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Effect of Rice Cultivation Methods and Nitrogen Management Practices on Physiological Growth Indices of Rice under Rice-Cowpea Cropping System

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Abstract

An investigation was carried out at College of Agriculture, V.C. Farm, Mandya during *kharif* season of 2022 and 2023 to study the effect of rice cultivation methods and nitrogen management practices on physiological growth attributes of rice under rice-cowpea cropping system. The experiment laid out in strip plot design comprised three vertical factors-Methods of rice cultivation (Transplanted rice, Wet-DSR & Dry-DSR) and five horizontal factors-Nitrogen management practices (Control, 75% RDN, 100% RDN, 75% RDN+2 foliar sprays of 0.4% nano urea & 100% RDN + 2 foliar sprays of 0.4% nano urea at tillering (T) and panicle initiation (PI) with three replications. The results of the experiment demonstrated that among the rice cultivation methods and nitrogen management practices tested, the transplanted rice with application of 100 per cent recommended dosage of nitrogen (RDN) along with foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) recorded significantly higher absolute growth rate (AGR), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area duration (LAD) and leaf area ratio (LAR).

Keywords : Dry-direct seeded rice (DSR), Nano urea, Physiological attributes, Transplanted rice, Wet- direct seeded rice (DSR)

Rice is the vital staple food crop of the world, supporting the livelihood of more than 100 million farm families providing the energy requirement of billions of people and playing a pivotal role in the agro-ecosystem and biodiversity (Ram *et al.,* 2020). Global requirements of rice are expected to be about 280 million tonnes produced in the next 30 years and feeding more than 9 billion people by 2050 will require doubling of production on a sustainable basis (FAO, 2016). More than three-fourths of rice output in India is realized from 79 million ha of irrigated lowland and it is predicted that 17 out of 75 million hectares of Asia's flood irrigated rice crop will experience physical water scarcity and 22-million-hectare areas may experience economic water scarcity (Lal *et al*., 2013). This clearly indicates a question about rice production sustainability in traditional wetland eco-system under flooded conditions. Moreover, arsenic pollution, nitrate contamination, chromium toxicity and methane emission in traditional rice culture threatens the issues pertaining to rice yield sustainability and profitability under the backdrop of a shrinking water resource base (Midya *et al.,* 2017).

The current situation indicates that research on rice crop cultivation methods and management techniques are getting more emphasis. This is mostly due to differences in crop cultivation methods in terms of energy requirements, resource use and potential to operate as a climate change mitigation technique, which may have far-reaching ramifications in terms of yield and revenue for farmers, as well as environmental health. Further more, novel crop cultivation methods and management strategies are becoming increasingly important to address concerns such as natural resource degradation and the rising cost of chemical and agronomic treatments or resources (Shahane *et al.,* 2020).

Transplanted rice cultivation, a traditional agricultural practice in India, has played a pivotal role in shaping the country's agrarian landscape. Transplanting has been the most important and common method of crop establishment under favorable rainfed and irrigated lowland in tropical Asia. In India, 44 per cent of rice area (19.6 million ha) is under transplanting in irrigated lowland. This practice provides several benefits to rice, such as weed control, ease of transplanting, decrease in deep percolation losses of water and nutrients and improved nutrient availability (Sharma and de Datta, 1985). However, the area under traditional method of transplanted rice in world is going to decrease due to limitation of water and labour therefore, alternate method of cultivation should be promoted for enhancing the crop and water productivity (Farooq *et al.,* 2011). In India direct seeded rice has grown in the area of 7.2 M ha. Direct seeding of rice eliminates the need of nursery raising and subsequent labour intensive transplanting thus reducing cost of cultivation and is now fast replacing traditionally transplanted rice (Balasubramanian and Hill, 2000). Wet Direct Seeded Rice (Wet-DSR) and Dry Direct Seeded Rice (Dry-DSR) are the best alternate methods of rice sowing. In wet seeding, pre-germinated seeds are sown into puddled and levelled field which are free from standing water and in dry seeding; dry rice seeds are drilled or broadcast on unpuddled soil either after dry tillage or zero tillage or on a raised bed. DSR is efficient resource conservation technology which saves the labour to the extent of about 40 per cent and water up to 60 per cent (Nainwal and Verma, 2013).

Yield gap realized in many Asian countries is the difference between the 'potential yield', determined by variety and climate and the yield achieved in farmer's fields. Studies indicate that it is due to continuous 'nutrient mining' of soils and imbalanced fertilizer application including micronutrients as one of the major reasons that also resulted in progressive irreversible degradation of soils (David *et al*., 2009). Hence, fertilizers play a pivotal role in agricultural production. Fertilizers have taken axial role with respect to boosting crops yield and nutritional quality especially after the development of fertilizer responsive crop varieties. After carbon, hydrogen and oxygen, nitrogen (N) is one of the important elements in plants because of its key part in chlorophyll production, which is basic for the photosynthetic process.

Nitrogen fertilizer plays an important role in crop production and has the most effect on increasing agricultural production and income. Nitrogen is a major nutrient for plants, which is very important for the improvement of photosynthesis, growth, development, yield, quality and biomass of rice and an component of amino acid in protein and chlorophyll in photosynthesis and it exists in various plant parts. Nitrogen management is of crucial importance as rice is a nitro-positive crop that demands nitrogen in larger quantities compared to most of the other cereals (Theerthana *et al*., 2022). Nitrogen in rice has prominent problems such as a large amount of nitrogen is lost due to rapid chemical transformations such as leaching, which contaminates soil and water bodies and volatilization which leads to emissions of nitrous oxide into the atmosphere (Umar *et al*., 2022).

The role of nano fertilizers is prime importance in the field of Agriculture and has drawn the attention of the soil scientists as well as the environmentalists due to its capability to increase yield, improve soil fertility, reduce pollution and make a favorable environment for microorganisms. Nano particles with small size and large surface area are expected to be the ideal forms for use as a fertilizer in plants. Farmers are applying different fertilizers for soil and as foliar applications; however, the efficacy is low (Uma *et al.,* 2019). So that, application of nano fertilizers in minute quantity improves crop growth and reduces environmental pollution (Pruthviraj *et al*., 2022). Due to its ultra-small size and unique surface properties, liquid Nano urea is absorbed more effectively by plants when sprayed on their leaves. Once absorbed, these nano-particles reach plant parts requiring nitrogen and release nutrients in a controlled manner. This reduction in usage minimizes wastage in the environment. Additionally, it offers protection to plants against various biotic and abiotic stresses. Beyond yield improvement, increased nutrient use efficiency, enhanced nutritional quality of crops and it also promotes soil health. It reduces undesirable toxicities in soil and mitigates potential negative effects associated with over-application, thus reducing the frequency of application.

The rice cultivation methods and nitrogen management play a vital role in achieving higher yield levels of rice. Due to proper distributions of crop plant per unit area and efficient utilization of available nutrient and other resources as well as environment. The functional leaves, dry matter production and leaf area index are the main growth factor which may directly reflect to grain yield. The different growth indices were calculated based on the growth parameters with given formula. Growth indices *viz*., absolute growth rate (AGR) indicates the increase in dry matter per unit time, crop growth rate (CGR) are product of LAI, Relative growth rate (RGR) measures the increase in dry matter with a given amount of assimilatory material at a given point of time and net assimilation rate (NAR) is the net gain in total dry matter per unit leaf area per unit time, Leaf area duration, leaf area ratio and dry matter efficiency are the measures of grain yield. Hence, a field experiment was conducted to study the effect of rice cultivation methods and nitrogen management practices on physiological growth indices of rice.

Material and Methods

A field experiment was conducted in the *kharif* seasons of 2022 and 2023 at A-block, College of Agriculture, Vishweshwaraiah Canal Farm, Mandya. It is situated in the Agro-Climatic Zone VI (Southern Dry Zone) of Karnataka at 12° 57' N latitude and 76° 83'E longitude at an altitude of 678 meters above mean sea level. The initial soil available nitrogen, potassium and phosphorus was 308.41, 33.54 and 209.45 kg ha^{-1}, respectively. The experiment was laid out in strip plot design comprising were three vertical factors *viz*. rice cultivation methods (Transplanted rice-M$_1$, Wet-DSR-M$_2$ & Dry-DSR-M$_3$) and five horizontal factors *viz.* Nitrogen management practices (Control - N$_1$, 75% RDN - N$_2$, 100% RDN - N$_3$, 75% RDN + 2 foliar spray of 0.4% nano urea - N$_4$ & 100% RDN + 2 foliar spray of 0.4% nano urea - N$_5$) with three replications, Recommended FYM, 100% P and K were common to all the treatments as per the UAS(B) package of practices. The MTU1001 rice variety were used in the present study.

In case of transplanted rice 25 days old seedlings were transplanted to main field. Pre-germinated seeds of rice sown in puddled field using drum seeder in case of wet-DSR method. In dry-DSR methods the seeds were directly sown in non-puddled dry seed bed by using seed drill. The recommended FYM (10 t ha^{-1}) was applied to the experimental plots at fifteen days prior to transplanting or sowing. The recommended dose of 100 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1}, 50 kg K_2O ha^{-1} and 20 kg $ZnSO_4$ ha^{-1} were applied as per the treatments through urea, single super phosphate (SSP), muriate of potash (MOP) and zinc sulphate ($ZnSO_4$), respectively. After the harvest of rice, cowpea was sown as a sequential crop with recommended dosage of fertilizers to improve the soil fertility status of rice fields with long term sustainability of rice based cropping system.

Five plants from each plot were randomly selected from the net plot and tagged. These plants were used for recording the observations on different physiological growth attributes. The plants from the gross plot for each treatment were cut above the ground and leaves were fed to leaf area meter for estimating the photosynthetically active area (leaf area). The same plants were oven dried at 65°C and the dry weight per plant was noted. Further, physiological growth indices were calculated using following formulas as given below.

Absolute Growth Rate (AGR)

It indicates the increase in dry matter per unit time and expressed as gram of dry matter produced per day. Absolute growth rate was calculated between 0 to 30 DAS, 30 to 60, 60 to 90 DAS and 90 DAS to harvest by the formula by Power *et al*. (1967).

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

AGR = Absolute growth rate expressed in g day^{-1}

W_1 = Dry weight of plant at time t_1

W_2 = Dry weight of plant at time t_2

Crop Growth Rate (CGR)

It indicates the rate of crop growth per unit area per unit time. Crop growth rate was calculated between 0 to 30 DAS, 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest by the formula as given by Watson (1952). It is expressed as gram of dry matter produced per unit land area in a day.

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{\text{Land area}}$$

Where,

AGR = Absolute growth rate expressed in g m^{-2} day^{-1}

W_1 = Dry weight of plant at time t_1

W_2 = Dry weight of plant at time t_2

Relative Growth Rate (RGR)

It indicates the rate of biomass produced per unit dry matter over a time. Relative growth rate was calculated between 0 to 30 DAS, 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest by the formula as given by Redford (1967). It can be expressed as gram of dry matter produced by g of existing dry matter in a day

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where,

AGR = Absolute growth rate expressed in g $g^{-1}day^{-1}$

W_1 = Dry weight of plant at time t_1

W_2 = Dry weight of plant at time t_2

Net Assimilation Rate (NAR)

It indirectly indicates the rate of net photosynthesis. It is expressed as gram of dry matter produced per cm^2 of leaf area in a day. Net assimilation rate is calculated between 0 to 30 DAS, 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest by the formula given by Gregory (1926).

$$NAR = \frac{(W_2 - W_1)}{t_2 - t_1} \times \frac{(\log_e L_2 - \log_e L_1)}{L_2 - L_1}$$

Where,

AGR = Absolute growth rate expressed in g $m^{-2}day^{-1}$

W_1 and L_1 = Dry weight and leaf area of plant at time t_1

W_2 and L_2 = Dry weight and leaf area of plant at time t_2

Leaf Area Duration (LAD)

Leaf area duration is calculated between 0-30 DAS, 30 to 60 DAS, 60 to 90 DAS and 90 DAS to harvest by using the formula given by Power *et al.* (1967).

$$LAD = \frac{LAI_1 + LAI_2}{2} \times t_2 - t_1$$

Where,

LAD = Leaf area duration, expressed in days

LAI_1 = Leaf area index of hill at time t_1

LAI_2 = Leaf area index of hill at time t_2

Leaf Area Ratio (LAR)

It expresses the ratio between the areas of leaf lamina to the total plant biomass or the LAR reflects the leafiness of a plant or amount of leaf area formed per unit of biomass and expressed in $cm^2 g^{-1}$ of plant dry weight.

$$\text{Leaf Area Ratio (LAR)} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Plant dry weight (g)}}$$

Dry Matter Efficiency (DME)

It is defined as the per cent of dry matter accumulated in the grain from the total dry matter produced over the crop growth period.

$$\text{Dry matter efficiency (DME)} = \frac{\text{Harvest index}}{\text{Duration of genotype}}$$

The statistical analysis of the data of various observations recorded during investigation was carried out under strip plot Design through analysis of variance technique as described by Gomez and Gomez (1984). The standard error of mean was calculated for all the parameters however, the critical difference were calculated when the difference among treatments were found significant. Otherwise against CD values abbreviation 'NS' (Non-significant) was indicated. Co-efficient of variance (%) was also worked out for all the characters under study. Further, pooled analysis of variance for two years data were workout to study the effect on treatment and their interaction.

Results and Discussion

Physiological Growth Analysis

Absolute Growth Rate

The data pertaining to absolute growth rate of rice as influenced by rice cultivation methods and nitrogen management is presented in Table 1.

Among the methods of rice cultivation, transplanted rice (M_1) recorded significantly superior absolute growth rate at 0-30, 30-60, 60-90 DAS and 90 DAS-at harvest (0.12, 0.89, 1.30 and 0.37 g day^{-1}, respectively) as compared to wet DSR (M_2) (0.11, 0.81, 1.25 and 1.32 g day^{-1}, respectively) and dry-DSR (M_3) of rice cultivation (0.11, 0.75, 1.18 and 0.28 g day^{-1}, respectively). Among nitrogen management

Table 1

Effect of rice cultivation methods and nitrogen management practices on absolute growth rate of rice under rice-cowpea cropping system

Treatment	Absolute growth rate (g day^{-1})											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice Cultivation Methods (M)												
M_1	0.10	0.13	0.12	0.78	1.00	0.89	1.21	1.39	1.30	0.31	0.42	0.37
M_2	0.10	0.12	0.11	0.72	0.89	0.81	1.14	1.36	1.25	0.27	0.38	0.32
M_3	0.09	0.12	0.11	0.66	0.83	0.75	1.05	1.32	1.18	0.23	0.34	0.28
S.Em.±	0.001	0.001	0.001	0.006	0.008	0.007	0.009	0.011	0.010	0.002	0.002	0.002
CD(p=0.05)	0.003	0.004	0.004	0.024	0.031	0.028	0.036	0.041	0.039	0.009	0.009	0.009
Nitrogen Management Practices (N)												
N_1	0.07	0.10	0.08	0.43	0.55	0.49	0.93	1.16	1.05	0.18	0.29	0.23
N_2	0.10	0.12	0.11	0.65	0.76	0.70	1.12	1.32	1.22	0.25	0.36	0.31
N_3	0.10	0.13	0.12	0.76	0.93	0.85	1.18	1.38	1.28	0.28	0.39	0.33

Continued....

TABLE 1 Continued....

Treatment	Absolute growth rate (g day^{-1})											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N_4	0.10	0.13	0.12	0.86	1.07	0.97	1.20	1.43	1.32	0.31	0.42	0.37
N_5	0.11	0.14	0.12	0.90	1.21	1.06	1.24	1.47	1.35	0.33	0.44	0.38
S.Em.±	0.001	0.001	0.001	0.006	0.007	0.007	0.008	0.010	0.009	0.002	0.002	0.002
CD(p=0.05)	0.002	0.003	0.003	0.018	0.023	0.021	0.026	0.032	0.029	0.007	0.007	0.007
Interactions (MXN)												
M_1N_1	0.07	0.11	0.09	0.44	0.60	0.52	1.09	1.25	1.17	0.18	0.29	0.23
M_1N_2	0.10	0.13	0.11	0.68	0.82	0.75	1.15	1.34	1.25	0.32	0.43	0.37
M_1N_3	0.11	0.13	0.12	0.84	1.00	0.92	1.23	1.41	1.32	0.34	0.45	0.39
M_1N_4	0.11	0.14	0.12	0.95	1.19	1.07	1.27	1.47	1.37	0.35	0.46	0.41
M_1N_5	0.11	0.15	0.13	1.00	1.36	1.18	1.30	1.47	1.39	0.37	0.48	0.43
M_2N_1	0.07	0.10	0.08	0.42	0.55	0.48	0.86	1.13	1.00	0.20	0.31	0.26
M_2N_2	0.10	0.12	0.11	0.67	0.74	0.71	1.18	1.33	1.25	0.25	0.36	0.31
M_2N_3	0.10	0.13	0.11	0.76	0.93	0.85	1.21	1.39	1.30	0.27	0.38	0.33
M_2N_4	0.10	0.13	0.12	0.86	1.07	0.97	1.23	1.43	1.33	0.30	0.41	0.35
M_2N_5	0.11	0.14	0.12	0.90	1.16	1.03	1.24	1.50	1.37	0.33	0.44	0.39
M_3N_1	0.07	0.09	0.08	0.43	0.51	0.47	0.83	1.11	0.97	0.15	0.26	0.21
M_3N_2	0.10	0.12	0.11	0.61	0.71	0.66	1.04	1.29	1.17	0.19	0.30	0.24
M_3N_3	0.10	0.12	0.11	0.68	0.86	0.77	1.11	1.35	1.23	0.23	0.34	0.29
M_3N_4	0.10	0.13	0.12	0.77	0.97	0.87	1.12	1.39	1.26	0.28	0.39	0.34
M_3N_5	0.11	0.13	0.12	0.82	1.12	0.97	1.17	1.44	1.30	0.28	0.39	0.33
S.Em.±	0.002	0.002	0.002	0.014	0.018	0.016	0.022	0.026	0.024	0.005	0.005	0.005
CD(p=0.05)	NS	NS	NS	0.042	0.055	0.049	0.065	1.252	0.659	NS	NS	NS

Vertical factors : Rice cultivation methods (M); Horizontal factors : Nitrogen management practices (N); M_1 : Transplanted rice; N_1 : Control (Without nitrogen); M_2 : Wet-Direct seeded rice (Drum seeding); N_2 : 75% RDN; M_3 : Dry-Direct seeded rice (Seed drill); N_3 : 100% RDN; N_4 : 75% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage; N_5 : 100% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage

practices, application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5) resulted in significantly higher absolute growth rate at 0-30, 30-60, 60-90 DAS and 90 DAS-at harvest (0.12, 1.06, 1.35 and 0.38 g day^{-1}, respectively) compared to other treatments. While, lower absolute growth rate was recorded in control (without-N) (N_1) (0.08, 0.49, 1.05 and 0.23 g day^{-1}, respectively).

Among the interactions, transplanted rice with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) recorded significantly higher absolute growth rate at 30-60 DAS and 60-90 DAS (1.18 and 1.39 g day^{-1}, respectively) over other interactions. However, it was on par with transplanted rice with application of 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_4) (1.07 and 1.37g day^{-1}, respectively) and these treatments found superior over other treatments.

The application of Nano urea during the various stages of rice improved the leaf area because the application of nitrogen through conventional fertilizer along with two foliar sprays of Nano urea at tillering and panicle initiation stages ensures better nutrient absorption and penetration *via* leaves, promoting overall canopy development and leaf growth. Similar results were also recorded by Gewaily *et al.* (2019) and Navya *et al.* (2022).

Crop Growth Rate

Pooled data on the crop growth rate of rice as modified by the impact of rice establishment methods and nitrogen management at various phases of growth are reported (Table 2).

As crop growth rate represents dry matter production per unit area over a period of time and it is considered as the most critical and meaningful growth function. The mean crop growth rate (CGR) was slow between 0-30 DAT, then increased linearly between 30-60 DAT, thereafter increasing slowly between 60 and 90 DAT and finally it decreased sharply towards harvest irrespective of treatments (Table 2).

Significantly superior crop growth rate at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest was observed in transplanted rice (5.73, 41.12, 54.91 and 16.59 g m^{-2} day^{-1}, respectively) compared to wet and dry DSR methods of rice cultivation. Significantly higher crop growth rate at 0-30, 30-60, 60-90 DAS and 90DAS at

TABLE 2

Effect of rice cultivation methods and nitrogen management practices on crop growth rate of rice under rice-cowpea cropping system

Treatment	Crop growth rate (g m^{-2} day^{-1}) 0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice cultivation methods (M)												
M_1	5.03	6.44	5.73	32.49	49.75	41.12	40.39	69.43	54.91	15.54	17.63	16.59
M_2	4.73	6.14	5.44	29.67	44.51	37.09	36.72	67.77	52.25	13.47	14.40	13.94
M_3	4.68	5.97	5.32	25.58	35.52	30.55	35.65	53.84	44.74	10.70	12.97	11.84
S.Em.±	0.04	0.05	0.04	0.31	0.41	0.36	0.46	0.58	0.52	0.12	0.12	0.12
CD(p=0.05)	0.14	0.19	0.17	1.22	1.60	1.41	1.79	2.27	2.03	0.48	0.46	0.47
Nitrogen management practices (N)												
N_1	3.48	4.87	4.17	16.08	26.51	21.30	25.69	55.39	40.54	8.58	10.14	9.36
N_2	4.86	6.08	5.47	25.48	36.53	31.01	34.93	62.08	48.50	12.58	14.85	13.71
N_3	5.11	6.33	5.72	30.93	44.78	37.86	39.00	65.06	52.03	13.98	15.98	14.98
N_4	5.21	6.65	5.93	35.78	51.32	43.55	39.92	67.07	53.50	14.95	16.38	15.66
N_5	5.42	6.97	6.20	37.95	57.16	47.55	48.39	68.80	58.60	16.12	17.65	16.88
S.Em.±	0.04	0.04	0.04	0.27	0.33	0.30	0.41	0.45	0.43	0.11	0.11	0.11
CD(p=0.05)	0.11	0.14	0.13	0.89	1.06	0.98	1.34	1.47	1.40	0.34	0.37	0.36
Interactions (MXN)												
M_1N_1	3.65	5.28	4.47	17.56	30.17	23.86	34.28	62.62	48.45	8.73	10.82	9.77
M_1N_2	4.98	6.25	5.62	26.73	40.80	33.77	37.69	67.06	52.38	15.93	17.62	16.77
M_1N_3	5.35	6.47	5.91	34.87	50.20	42.53	41.53	70.70	56.12	16.75	19.56	18.15

Continued....

TABLE 2 Continued....

Treatment	Crop growth rate (g m-2 day-1)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
M_1N_4	5.47	6.90	6.18	40.50	59.40	49.95	43.23	73.23	58.23	17.64	19.64	18.64
M_1N_5	5.68	7.28	6.48	42.77	68.17	55.47	45.20	73.53	59.37	18.67	20.52	19.59
M_2N_1	3.40	4.82	4.11	16.53	27.48	22.01	23.15	56.68	39.92	10.00	10.50	10.25
M_2N_2	4.77	6.05	5.41	26.55	37.07	31.81	36.35	66.30	51.32	12.61	14.00	13.31
M_2N_3	5.03	6.32	5.68	31.13	46.65	38.89	40.61	69.50	55.06	13.50	14.86	14.18
M_2N_4	5.13	6.58	5.86	36.22	53.23	44.73	41.35	71.55	56.45	14.75	15.14	14.94
M_2N_5	5.32	6.93	6.13	37.93	58.12	48.03	42.14	74.82	58.48	16.50	17.52	17.01
M_3N_1	3.38	4.50	3.94	14.16	21.88	18.02	19.64	46.87	33.26	7.02	9.10	8.06
M_3N_2	4.82	5.95	5.38	23.15	31.73	27.44	30.75	52.87	41.81	9.19	12.93	11.06
M_3N_3	4.93	6.22	5.58	26.80	37.50	32.15	34.84	54.96	44.90	11.67	13.53	12.60
M_3N_4	5.02	6.47	5.74	30.63	41.33	35.98	35.19	56.42	45.80	12.45	14.36	13.40
M_3N_5	5.25	6.70	5.98	33.15	45.19	39.17	57.83	58.06	57.95	13.17	14.92	14.05
S.Em.±	0.10	0.12	0.11	0.70	0.83	0.77	1.08	1.17	1.12	0.26	0.30	0.28
CD(p=0.05)	NS	NS	NS	2.10	2.50	2.30	3.22	3.52	3.37	0.78	0.90	0.84

Vertical factors: Rice cultivation methods (M); Horizontal factors' Nitrogen management practices (N); M_1 : Transplanted rice; N_1 : Control (Without nitrogen) ; M_2 : Wet-Direct seeded rice (Drum seeding); N_2 : 75% RDN; M_3 : Dry-Direct seeded rice (Seed drill) N_3 : 100% RDN; N_4 : 75% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage; N_5 : 100% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage

harvest resulted in response to application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5) (6.20, 47.55, 58.60 and 16.88 g m^{-2} day^1, respectively) compared to other nitrogen management practices in rice.

Transplanted rice with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) resulted in significantly higher crop growth rate at 30-60, 60-90 DAS and 90 DAS-at harvest (55.47, 59.37 and 19.59 g m^{-2} day^{-1} respectively) compared to other interactions. However, it was on par with wet-DSR with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_2N_5) and transplanted rice with application of 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_4). Lower crop growth rate was observed in dry-DSR without nitrogen application (M_3N_1).

Up to 90 DAS, the CGR showed an increasing tendency thereafter, it progressively decreased. The CGR at 90 DAS was greatest for M_1N_5 treatment indicating a significant increase in crop growth rate due to combined application of neem coated urea and nano urea. The increased dry matter accumulation in CGR can be attributed to various reasons related to nano urea, such as better nitrogen uptake efficiency, decreased nitrogen losses and increased nutrient utilization efficiency. The present results are consistent with previous research conducted by Zhu *et al.* (2017) and Zhang *et al.* (2020), which documented comparable impacts of nano urea on CGR and dry matter accumulation.

Relative Growth Rate

The data pertaining to relative growth rate was represented in Table 3 as influenced by different treatment combinations in rice.

TABLE 3

Effect of rice cultivation methods and nitrogen management practices on relative growth rate of rice under rice-cowpea cropping system

Treatment	Relative growth rate (10^{-3} g g^{-1} day^{-1})											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice cultivation methods (M)												
M_1	15.81	19.48	17.64	31.03	34.06	32.55	13.78	14.06	13.92	2.60	2.68	2.64
M_2	14.92	18.77	16.85	30.93	33.96	32.45	13.14	13.42	13.28	2.47	2.55	2.51
M_3	14.78	18.33	16.55	30.07	33.10	31.58	11.98	12.26	12.12	2.16	2.24	2.20
S.Em.±	0.12	0.15	0.13	0.24	0.24	0.24	0.10	0.11	0.11	0.02	0.02	0.02
CD(p=0.05)	0.46	0.57	0.51	0.92	0.93	0.93	0.41	0.42	0.41	0.08	0.09	0.09
Nitrogen management practices (N)												
N_1	10.64	15.48	13.06	28.48	31.51	30.00	11.37	11.65	11.51	1.79	1.87	1.83
N_2	15.48	18.74	17.11	29.53	32.56	31.04	12.81	13.09	12.95	2.26	2.34	2.30
N_3	16.20	19.32	17.76	30.87	33.90	32.39	12.91	13.19	13.05	2.46	2.54	2.50
N_4	16.48	20.03	18.25	32.20	35.23	33.72	13.66	13.94	13.80	2.74	2.82	2.78
N_5	17.05	20.71	18.88	32.30	35.33	33.82	14.08	14.36	14.22	2.81	2.89	2.85
S.Em.±	0.11	0.14	0.12	0.22	0.23	0.23	0.09	0.10	0.09	0.02	0.02	0.02
CD(p=0.05)	0.36	0.44	0.40	1.43	0.73	1.08	0.30	0.31	0.31	0.06	0.06	0.06
Interactions (MXN)												
M_1N_1	11.35	16.70	14.03	28.11	31.14	29.63	11.53	11.81	11.67	1.97	2.05	2.01
M_1N_2	15.86	19.13	17.50	29.68	32.71	31.19	13.77	14.05	13.91	2.54	2.62	2.58
M_1N_3	16.88	19.63	18.26	31.53	34.56	33.04	13.81	14.09	13.95	2.70	2.78	2.74
M_1N_4	17.20	20.57	18.88	32.88	35.91	34.39	14.37	14.65	14.51	2.87	2.95	2.91
M_1N_5	17.76	21.35	19.55	32.98	36.01	34.49	15.42	15.70	15.56	2.91	2.99	2.95
M_2N_1	10.32	15.36	12.84	28.39	31.42	29.91	11.43	11.71	11.57	1.86	1.94	1.90
M_2N_2	15.21	18.66	16.94	30.17	33.20	31.69	13.47	13.75	13.61	2.31	2.39	2.35
M_2N_3	16.00	19.29	17.64	31.11	34.14	32.63	12.98	13.26	13.12	2.49	2.57	2.53
M_2N_4	16.29	19.89	18.09	32.47	35.50	33.98	13.86	14.14	14.00	2.82	2.90	2.86
M_2N_5	16.79	20.64	18.72	32.52	35.55	34.03	13.97	14.25	14.11	2.86	2.94	2.90
M_3N_1	10.25	14.38	12.32	28.94	31.97	30.46	11.16	11.44	11.30	1.54	1.62	1.58
M_3N_2	15.36	18.42	16.89	28.73	31.76	30.25	11.19	11.47	11.33	1.92	2.00	1.96
M_3N_3	15.71	19.06	17.38	29.98	33.01	31.50	11.95	12.23	12.09	2.18	2.26	2.22
M_3N_4	15.95	19.63	17.79	31.26	34.29	32.77	12.75	13.03	12.89	2.52	2.60	2.56
M_3N_5	16.61	20.14	18.38	31.42	34.45	32.93	12.85	13.13	12.99	2.65	2.73	2.69
S.Em.±	0.30	0.37	0.33	0.57	0.57	0.57	0.25	0.25	0.25	0.05	0.05	0.05
CD(p=0.05)	NS	NS	NS	1.71	1.72	1.72	0.74	0.76	0.75	NS	NS	NS

Vertical factors : Rice cultivation methods (M); Horizontal factors : Nitrogen management practices (N) ; M_1 : Transplanted rice N_1 : Control (Without nitrogen); M_2 : Wet-Direct seeded rice (Drum seeding) N_2 : 75% RDN; M_3 : D ry-Direct seeded rice (Seed drill) N_3 : 100% RDN; N_4 : 75% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage; N_5 : 100% RDN+ foliar spray of 0.4% nano urea at Tillering and PI stage

The rate at which a plant incorporates new material of dry matter accumulation into its sink is measured by RGR and is expressed in g g^{-1} day^{-1}. Mean relative growth rate was very high between 30-60 DAS thereafter it decreased gradually between 60-90 DAS, 90 DAS and it continued to decrease appreciably towards harvest.

Among methods of rice cultivation, transplanted rice recorded significantly higher relative growth rate at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest (17.64, 32.55, 13.92 and 2.64 10^{-3} g g^{-1} day^{-1} respectively) compared to other rice cultivation methods. Application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5) resulted in significantly higher relative growth rate at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest (18.88, 33.82, 14.22 and 2.85 10^{-3} g g^{-1} day^{-1} respectively) compared to other nitrogen management practices in rice.

Among the interactions, transplanted rice with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) recorded significantly higher relative growth rate at 30-60 DAS and 60-90 DAS (34.49 and 15.56 10^{-3} g g^{-1} day^{-1} respectively) over other interactions. However, it was on par with transplanted rice with application of 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_4) (34.39 and 14.51 10^{-3} g g^{-1} day^{-1} respectively) and these treatments found superior over other treatments.

Together, nano urea and neem coated urea had an impact on relative growth rate up to 60 DAS, crop age showed an increasing trend in RGR: treatment M_1N_5 had highest RGR in comparison to other interactions. The reason for increase in RGR is that plants are able to more efficiently use available nitrogen for growth due to greater nutrient utilization efficiency of nitrogen. According to earlier study by Zhang *et al*. (2020) nano urea can increase plants RGR by up to 22 per cent when compared to normal urea. These findings are consistent with Zhu *et al*. (2017) and Rathnayaka *et al*. (2018).

Net Assimilation Rate

Pooled data on the net assimilation rate of rice as modified by the impact of rice establishment methods and nitrogen management at various phases of growth are reported (Table 4).

TABLE 4

Effect of rice cultivation methods and nitrogen management practices on net assimilation rate of rice under rice-cowpea cropping system

Treatment	Net assimilation rate (10-3 g m-2 day-1)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice cultivation methods (M)												
M_1	71.33	72.71	72.02	4.86	5.74	5.30	11.15	11.50	11.32	0.74	0.77	0.75
M_2	70.97	71.75	71.36	4.28	5.15	4.72	10.77	11.11	10.94	0.65	0.68	0.66
M_3	70.86	70.32	70.59	3.98	4.85	4.42	9.33	9.67	9.50	0.62	0.64	0.63
S.Em.±	0.54	0.55	0.55	0.04	0.04	0.04	0.09	0.09	0.09	0.01	0.01	0.01
CD(p=0.05)	2.12	2.17	2.15	0.14	0.16	0.15	0.35	0.36	0.36	0.02	0.02	0.02
Nitrogen management practices (N)												
N_1	62.62	63.81	63.22	3.09	3.96	3.53	8.81	9.15	8.98	0.32	0.35	0.33
N_2	71.41	71.70	71.55	3.29	4.17	3.73	10.31	10.65	10.48	0.55	0.58	0.57
N_3	72.64	72.69	72.67	4.87	5.75	5.31	10.69	11.04	10.87	0.70	0.72	0.71
N_4	73.86	74.34	74.10	5.11	5.98	5.54	10.97	11.32	11.15	0.87	0.90	0.88

Continued....

TABLE 4 Continued....

Treatment	Net assimilation rate (10-3 g m-2 day-1)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N_5	74.74	75.42	75.08	5.50	6.38	5.94	11.29	11.64	11.46	0.90	0.93	0.92
S.Em.±	0.51	0.52	0.52	0.03	0.04	0.04	0.08	0.08	0.08	0.01	0.01	0.01
CD(p=0.05)	1.67	1.69	1.68	0.11	0.13	0.12	0.25	0.26	0.25	0.02	0.02	0.02
Interactions (MXN)												
M_1N_1	63.57	67.20	65.39	3.14	4.02	3.58	9.72	10.07	9.89	0.34	0.37	0.35
M_1N_2	71.25	72.17	71.71	3.45	4.33	3.89	11.22	11.57	11.39	0.61	0.63	0.62
M_1N_3	72.41	72.99	72.70	5.63	6.51	6.07	11.44	11.78	11.61	0.82	0.85	0.83
M_1N_4	74.34	75.09	74.71	5.84	6.72	6.28	11.56	11.90	11.73	0.95	0.97	0.96
M_1N_5	75.08	76.09	75.59	6.24	7.11	6.68	11.81	12.16	11.99	0.99	1.01	1.00
M_2N_1	61.87	65.03	63.45	3.04	3.92	3.48	8.46	8.80	8.63	0.31	0.34	0.32
M_2N_2	71.57	71.62	71.60	3.26	4.13	3.70	11.08	11.43	11.25	0.58	0.60	0.59
M_2N_3	72.52	72.66	72.59	4.63	5.51	5.07	11.23	11.57	11.40	0.66	0.68	0.67
M_2N_4	74.03	73.81	73.92	5.03	5.91	5.47	11.41	11.75	11.58	0.85	0.87	0.86
M_2N_5	74.87	75.63	75.25	5.43	6.31	5.87	11.66	12.00	11.83	0.86	0.89	0.88
M_3N_1	62.42	59.21	60.81	3.09	3.96	3.52	8.25	8.59	8.42	0.31	0.33	0.32
M_3N_2	71.39	71.31	71.35	3.17	4.04	3.61	8.62	8.96	8.79	0.48	0.50	0.49
M_3N_3	72.99	72.44	72.71	4.36	5.23	4.80	9.41	9.75	9.58	0.62	0.64	0.63
M_3N_4	73.22	74.12	73.67	4.44	5.32	4.88	9.96	10.30	10.13	0.82	0.85	0.84
M_3N_5	74.28	74.55	74.41	4.83	5.71	5.27	10.40	10.75	10.57	0.86	0.89	0.87
S.Em.±	1.35	1.36	1.36	0.08	0.10	0.09	0.20	0.20	0.20	0.01	0.01	0.01
CD(p=0.05)	NS	NS	NS	0.24	0.29	0.27	0.59	0.61	0.60	NS	NS	NS

NAR is the physiological potential for converting the total dry matter into grain yield. The NAR is used as a measure of the rate of photosynthesis minus respiration losses. NAR was high between 0-30 DAS and decreased rapidly between 60 and 90 DAS and this continued to decrease towards harvest. Significantly superior net assimilation rate was observed in transplanted rice at 0-30, 30-60, 60-90 DAS and 90 DAS-at harvest (72.02, 5.30, 11.32 and 0.75 10^{-3} g m^{-2} day^{-1} respectively), compared to wet and dry DSR methods of rice cultivation. Application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5) resulted in significantly higher net assimilation rate at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest (75.08, 5.94, 11.46 and 0.92 10^{-3} g m^{-2} day^{-1} respectively) compared to other nitrogen management practices in rice.

Transplanted rice with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) resulted in significantly higher net assimilation rate at 30-60, 60-90 DAS and 90 DAS-at harvest (6.68 and 11.99 10^{-3} g m^{-2} day^{-1} respectively) compared to other interactions. However, it was on par with wet-DSR with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_2N_5) (5.87 and 11.83 10^{-3} g m^{-2} day^{-1}, respectively) and transplanted rice with application of 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_4) (6.28 and 11.73 10^{-3} g

m^{-2} day^{-1} respectively). Significantly Lower crop growth rate was observed in dry-DSR without nitrogen application (M_3N_1) (3.52 and 8.42 10^{-3} g m^{-2} day^{-1} respectively). This might be due to supplies adequate amount of nitrogen both in root zone and plant system the findings are confirmed by Algym and Alasady (2020) and Khan *et al*. (2023). Similarly, Madhurya *et al.* (2022) reported that for maximum crop growth, enough leaves must be present in the canopy to intercept most of the incident NAR which was significantly higher under the transplanted rice with nano urea application treatment in terms of leaf area.

In generally the measured growth indices namely AGR, CGR, RGR and NAR were found to be higher in treatment M_1N_5 (transplanted rice along with application of 100 per cent RDN + Spray of 0.4 per cent nano urea at tillering and panicle initiation stage). In SRI and transplanted rice, the increase in plant height and number of leaves including sufficient tiller number in young seedlings could be due to the early phyllochron stage (fewer than four leaves) and its proper establishment than that of older ones. This resulted in full utilization of the earlier root structure for the absorption of nutrients and their upward flow in young seedlings producing vigorous plants at later growth stages leads to formation of more active photosynthetic active leaf area (Nemoto & Yamazaki, 1995 and Sinha & Talati, 2007). Nano-urea can either provide nutrients for the plant or aid in the transport or absorption of available nutrients resulting in better crop growth. Nano-urea might have a synergistic impact on the conventional urea fertilizer for better nutrient absorption by plant cells, resulting in optimal growth and development of rice. These findings are in line with those found by Gewaily *et al.* (2019) and Dhamankar *et al*. (2023).

The phenomena of AGR, CGR, RGR and NAR tend to be low again during later stage and negative towards maturity (Table 1 to 4) considerably due to several reasons like leaves shading owing to early closure of canopy which hinder solar radiation absorbed by the leaves therefore less photosynthetic assimilates produced which causes lowering the net assimilation rate, excessive leaf senescence after reproductive stage diminishing photosynthesis rate upkeep of respiration burden increases over time which hinge on biomass and particularly its N content and ineptitude of the plants to maintain post floral N uptake or cannot store significant N reserves in other organs excepting leaves. These results are in agreement with those obtained by Azarpour *et al.* (2014), Paul *et al.* (2016) and Salem *et al*. (2011).

Leaf Area Duration

The data pertaining to leaf area duration was represented in Table 5 as influenced by different treatment combinations in rice.

TABLE 5

Effect of rice cultivation methods and nitrogen management practices on leaf area duration of rice under rice-cowpea cropping system

Treatment	Leaf area duration (days)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice cultivation methods (M)												
M_1	6.96	8.49	7.73	52.89	58.83	55.86	116.83	117.89	117.36	32.33	34.78	33.56
M_2	6.57	8.31	7.44	50.95	57.54	54.25	115.54	115.49	115.52	30.53	32.98	31.76
M_3	6.39	8.10	7.25	45.45	53.91	49.68	111.91	111.80	111.86	26.24	28.69	27.47
S.Em.±	0.06	0.07	0.06	0.43	0.50	0.46	0.50	0.45	0.47	0.46	0.46	0.46
CD(p=0.05)	0.22	0.26	0.24	1.67	1.95	1.81	1.95	1.77	1.86	1.80	1.80	1.80

Continued....

Table 5 Continued....

Treatment	Leaf area duration (days)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Nitrogen management practices (N)												
N_1	3.75	5.65	4.70	31.90	36.90	34.40	94.90	96.50	95.70	17.02	19.47	18.25
N_2	5.95	7.70	6.83	46.00	50.75	48.38	108.75	110.45	109.60	23.37	25.82	24.60
N_3	6.95	8.70	7.83	51.95	57.95	54.95	115.95	117.00	116.48	29.92	32.37	31.15
N_4	8.00	9.30	8.65	58.00	66.55	62.28	124.55	124.35	124.45	37.27	39.72	38.50
N_5	8.55	10.15	9.35	60.97	71.65	66.31	129.65	127.00	128.33	40.92	43.37	42.15
S.Em.±	0.05	0.06	0.06	0.37	0.42	0.40	0.42	0.40	0.41	0.40	0.40	0.40
CD(p=0.05)	0.17	0.20	0.18	1.21	1.38	1.29	1.38	1.31	1.34	1.30	1.30	1.30
Interactions (MXN)												
M_1N_1	4.05	5.85	4.95	31.65	39.00	35.33	97.00	97.40	97.20	17.92	20.37	19.15
M_1N_2	6.15	7.65	6.90	49.05	50.55	49.80	108.55	111.80	110.18	24.72	27.17	25.95
M_1N_3	7.20	8.85	8.03	54.45	62.10	58.28	120.10	120.35	120.23	33.27	35.72	34.50
M_1N_4	8.40	9.60	9.00	63.15	68.85	66.00	126.85	128.00	127.43	40.92	43.37	42.15
M_1N_5	9.00	10.50	9.75	66.15	73.65	69.90	131.65	131.90	131.78	44.82	47.27	46.05
M_2N_1	3.60	5.85	4.73	30.75	37.50	34.13	95.50	96.20	95.85	16.72	19.17	17.95
M_2N_2	5.85	7.65	6.75	47.10	52.65	49.88	110.65	111.95	111.30	24.87	27.32	26.10
M_2N_3	6.90	8.70	7.80	54.15	58.95	56.55	116.95	118.55	117.75	31.47	33.92	32.70
M_2N_4	8.10	9.15	8.63	59.85	66.90	63.38	124.90	125.45	125.18	38.37	40.82	39.60
M_2N_5	8.40	10.20	9.30	62.90	71.70	67.30	129.70	125.30	127.50	41.22	43.67	42.45
M_3N_1	3.60	5.25	4.43	33.30	34.20	33.75	92.20	95.90	94.05	16.42	18.87	17.65
M_3N_2	5.85	7.80	6.83	41.85	49.05	45.45	107.05	107.60	107.33	20.52	22.97	21.75
M_3N_3	6.75	8.55	7.65	47.25	52.80	50.03	110.80	112.10	111.45	25.02	27.47	26.25
M_3N_4	7.50	9.15	8.33	51.00	63.90	57.45	121.90	119.60	120.75	32.52	34.97	33.75
M_3N_5	8.25	9.75	9.00	53.85	69.60	61.73	127.60	123.80	125.70	36.72	39.17	37.95
S.Em.±	0.13	0.16	0.15	0.97	1.12	1.04	1.12	1.04	1.08	1.04	1.04	1.04
CD(p=0.05)	NS	NS	NS	2.89	3.36	3.13	3.36	3.11	3.24	NS	NS	NS

Vertical factors : Rice cultivation methods (M); Horizontal factors : Nitrogen management practices (N); M_1 : Transplanted rice; N_1 : Control (Without nitrogen); M_2 : Wet-Direct seeded rice (Drum seeding); N_2 : 75% RDN; M_3: Dry-Direct seeded rice (Seed drill) ; N_3 : 100% RDN; N_4 : 75% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage; N_5 : 100% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage

Leaf area duration (LAD) measures the ability of the plant to produce and maintain leaf area. Leaf area duration was low between 0-30 DAT, thereafter it increased linearly and attained peak values between 60-90 DAT and later declined towards harvest irrespective of the treatments. Among methods of rice cultivation, transplanted rice recorded significantly higher leaf area duration at 0-30, 30-60, 60-90 DAS and 90 DAS-at harvest (7.73, 55.86, 117.36 and 33.56 days, respectively) compared to other rice cultivation methods.

Application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5)

resulted in significantly higher leaf area duration at 0-30, 30-60, 60-90 DAS and 90 DAS-at harvest (9.35, 66.31, 128.33 and 42.15 days, respectively) compared to other nitrogen management practices in rice.

Among the interactions, transplanted rice with application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_5) recorded significantly higher leaf area duration at 30-60 DAS and 60-90 DAS (69.90 and 131.78 days, respectively) over other interactions. However, it was on par with transplanted rice with application of 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (M_1N_4) (66.00 and 127.43 days, respectively) and these treatments found superior over other treatments.

The dry matter production increased progressively with an increased in the levels of nitrogen applied. The increased in plant height, number of green leaves and leaf area. This might be due to better utilization of resources at higher level of nitrogen. With increasing photosynthetic area and longer periods of green leaves (LAD), the rice plants accumulated the higher bio mass at higher nitrogen levels. Pattnaik *et al*. (2020) were also opinion that the DMP (Dry Matter Production) of rice increased with increased in the level of nitrogen applied. Irrespective of method of nitrogen applied, the dry matter production and LAD was higher with nano urea combination. Application of liquid nano urea boosted the absorption rate and aided in formation of higher green leaves so it leads to greater number of green leaves added to bio mass of rice. Similar findings were also observed by Liu & Liao (2008) and Zunejo *et al.* (2012).

Leaf Area Ratio

The data pertaining to leaf area ratio of rice as influenced by rice cultivation methods and nitrogen management is presented in Table 6.

TABLE 6

Effect of rice cultivation methods and nitrogen management practices on leaf area ratio of rice under rice-cowpea cropping system

Treatment	Leaf area ratio (cm2 g-1)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Rice cultivation methods (M)												
M_1	43.18	49.16	46.17	6.55	9.46	8.01	5.54	6.61	6.08	3.96	4.74	4.35
M_2	41.81	47.79	44.80	6.36	9.27	7.81	5.27	6.34	5.81	3.84	4.62	4.23
M_3	40.35	46.33	43.34	6.10	9.01	7.56	5.05	6.12	5.59	3.68	4.46	4.07
S.Em.±	0.34	0.38	0.36	0.05	0.07	0.06	0.04	0.05	0.05	0.03	0.04	0.03
CD(p=0.05)	1.32	1.50	1.41	0.20	0.28	0.24	0.17	0.20	0.18	0.12	0.14	0.13
Nitrogen management practices (N)												
N_1	30.29	36.27	33.28	5.34	8.25	6.80	3.70	4.77	4.24	2.83	3.61	3.22
N_2	41.67	47.65	44.66	6.10	9.01	7.56	5.31	6.38	5.84	3.86	4.64	4.25
N_3	42.43	48.41	45.42	6.35	9.26	7.81	5.46	6.53	6.00	4.00	4.78	4.39
N_4	46.70	52.68	49.69	6.86	9.77	8.31	5.91	6.98	6.45	4.17	4.95	4.56
N_5	47.81	53.79	50.80	7.03	9.94	8.49	6.07	7.14	6.60	4.28	5.06	4.67
S.Em.±	0.30	0.35	0.33	0.05	0.07	0.06	0.04	0.05	0.04	0.03	0.03	0.03
CD(p=0.05)	0.99	1.13	1.06	0.15	0.22	0.18	0.13	0.15	0.14	0.09	0.11	0.10

Continued....

TABLE 6 Continued....

Treatment	Leaf area ratio (cm2 g-1)											
	0-30 DAS			30-60 DAS			60-90 DAS			90-At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Interactions (MXN)												
M_1N_1	30.90	36.88	33.89	5.52	8.43	6.98	3.98	5.05	4.52	3.00	3.78	3.39
M_1N_2	43.09	49.07	46.08	6.32	9.23	7.78	5.59	6.66	6.12	4.01	4.79	4.40
M_1N_3	44.62	50.60	47.61	6.52	9.43	7.98	5.63	6.70	6.17	4.11	4.89	4.50
M_1N_4	48.02	54.00	51.01	7.13	10.04	8.59	6.22	7.29	6.75	4.29	5.07	4.68
M_1N_5	49.25	55.23	52.24	7.26	10.17	8.72	6.30	7.37	6.83	4.38	5.16	4.77
M_2N_1	30.75	36.73	33.74	5.32	8.23	6.78	3.85	4.92	4.39	2.81	3.59	3.20
M_2N_2	41.98	47.96	44.97	6.12	9.03	7.58	5.24	6.31	5.78	3.90	4.68	4.29
M_2N_3	42.31	48.29	45.30	6.32	9.23	7.78	5.43	6.50	5.97	4.01	4.79	4.40
M_2N_4	46.26	52.24	49.25	6.96	9.87	8.42	5.81	6.88	6.34	4.20	4.98	4.59
M_2N_5	47.73	53.71	50.72	7.07	9.98	8.53	6.03	7.10	6.57	4.27	5.05	4.66
M_3N_1	29.21	35.19	32.20	5.19	8.10	6.65	3.27	4.34	3.80	2.67	3.45	3.06
M_3N_2	39.93	45.91	42.92	5.87	8.78	7.33	5.09	6.16	5.63	3.67	4.45	4.06
M_3N_3	40.36	46.34	43.35	6.22	9.13	7.68	5.32	6.39	5.86	3.87	4.65	4.26
M_3N_4	45.82	51.80	48.81	6.48	9.39	7.94	5.71	6.78	6.24	4.01	4.79	4.40
M_3N_5	46.45	52.43	49.44	6.76	9.67	8.22	5.87	6.94	6.40	4.20	4.98	4.59
S.Em.±	0.82	0.94	0.88	0.12	0.18	0.15	0.11	0.13	0.12	0.08	0.09	0.08
CD(p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Among the methods of rice cultivation, transplanted rice (M_1) recorded significantly superior leaf area ratio at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest (46.17, 8.01, 6.08 and 4.35 cm^2 g^{-1}, respectively) as compared to wet DSR (M_2) (44.80, 7.81, 5.81 and 4.23 cm^2 g^{-1}, respectively) and dry-DSR (M_3) of rice cultivation (43.34, 7.56, 5.59 and 4.07 cm^2 g^{-1}, respectively).

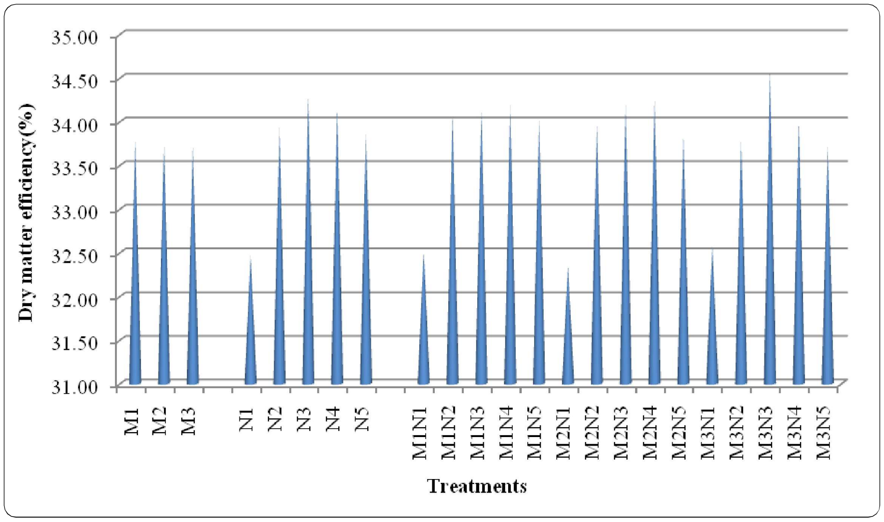
Among nitrogen management practices, application of 100 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_5) resulted in significantly higher leaf area ratio at 0-30, 30-60, 60-90 DAS and 90 DAS at harvest (50.80, 8.49, 6.60 and 4.67 cm^2 g^{-1}, respectively) compared to other treatments. While, lower absolute growth rate was recorded in control (without-N) (N_1) (33.28, 6.80, 4.24 and 3.22 cm^2 g^{-1}, respectively). Interaction found no significant effect among treatment combinations.

Leaf area ratio (LAR) indicates the efficiency with which a leaf area utilized to produce plant material and results indicate the treatment differences. Apart from control, all the treated plots found almost alike even though differences are little vary for those treatments at 60 DAS only. It clearly passionate the activity of leaf or leaves by concerned treatments and its peak contribution was observed in transplanted rice with application of 100 per cent RDN + 2 foliar spray of 0.4 per cent nano urea at tillering and PI stage .

Dry Matter Efficiency

The grape-1 deprecated the dry matter efficiency of rice cultivation methods and nitrogen management in rice under rice-cowpea cropping system.

Among rice cultivation methods dry matter production efficiency found no significant effect however, numerically higher dry matter production efficiency found in transplanted rice.



Vertical factors : Rice cultivation methods (M); Horizontal factors : Nitrogen management practices (N); M_1 : Transplanted rice; N_1 : Control (Without nitrogen); M_2 : Wet-Direct seeded rice (Drum seeding); N_2 : 75% RDN; M_3 : Dry-Direct seeded rice (Seed drill); N_3 : 100% RDN; N_4 : 75% RDN + foliar spray of 0.4% nano urea at Tillering and PI stage; N_5 : 100% RDN+ foliar spray of 0.4% nano urea at Tillering and PI stage

Among nitrogen management practices, 100 per cent RDN recorded significantly higher dry matter efficiency (34.29%) compared to other treatment, however, it was on par with 75 per cent RDN + foliar spray of 0.4 per cent nano urea at tillering and PI stage (N_4) (34.15%). It might be due to higher harvest index. Interaction effect found no significant effect on dry matter efficiency.

Based on the results, among rice cultivation methods transplanted rice (M_1) recorded higher physiological growth indices compared to Wet-DSR and Dry-DSR. Among nitrogen management practices, application of 100 per cent RDN along with 0.4 per cent nano urea at tillering and panicle initiation (PI) stage recorded significantly higher physiological growth indices compared to other treatments. Interactions, transplanted rice with application of 100 per cent RDN along with 0.4 per cent nano urea at tillering and panicle initiation (PI) stage in rice (N_5) recorded significantly higher physiological growth parameters like absolute growth rate, crop growth rate, relative growth rate, net assimilation rate, leaf area duration, and leaf area ratio, however, which was on par with transplanted rice with application of 75 per cent RDN along with 0.4 per cent nano urea at tillering and panicle initiation (PI) stage in rice (M_1N_4).

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