{0.8}$ in T_5 could have produced the tallest plants, higher LAI, and more tillers m^{-2} in rice. The schedule of N application closely coincided with the active tillering (35 DAS) and PI stage (65 DAS) in T_5 unlike T_4 (N as basal + topdressing at $SPAD_{37.5}$) at 42 and 77 DAS (Table 1). This might have resulted in the production of taller plants with wider leaves and more tillers in T_5 (Table 3). Although in T_3, the N was also applied at active tillering and PI the top-dressed dose was only 15 kg ha^{-1} at each time which might not have been sufficient to provide desired plant nutrition to compete with T_5 where 20 kg ha^{-1} N was top-dressed each time. On a similar note, Kamiji *et al.* (2011) opined that 'N' application during the panicle development stage effectively improved plant biomass as well as spikelet number in rice. The synergistic effects of increased plant growth *viz*., plant height, tiller number, leaf area, and enhanced the total plant dry matter in T_5. Application of N leads to the production of higher plant dry matter. The discussion made supporting studies quoted for higher plant dry matter production in T_5 (N as basal + $NDVI_{0.8}$) also holds good for higher CGR.

Yield components and yield

Nitrogen application with a real-time decision support system significantly ($p<0.05$) influenced yield contributing characters and yield of rice (Table 4). The maximum number of effective tillers (315 m^{-2}) was noticed in T_5(N as basal + $NDVI_{0.8}$) which was statistically similar to T_7 (312.3 m^{-2}) (N as basal + $SPAD_{37.5}$), but the former was significantly higher than all other treatments. The longest panicle (25.4 cm) was recorded in T_5(N as basal + $NDVI_{0.8}$) which was at par with T_7 (24.6 cm) i.e., N as basal + topdressing at $SPAD_{37.5}$(Table 4). The highest number of grains $panicle^{-1}$ (105.3) was counted in T_5 which was at par with T_7 (103.1), T_4 (98.5), and T_6 (95.7). The maximum number of filled grains was noticed in T_5 (99.4) which were at par with T_7(95.1). A similar trend was also observed for the test weight. The findings of Baral *et al.* (2021) who advocated for basal application, and topdressing of N before 45 DAT for obtaining superior yield components corroborate our results indicating better performance by T_3, T_4, T_5, T_6 and T_7 over T_1 and T_2.

Grain yield ranged from 1,509.1 to 4,438.6 kg ha^{-1}in various treatments with a mean yield of 3,358 kg ha^{-1}. The maximum grain yield of 4,438.6 kg ha^{-1} was obtained in T_5 (N as basal + $NDVI_{0.8}$) which was statistically higher than T_7 (4,143.8 kg ha^{-1}), T_4(N as basal + $NDVI_{0.75}$), and all other treatments. The highest straw yield was obtained in T_5 (5,092.8 $kgha^{-1}$) which was at par with T_7 (4,880.4 $kgha^{-1}$), but both were statistically higher than T_4 (4,346.2 kg ha^{-1}) with basal + NDVI threshold level of 0.75 and T_6 (4,080 $kgha^{-1}$) with SPAD threshold of 35 (Table 4). The HIranged from 43.0% to 46.7% in different treatments and the maximum value resulted in T_5 (46.7%) which was ensued by T_6 and T_4 (46.5%), and T_3 (46.4%). The overall yield performance in GS-based N management was relatively superior over the SPAD-based practice, and conventional methods. Better HI was also recorded in GS-based N management over all other treatments. Complete omission of N (control) trailed behind other treatments in recording all growth and yield attributing

Table 4. Effect of N application schedules on yield attributes and yield

Treatments	Effective tillers m^{-2}	Panicle length (cm)	Total grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1: N omission (control)	183.6	16.5	72.1	60.6	18.1	1509.1	2000.2	43.0
T_2: N (B + AT)	271.3	19.8	82.6	70.3	21.6	2742.1	3412.3	44.0
T_3: N (B + AT + PI)	280.1	21.4	86.0	74.9	22.6	3324.3	3840.6	46.4
T_4: N (B + $NDVI_{0.75}$)	303.7	23.0	98.5	91.1	23.1	3770.3	4346.2	46.5
T_5: N (B + $NDVI_{0.8}$)	315.0	25.4	105.3	99.4	23.8	4438.6	5092.8	46.7
T_6: N (B + $SPAD_{35}$)	299.2	22.5	95.7	88.2	23.1	3585.2	4080.3	46.5
T_7: N (B + $SPAD_{37.5}$)	312.3	24.6	103.1	95.1	23.5	4143.8	4880.4	45.9
SEm	4.23	0.66	4.31	2.11	0.18	20.33	159.31	0.01
CD (0.05)	12.9	2.04	13.3	6.5	0.6	62.6	490.8	0.03

components, and finally, the yield. On a similar note, Baral *et al*. (2021) in their experiment have strongly advocated for the basal application of N for both real-time and conventional N management practices to get better yielding ability in rice. The timing of N application coinciding with the active tillering and PI stage in T_5 continuously supported the holistic growth of rice plants which finally produced higher straw yield compared to other treatments. This conforms to the findings of Bijay-Singh and Craswell (2021).

Nutrient uptake and efficiencies

Fertilizer application, regardless of the methods followed and decision support tool adopted, significantly augmented the uptake of N over the control (Table 5). N uptake was also higher in SPAD and NDVI-based N management than in blanket applications. The highest Nuptake in grain (50.1 kg ha^{-1}) recorded in T_5(N as basal + topdressing at NDVI$_{0.8}$) was higher than T_7 (48.5 kg ha^{-1}), T_4 (44.9 kg ha^{-1}) and T_6 (43.4 kg ha^{-1}), where it was guided by N as basal + topdressing at SPAD$_{37.5}$, NDVI$_{0.75}$, and SPAD$_{35}$, respectively. The N uptake in straw also followed the same trend as grain N uptake. An almost similar trend was observed in total P and K uptake, and total nutrient uptake both in grain and straw as well. The total uptake was higher in GS-based management practices over SPAD-based and conventional N management practices. The lowest N uptake in the N omission plot could be ascribed to the inadequacy of N but the lowest P and K uptake in this treatment is due to inferior growth and yield contributing components of rice.

The maximum recovery efficiency (RE_N) was observed in T_5 (65.8%) with N as basal+ topdressing at an NDVI threshold level of 0.8 which was statistically similar to T_7 (63.1%) with basal N + SPAD threshold of 37.5 (Table 6). A similar trend of results was obtained in the case of agronomic AE_N and PE_N as well as PFP_N. The maximum energy input of 9,948 MJ ha^{-1} was recorded in T_4, T_5, T_6, and T_7 (Figure 2). However, the maximum energy output (1,28,888 MJ ha^{-1}) and energy use efficiency (12.9%) were realized in T_5(N as basal + NDVI$_{0.8}$), followed by T_7 (1,21,902 MJ ha^{-1} and 12.3%), T_4 (1,09,744 MJ ha^{-1} and 11%).

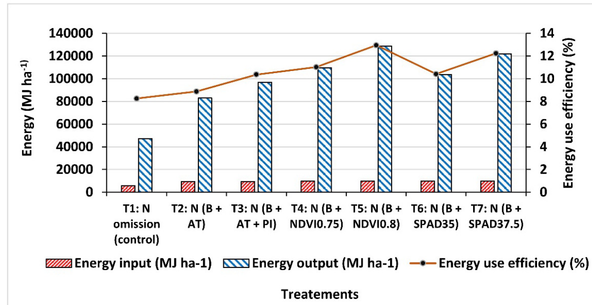

Fig. 2. Effect of 'N' application schedules on energy use efficiency in rice

Production economics

Among the different N application schedules, the lowest production cost (41,635 ha^{-1}) was estimated in T_1 where no N was applied, followed by T_2 (42,125 ha^{-1}) where N was applied basal and top-dressed only at an active tillering stage (Figure 3). The maximum cost of cultivation (42,565 ha^{-1}) was estimated in T_5 and T_7 where N topdressing was done with the help of NDVI and SPAD threshold levels of 0.8 and 37.5, respectively. The increase in gross return, net return, and BCR were mostly due to the higher yield obtained under different N application schedules. The increase in cost was due to extra fertilizer application and labour required for fertilizer application

Table 5. Effect of N application schedules on nutrient uptake

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})			Total uptake (kg ha^{-1})
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	
T_1: N omission (control)	15.8	7.0	22.8	4.5	2.4	6.9	5.7	30.4	36.1	65.8
T_2: N (B+AT)	35.6	15.0	50.6	11.0	5.8	16.8	12.6	63.1	75.7	143.1
T_3: N (B+AT+PI)	42.2	16.1	58.3	13.0	6.1	19.1	15.0	69.9	84.8	162.2
T_4: N (B+NDVI$_{0.75}$)	44.9	16.9	61.8	13.2	6.5	19.7	16.2	74.8	91.0	172.5
T_5: N (B + NDVI$_{0.8}$)	50.1	18.8	68.9	14.2	6.6	20.8	17.3	79.4	96.7	186.4
T_6: N (B + SPAD$_{35}$)	43.4	16.3	59.7	13.3	6.5	19.8	15.8	71.8	87.6	167.1
T_7: N (B + SPAD$_{37.5}$)	48.5	18.5	67.0	14.1	6.8	20.9	16.2	77.6	93.7	181.6
SEm	0.22	0.11	1.52	0.25	0.06	0.74	0.17	0.61	4.14	6.92
CD (0.05)	0.7	0.6	4.6	0.8	0.2	2.8	0.5	1.8	12.6	21.1

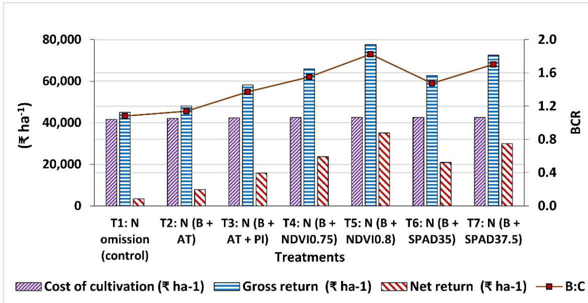

Fig. 3. Effect of 'N' application schedules on production economics of rice

at different times. Dineshkumar (2011) has too recorded higher net returns and BCR with the RTNM.

Correlation study

The correlation between plant growth and yield contributing traits and grain yield was positive and significant (Figure 4). The grain yield has positive and significant relationship with plant height(r=0.98, P≤0.01), tiller numbers at 90 DAS (r=0.98, P≤0.01), effective tillers (r=0.97, P≤0.01), grains panicle^{-1} (r=0.97, P≤0.01), filled grains panicle^{-1} (r=0.96, P≤0.01), and test weight (r=0.97, P≤0.01). Higher effective tillers in T_5 were due to a positive correlation (r = 0.99**) between the number of total tillers and effective tillers. The PI and development stage was ladened with the application of 1st topdressing of N in T_5 (N as basal + topdressing at $NDVI_{0.8}$) which

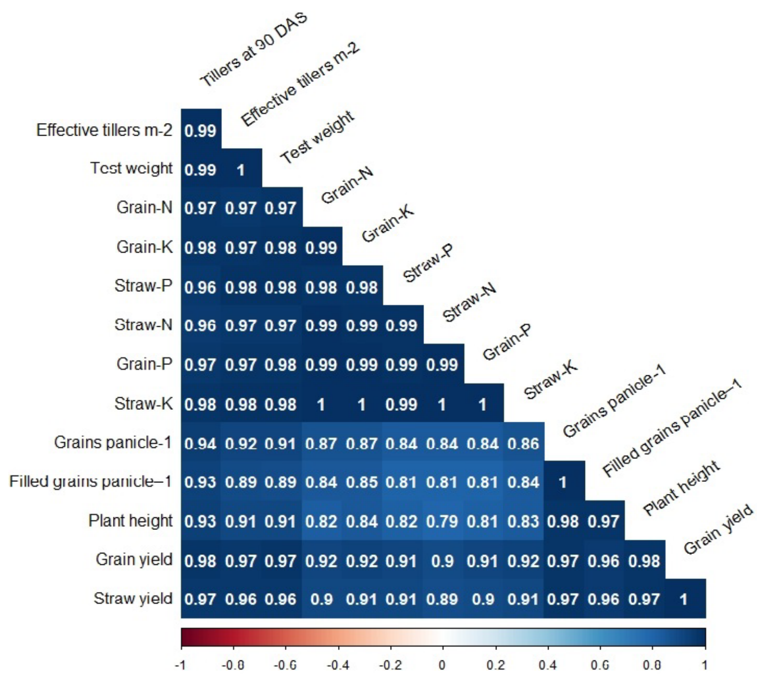

Fig. 4. Correlation matrix of growth and yield components, and yield of rice

Table 6. Effect of N application schedules on recovery efficiency (RE_N), physiological efficiency (PE_N), agronomic efficiency (AE_N) and partial factor productivity (PFP_N)

Treatment	RE_N (%)	AE_N	PE_N	PFP_N
T_1: N omission (control)	-	-	-	-
T_2: N (B + AT)	46.3	20.6	44.3	45.7
T_3: N (B + AT + PI)	59.1	30.3	51.1	55.4
T_4: N (B + $NDVI_{0.75}$)	55.7	32.3	57.9	53.9
T_5: N (B + $NDVI_{0.8}$)	65.8	41.8	63.5	63.4
T_6: N (B + $SPAD_{35}$)	52.7	29.7	56.2	51.2
T_7: N (B + $SPAD_{37.5}$)	63.1	37.6	59.5	59.2
SEm	1.10	0.48	1.50	0.72
CD (0.05)	3.5	1.4	4.7	2.3

might have led to better tiller growth and panicle emergence resulting in longest panicles, a maximum number of grains, and filled grains panicle^{-1} in T_5. A positive correlation (r = 0.99**) also existed between total grains and filled grains panicle^{-1} in rice. Similar results were also obtained by Bah *et al.* (2009) and Zhang *et al.* (2013).

Rice grain yield and nutrient uptake in grain and straw exhibited positive correlations. A positive and significant correlation existed between grain yield and grain N uptake (r=0.92, P≤0.01), straw N uptake (r= 0.9, P≤0.01), grain P uptake (r=0.91, P≤0.01), straw P uptake (r=0.91, P≤0.01), grain K uptake (r= 0.91, P≤0.01), and straw K uptake (r=0.91, P≤0.01). Plant N content at the PI stage is directly correlated with the grain yield at maturity (Zhang *et al*., 2009). The schedule of N application, when it was directed by an NDVI threshold of 0.8, closely coincided with the PI stage produced a higher number of effective tillers m^{-2}, longer panicles, heavier grains, and a higher number of filled grains panicle^{-1} that ultimately were reflected in term of higher grain yield. Higher straw and grain yield in T_5 contributed to the higher nutrient uptake. The first topdressing of N in T_7 (N as basal + topdressing at $SPAD_{37.5}$) was delayed beyond the PI stage which led to lesser yield as N content during PI is strongly correlated with the yield (Nageswari and Balasubramaniayan, 2004; Fu *et al*., 2021). This also holds good for higher straw yield and harvest index in T_5 (N as basal + $NDVI_{0.8}$). Similar results were found by Lin *et al.* (2009) and Artacho *et al.* (2009). Higher grain yield in T_5 contributed to the higher RE_N, AE_N, PE_N, and PFP_N as well as energy efficiencies this corroborates the earlier findings of Kumar and Ladha (2011).

Conclusion

The current N management practice of blanket application for DDSR is not efficient whereas the soil test-based N management is also time and resource-consuming. Hence, alternative N management strategies based on Green Seeker and SPAD in a real-time schedule resulted in optimal yield and NUE over blanket application. Basal application of 30 kg N ha^{-1} and topdressing of 20 kg N ha^{-1} guided by NDVI threshold value of 0.8 (T_5) was superior in terms ofthe growth and development, productivity, and yield attributing characters, nutrient uptake, energy use efficiency, and production economics. Hence, the farming community may be recommended for the adoption of real-time N management in rice.

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Conflict of interest

The authors declare that the research was conducted without any commercial and financial relationships that resulted in no conflict of interest concerning this article.

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