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Effect of differential nitrogen management practices on growth, yield and water use efficiency of rice under varying moisture regimes

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ABSTRACT

Pot experiments were conducted during 2018and 2019 at the College of Agriculture, Central Agricultural University, Imphal, Manipur, India to investigate the effect of different nitrogen management practices on growth, yield and water use efficiency of rice variety "CAU R1" under varying moisture regimes. Keeping this rationale, three nitrogen management practices {60 kg N/ha (Urea), 40 kg N/ha (Urea) + 20 kg N/ha equivalent FYM, 30 kg N/ha (Urea) + 15 kg N/ha equivalent FYM + 15 kg N/ha equivalent *Azolla* and three levels of moisture regime {continuous flooding (5 cm depth), no standing water (wetting soil just after hairy cracks appear), 5 cm water depth at tillering, panicle initiation and flowering stage} were tested in a Factorial Randomized Block Design and replicated thrice. Overall, the results of investigational findings indicated that the integrated approach of nitrogen management *viz.* 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* with maintenance of 5 cm water depth at tillering, panicle initiation and flowering stage markedly improved growth and yield attributes and subsequently yield and water use efficiency of rice as compared to conventional method of nitrogen supplementation through fertilizer. Multivariate principal component analysis and stepwise regression showed that number of tillers/hill is the most important yield attributing characters implicated in augmenting the rice yield significantly.

Introduction

Rice (*Oryza sativa* L.) is one of the most important starchy grain crops of the world which feeds about a half of the Earth's population. However, its cultivation is under a serious crisis globally due to several constraints including stagnating yields, dwindling area, rising input costs, shortage of water

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and labour (Thakur *et al.,* 2016). This further adds a tremendous onus on the shoulders of the rice growers to produce adequate tonnes of rice to feed the burgeoning population of the world. In this context, exploiting the production potential of rice through efficient agronomic management is one of the alternatives to safeguard and sustain food security. Nitrogen (N) and water management are two production factors which play significant role in enhancing the rice production (Jat *et al.,* 2020).

N is one of the major essential macro-nutrients of plants, which insufficient availability in soil limits the crop yield. Application of inorganic N fertilizers has contributed substantially to the spectacular increase in agricultural production. However, low fertilizer N-use efficiency, ranging from 18 to 40 %, has been registered in rice soils due to rapid loss of applied inorganic N from the soil through various processes like ammonia volatilization and denitrification, which further contributes in environmental pollution. Also, continuous and disproportionate application of chemical fertilizers has been attributed to soil contamination and nutrient stress (Bisht and Chauhan, 2020). So, there arises an obligation to formulate ways to endure and enhance the overall productivity of rice-based cropping systems for better livelihood. Sustainable practices like integrated use of both organic and inorganic fertilizers have been often regarded as a viable alternative to address this problem (Yadav and Meena, 2014). The conjunctive use of organic manures and chemical fertilizers ensures the supply of essential nutrients in adequate amount and proportion, improves nutrient uptake by altering the soil physical behaviour and enhances the use-efficiency of native and applied nutrients (Sharma *et al.,* 2019), and restores the soil health (Kumrawat *et al.,* 2019). Therefore, the integrated use of organic manure and inorganic fertilizer will restore the soil health and improve the performance in crops like rice by sustaining higher yield. Probably, there is no universally acceptable formula of integrated nutrient management practice. Thus, more efforts are needed to identify the improved nutrient management strategy for a particular target environment. Multivariate statistical tools like principal component analysis can identify significant yield attributing characters influencing the rice yield and, these results can now be effectively resorted by breeders to develop high yielding rice varieties and novel breeding procedures for rice improvement in the future (Maji, 2012).

Rice cultivation consumes more than 50% of the total fresh water utilised under irrigated agriculture in the world (Jat *et al.,* 2016). It is estimated that about 3000-5000 litres of water are utilized to yield one kg of rice (Jat *et al.,* 2020). However, water is becoming increasingly scarce because of population explosion, rapid urban and industrial development and its dwindling availability resulting from pollution and resource depletion (Boretti and Rosa, 2019). Escalating water scarcity due to its increasing demand from other sectors threatens the sustainability of irrigated rice production and calls for development of innovative technologies that necessitate less water than conventional flooded rice without experiencing yield losses. There is clearly an urgent need to find ways to grow more rice with less water and fewer inputs. Hence, there is an urgent need to study the effects of different N management practices on growth, yield and water use efficiency of rice crop under varying moisture regimes.

Material and Methods

Details of the study area

The pot experiment was conducted in polyhouse of the College of Agriculture, Central Agricultural University, Imphal campus during the *kharif* 2018 and 2019. The geographical position of the polyhouse is as such - Latitude $24^0 45^/$ N, Longitude $93^0 54^/$ E with an altitude of 774m above mean sea level. 245.9 and 236.14 mm of mean monthly rainfalls were recorded during *kharif* 2018 and 2019, respectively. Monthly mean temperature ranged from 11.1 to 22.6 ^{o}C and 13.5 to 22.5^{o}C, respectively during both years of investigation. The soil was clay in texture (13.6% sand, 24.3% silt, and 62.1% clay), acidic (pH 5.4) and low in available phosphorus (P) with medium in available N and potassium (K) status.

Treatment details

The pot experiment was laid out in Factorial Randomized Block Design with 3 levels of Nutrient Management Practices {N_1: 100% recommended dose of N (RDN) throughUrea,N_2: 66.67%RDN through Urea + 33.33% RDN through FYM, N_3:

50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla*} and 3 levels of moisture regime {M_1: Continuous flooding (5 cm depth); M_2: No standing water (wetting soil just after hairy cracks appear); M_3: 5 cm water depth at tillering, panicle initiation and flowering stages} which were combined into 9 treatments and replicated thrice. 60 kg N/ha was the recommended dose of N in rice.

Pot preparation

Soil was collected from a farm field for filling the pots. In this case, the field was disturbed by giving one deep ploughing. Then soils were selected from 5 different random spots of the field and they had been evenly mixed together before filling the pots. Pots of dimension 24 cm × 24 cm × 30 cm each with no single hole on them was used for the experiment. Each pot was filled with measured 10 kg of pre-collected soil and was kept as according to the experimental design alignment and labelled. As per our nutrient management criteria, N_2 and N_3 labelled pots needed addition of FYM and both *Azolla* and FYM respectively other than inorganic nutrients. So, about 15 days before transplantation, those nutrient supplements were added to their respective pots in their mentionable amount. Just before transplanting, the soils in the pots were tilled using any hand tool (*khurpi*) and was irrigated up to 5 cm depth, resembling a puddled field condition. Seed was sown on first week of July on nursery bed and then transplanted using 23 days old seedlings. 3 seedlings were transplanted in each pot by keeping them in an equal distance of 10 cm in triangular spacing from each other.

Nutrient and water management

Application of both inorganic (NPK) and organic (FYM and *Azolla*) nutrient sources were done as according to the treatment. FYM and *Azolla* were applied and incorporated to the soil 15 days before transplanting for the recommended pots (N_2 and N_3 labelled). In case of inorganic fertilizers, half of the N dose i.e., 60, 40 and 30 kg/ha for N_1, N_2 and N_3 respectively and full of the doses of P and K were applied as basal, just before transplanting. The remaining half of N dose was applied into two equal splits as top-dressing at the time of tillering and panicle initiation. Recommended doses of P and K were 40 kg P_2O_5/ha and 30 kg K_2O/ha, respectively. Super Phosphate and Muriate of Potash were the sources of P and K, respectively. Irrigation was started from the time of transplanting with initially keeping 5 cm stagnation in all treatments. Specified moisture level as per treatment was followed in the subsequent irrigations. Tap water was used as the source of irrigation.

Intercultural operations

As the crop was transplanted in pots, there was no serious problem of weeds. Only need-based hand manual weeding was done during the crop season. There were no noticeable pest and disease problems except sheath rot disease infestation, during booting stage of the crop. To control it spray of Carbendazim solution @ 1 g/L was applied 2 times with one week gap.

Biometric observations

Plant height, number of leaves and tillers per hill were recorded at 40, 80 days after transplanting (DAT) and at harvest. Leaf length and leaf width were also recorded at 40, 80 DAT and at harvesting. Flag leaf length measurement was recorded at 80 DAT, and at harvest. At physiological maturity, number of effective tillers per plant was counted. Panicle length, number of spikelets and filled spikelets per panicle were determined before determining the grain yield. Test weight was calculated by using the following equation:

$$\textbf{Test weight} = \frac{\text{Weight of filled grain (g)}}{\text{Number of filled grain}} \times 1000$$

After drying, grain yield and straw yield from each hill from each pot were taken by using a digital electric balance and expressed in gram (g). Harvest index was calculated with following formula (Donald, 1963):

$$\textbf{Harvest index} = \frac{\text{Grain yield per pot (g)}}{\text{Biological yield per pot (g)}} \times 100$$

Water Use Efficiency (WUE) was measured by using the formula:

$$\textbf{Water Use Efficiency (WUE)} = \frac{\text{Grain yield per pot (g)}}{\text{Biological yield per pot (g)}}$$

Data analysis

The experimental data of two consecutive years were pooled and analysed statistically by applying the technique of analysis of variance (Gomez and Gomez, 1984) prescribed for the factorial randomized plot design to test the significant difference among treatments by the F test and conclusions were drawn at 5% probability levels. The least significant difference (LSD) at $\alpha=0.05$, was used to compare the treatment means. Significance or non-significance of the variance due to various treatment effects were determined by calculating respective 'F' values. Pearson's correlation was performed to determine the relations between the differential yield attributing parameters implicated in yield of crop. The principal component analysis (PCA) of all the data were performed using R studio for dimension reduction of data set. PCA is a statistical technique aimed to condense dimensions of multivariate dataset by retaining most of useful value of the input data thereby reducing its dimensions (Karkra *et al.,* 2016). It is commonly used procedure for independent variable assortment and eliminating redundant or highly correlated variables. Stepwise multiple linear regression analysis was accomplished using R studio to explore the significance and contribution of differential yield attributing parameters in the prediction of crop yield.

Results and Discussion

Growth attributes

N management practice did not exert any significant influence on plant height at all the stages of observation, except at 40 DAT, in which the markedly improved plant height was registered under 100% RDN through Urea (Table 1). Application of 50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla* perceptibly enhanced the number of tillers/hill and leaves/hill at all the stages of observation (Table 1). Inorganic fertilization along with organic supplements might have provided adequate nutrient and created a favourable soil physical condition for crop growth, thus improved growth attributes such as number of tillers and leaves at various growth stages. Oo *et al.* (2010) and Jeyajothi and Durairaj (2015) also observed that synergistic effects of combined application of chemical fertilizers along with organic nutrient sources like FYM, green leaf manuring and biofertilizers boosted the growth parameters of rice. Leaf length and leaf width remained statistically unaffected due to different nutrient management practices (Table 2). The significantly highest flag leaf length was recorded in all the crop growth stages under 100% RDN through Urea (Table 2). This could be attributed to the relative quicker and easier nutrient supplying capacity of inorganic fertilizers over organic nutrient sources to plants.

The tallest plant was recorded under continuous flooding in all the stages of observation, which was statistically superior among all moisture regimes (Table 1). However, the significantly highest number of tillers/hill was registered under 5 cm water depth at tillering, panicle initiation and flowering stages during the entire periodic assessment (Table 2). Growth attributes namely number of leaves/hill (Table 1), leaf length and leaf width (Table 2) did not vary statistically under different moisture regimes. Whereas, a conspicuous improvement in flag leaf length was noted under continuous flooding of rice crop at various stages of observation (Table 2). Alternate wetting and drying irrigation along with maintenance of flooding at the critical stages of crop growth renders a favourable situation of better root and shoot growth of rice (Zhang *et al*., 2009).

On critical analysis, it was noted that treatment combinations of N management practice and moisture regime had a marked impact on the growth attributes of rice, except leaf length and leaf width (Table 1 and 2). Application of 100% RDN through Urea under continuous flooding led to tangible enhancement in plant height, which superior among all treatment combinations. However, the highest number of tillers/hill and number of leaves/hill were found under 50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla* registered under 5 cm water depth at tillering, panicle initiation and flowering stages. Flag length was significantly improved due to the application of 100% RDN through Urea under no flooding, which was statistically at par with 50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla* registered under 5 cm water depth at tillering, panicle initiation and flowering stages at all the stages of record. Adequate N availability during active growth stages

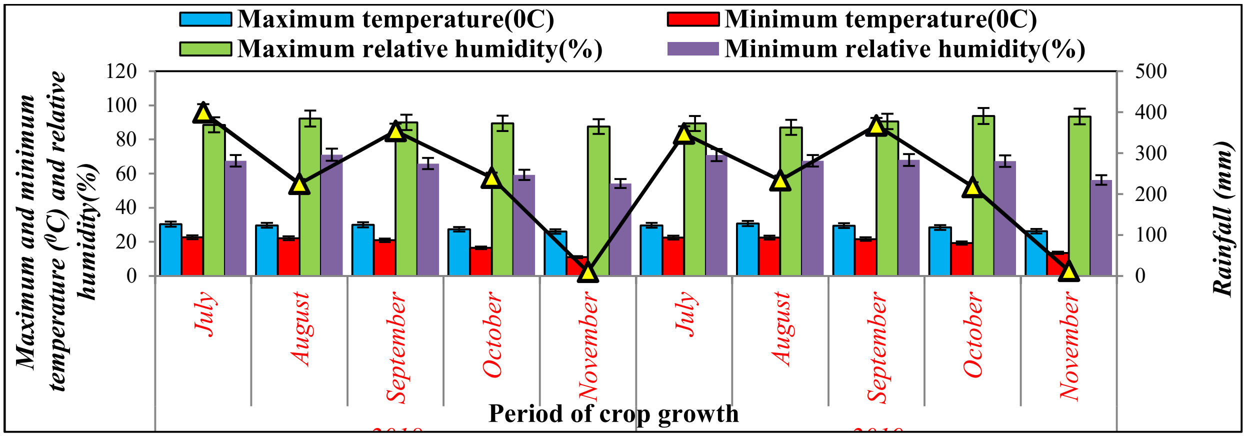

Figure 1: Meteorological observation of the pot experiment of rice during 2018-19

Table 1: Effect of different N management practices and moisture regimes on periodic plant height, number of tillers and leaves per hill of rice

Treatments	Plant height (cm)			Number of tillers/hill			Number of leaves/hill		
	40 DAT	80 DAT	At harvest	40 DAT	80 DAT	At harvest	40 DAT	80 DAT	At harvest
Nitrogen management practices (N)									
N_1	110.00	117.00	114.74	2.04	2.04	2.04	10.22	8.48	6.41
N_2	104.37	116.48	114.70	2.19	2.22	2.22	9.78	8.85	6.59
N_3	105.01	117.00	115.30	2.30	2.52	2.52	12.15	10.04	7.39
S.E(d)±	0.61	0.56	0.87	0.11	0.10	0.10	0.39	0.52	0.37
$LSD_{(P=0.05)}$	1.29	NS	NS	0.23	0.20	0.20	0.82	1.11	0.79
Moisture regimes (M)									
M_1	107.46	119.11	117.04	2.11	2.15	2.15	10.52	8.81	6.85
M_2	106.15	117.96	116.00	2.11	2.22	2.22	10.59	8.78	6.26
M_3	105.78	113.41	111.70	2.30	2.41	2.41	11.04	9.78	6.96
S.E(d)±	0.61	0.56	0.87	0.11	0.10	0.10	0.39	0.52	0.37
$LSD_{(P=0.05)}$	1.29	1.19	1.84	NS	0.20	0.20	NS	NS	NS
Interaction (N × M)									
N_1M_1	114.22	122.56	118.89	2.11	2.11	2.11	11.00	8.78	6.67
N_1M_2	107.78	118.11	116.44	2.00	2.00	2.00	10.22	8.11	6.11
N_1M_3	108.00	110.33	108.89	2.00	2.00	2.00	9.44	8.56	6.44
N_2M_1	104.56	117.00	115.89	2.11	2.22	2.22	10.33	9.00	7.11
N_2M_2	104.89	117.11	114.89	2.22	2.22	2.22	9.00	8.56	5.89
N_2M_3	103.67	115.33	113.33	2.22	2.22	2.22	10.00	9.00	6.78
N_3M_1	103.59	117.78	116.33	2.11	2.11	2.11	10.22	8.67	6.78
N_3M_2	105.78	118.67	116.67	2.11	2.44	2.44	12.56	9.67	6.78
N_3M_3	105.67	114.56	112.89	2.67	3.00	3.00	13.67	11.78	7.67
S.E(d)±	1.05	0.97	1.50	0.19	0.17	0.17	0.67	0.91	0.63
$LSD_{(P=0.05)}$	2.24	2.07	3.18	0.40	0.37	0.37	1.43	1.92	1.34

due to integrated N supplementation from both organic and inorganic coupled with adequate water availability could have resulted in marked improvement in growth and development of rice.

Yield attributes

Different N management practices had a noticeable impact on yield attributes of rice, except spikelets/ panicle, filled grains/panicle and panicle length

Table 2: Effect of different N management practices and moisture regimes on periodic leaf length, width and flag leaf length of rice

Treatments	Leaf length (cm)	Leaf width (cm)	Flag leaf length (cm)						
	40 DAT	80 DAT	At harvest	40 DAT	80 DAT	At harvest	60 DAT	100 DAT	At harvest
Nitrogen management practices (N)									
N_1	65.94	75.62	68.70	1.69	1.88	1.78	38.90	43.47	41.20
N_2	65.68	74.73	68.42	1.68	1.88	1.78	33.51	38.84	35.08
N_3	65.31	75.14	68.54	1.68	1.91	1.79	32.51	37.23	34.22
S.E(d)±	0.52	0.51	0.15	0.01	0.02	0.01	1.05	0.80	1.25
$LSD_{(P=0.05)}$	NS	NS	NS	NS	NS	NS	2.23	1.69	2.65
Moisture regimes (M)									
M_1	65.58	75.27	68.71	1.69	1.89	1.79	37.01	41.63	39.35
M_2	66.07	74.96	68.42	1.67	1.88	1.78	34.19	38.35	36.53
M_3	65.27	75.25	68.54	1.69	1.90	1.78	33.70	39.56	34.62
S.E(d)±	0.52	0.51	0.15	0.01	0.02	0.01	1.05	0.80	1.25
$LSD_{(P=0.05)}$	NS	NS	NS	0.03	NS	NS	2.23	1.69	2.65
Interaction (N × M)									
N_1M_1	66.01	76.22	68.89	1.68	1.89	1.8	41.13	45.57	43.54
N_1M_2	65.96	75.41	68.85	1.67	1.87	1.77	40.44	45.48	42.78
N_1M_3	65.86	75.22	68.37	1.71	1.87	1.77	35.11	39.35	37.28
N_2M_1	65.85	74.59	68.41	1.68	1.88	1.78	35.11	39.44	35.02
N_2M_2	64.7	74.89	68.41	1.67	1.87	1.76	30.91	38.74	33.43
N_2M_3	66.48	74.7	68.44	1.68	1.88	1.79	34.5	38.33	36.78
N_3M_1	65.78	74.78	68.33	1.67	1.88	1.77	27.63	31.24	30.04
N_3M_2	64.11	74.93	68.44	1.67	1.93	1.79	30.89	39.89	31.56
N_3M_3	66.04	75.71	68.86	1.71	1.92	1.82	39	40.57	41.07
S.E(d)±	0.91	0.89	0.26	0.02	0.03	0.02	1.82	1.38	2.17
$LSD_{(P=0.05)}$	NS	NS	NS	NS	NS	NS	3.86	2.92	4.60

(Table 3). The maximum values of effective tillers/hill and test weight were registered under 50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla*, which was significantly the highest among all the treatments. Enhanced soil aggregation, improved nutrient availability and soil microbial activity under integrated nutrient management might have created a favourable soil environment, which further better the uptake of nutrients, and consequently leading to prolific vegetative growth of plants and higher dry matter accumulation (Nataraja *et al*., 2021). Adequate and efficient supply of plant nutrients due to the combined application of urea along with FYM and *Azolla* might have beneficial effect on yield attributes like effective tillers per hill and test weight of rice. Yield attributes of rice, except, panicle length and test weight, responded significantly to varying moisture regimes (Table 3). Treatment no standing water recorded the statistically the highest number of effective tillers/hill. Treatment continuous flooding led to marked improvement in number of spikelets/panicle and filled grains/panicle, which was statistically at par with no standing water. A favourable growing and nutrient supply environment under continuous flooding might have increased number of spikelets and partitioning of dry matters at grain filling stage results in higher filled grains in panicle. Ramakrishna *et al.* (2007) reported that continuous water submergence markedly enhanced yield attributes (including number of panicles, grains/panicle, 1,000-grain weight) of rice. However, a safe alternate wetting and drying irrigation situation has been observed to be equally capable of providing congenial environment by facilitating crop to access moisture from subsurface levels, which remain saturated and

Table 3: Effect of different N management practices and moisture regimes on yield attributes, yields and water use efficiency of rice

Treatments	Effective Tillers/hill	Spikelets/ panicle	Filled grains/ panicle	Panicle length (cm)	Test Weight (g)	Grain Yield (g/hill)	Straw Yield (g/hill)	Harvest Index (%)	WUE (g/l)
Nitrogen management practices (N)									
N_1	2.04	144.20	128.96	22.27	26.18	6.35	4.79	57.09	1.28
N_2	2.04	148.00	132.73	21.88	26.28	6.32	5.47	55.99	1.33
N_3	2.48	147.98	128.55	22.24	28.08	7.55	5.87	57.57	1.67
S.E(d)±	0.12	3.75	2.86	0.30	0.58	0.19	0.24	1.60	0.07
$LSD_{(P=0.05)}$	0.25	NS	NS	NS	1.24	0.41	0.50	NS	0.15
Moisture regimes (M)									
M_1	2.11	150.47	133.98	22.29	26.80	6.67	5.27	56.15	0.91
M_2	2.07	149.70	132.76	22.06	26.67	6.52	4.95	58.87	1.64
M_3	2.37	140.01	123.51	22.04	27.07	7.01	5.90	55.63	1.74
S.E(d)±	0.12	3.75	2.86	0.30	0.58	0.19	0.24	1.60	0.07
$LSD_{(P=0.05)}$	0.25	7.95	6.06	NS	NS	0.41	0.50	NS	0.15
Interaction (N × M)									
N_1M_1	2.11	151.39	136.33	23.13	27.06	6.68	4.60	59.87	0.89
N_1M_2	2.00	153.33	138.11	22.11	26.39	6.62	3.98	62.94	1.62
N_1M_3	2.00	127.89	112.44	21.56	25.08	5.75	5.78	48.48	1.33
N_2M_1	2.11	147.48	134.89	21.54	26.99	6.67	5.48	55.27	0.93
N_2M_2	1.78	148.83	134.17	22.22	25.73	5.46	5.43	53.81	1.31
N_2M_3	2.22	147.69	129.15	21.89	26.13	6.82	5.50	58.88	1.74
N_3M_1	2.11	152.54	130.70	22.20	26.34	6.67	5.74	53.31	0.91
N_3M_2	2.44	146.93	126.00	21.85	27.90	7.49	5.43	59.87	1.97
N_3M_3	2.89	144.46	128.94	22.67	29.99	8.48	6.42	59.53	2.13
S.E(d)±	0.21	6.49	4.95	0.51	1.01	0.34	0.41	2.76	0.12
$LSD_{(P=0.05)}$	0.45	13.77	10.50	1.09	2.14	0.71	NS	5.86	0.26

Table 4: Pearson's correlation coefficient (r) matrix between the different soil chemicals, biological properties and with grain yield of rice

	Plant height	**Number of tillers/hill**	**Number of leaves/hill**	**Leaf length**	**Leaf width**	**Flag leaf length**	**Effective Tillers/hill**	**Spikelets/ panicle**	**Filled grains/ panicle**	**Panicle length**	**Test Weight**	**Grain Yield**
Plant height	**1.000**	-0.111	-0.072	0.330	0.073	0.036	-0.091	**0.874**	**0.816**	0.478	0.207	0.150
Number of tillers/hill	-0.111	**1.000**	**0.739**	0.302	**0.769**	0.062	**0.893**	-0.010	-0.023	0.292	**0.905**	**0.815**
Number of leaves/hill	-0.072	**0.739**	**1.000**	0.183	**0.815**	0.065	**0.866**	-0.068	-0.097	0.140	**0.786**	**0.833**
Leaf length	0.330	0.302	0.183	**1.000**	**0.584**	**0.887**	0.370	0.309	0.449	**0.737**	**0.532**	0.464
Leaf width	0.073	**0.769**	**0.815**	**0.584**	**1.000**	0.445	**0.884**	0.032	0.032	**0.517**	**0.854**	**0.864**
Flag leaf length	0.036	0.062	0.065	**0.887**	0.445	**1.000**	0.160	0.011	0.241	**0.523**	0.229	0.199
Effective Tillers/hill	-0.091	**0.893**	**0.866**	0.370	**0.884**	0.160	**1.000**	-0.049	-0.134	0.258	**0.913**	**0.959**
Spikelets/ panicle	**0.874**	-0.010	-0.068	0.309	0.032	0.011	-0.049	**1.000**	**0.918**	0.444	0.211	0.199
Filled grains/ panicle	**0.816**	-0.023	-0.097	0.449	0.032	0.241	-0.134	**0.918**	**1.000**	0.457	0.198	0.099
Panicle length	0.478	0.292	0.140	**0.737**	**0.517**	**0.523**	0.258	0.444	0.457	**1.000**	0.439	0.313
Test Weight	0.207	**0.905**	**0.786**	**0.532**	**0.854**	0.229	**0.913**	0.211	0.198	0.439	**1.000**	**0.934**
Grain Yield	0.150	**0.815**	**0.833**	0.464	**0.864**	0.199	**0.959**	0.199	0.099	0.313	**0.934**	**1.000**

Boldfaced italics and boldface values indicate that correlation is positive and highly significant at p < 0.01% and p < 0.05% level of probability (2 tailed). The correlation coefficient (*r*) values correspond directly to the colour codes from green to yellow and red, respectively.

improving nutrient availability through better N mineralization (Lu *et al.,* 2000; Ceesay *et al.*, 2006; Pandey *et al.*, 2010).

Various combinations of N management practice and moisture regime induced a significant influence on yield attributes of rice (Table 3). Application of 50% RDN through Urea + 25% RDN through FYM +25% RDN through *Azolla* under 5 cm depth at tillering, panicle initiation and flowering stages resulted in the highest number of effective tillers/hill which was significantly better than rest of treatment combinations, except 50% RDN through Urea + 25% RDN through FYM +25% RDN through *Azolla* under no standing water. However, a conspicuous increase in number of spikelets/panicle and filled spikelets/panicle was recorded due to application of 66.67% RDN through Urea + 33.33% RDN through FYM under continuous flooding. The highest panicle length was registered under 100% RDN through Urea under continuous flooding, which statistically equivalent to 100% RDN through Urea under no flooding, 66.67% RDN through Urea + 33.33% RDN through FYM under no standing water, 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under continuous flooding and 5 cm depth at tillering, panicle initiation and flowering stages. Application of 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under 5 cm at tillering, panicle initiation and flowering stages gave the maximum value of test weight, which was significantly higher than the rest of treatment combinations, 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under no standing water. The synergism between integrated approach of N supply and standing water at critical stages could have caused better nutrient availability and its partitioning, thus significant improvement in yield attributes of rice.

Yields and water use efficiency

Grain and straw yield, and water use efficiency of rice were statistically influenced by different N management practices and moisture regimes (Table 3). However, treatment effect on harvest index was non-significant. Application of 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* significantly bettered both the grain and straw yield over 100% RDN through Urea. The gain in grain and straw yield due this treatment was in the tune of 18.90% and 22.55% over 100% RDN through Urea. Being a constituent of amino acids, nucleotides, nucleic acid, a number of coenzyme and growth promoters, N promotes cell elongation, cell enlargement and cell division. These activities in turn activate meristematic tissues which remain functional for longer periods resulting in better expression of yield and yield attributes converting more solar energy to productive energy. Controlled release of nutrients, including N through mineralisation of organic manures under integrated nutrient management practices facilitate better crop growth (Meshram *et al.*, 2018) and improved yield attributes namely number of effective tillers/hill and test weight, which ultimately translate into higher yield of rice. Similarly, the highest water use efficiency was registered under 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla.* Efficient plant nutrition is a good strategy to enhance yield, water use efficiency and productivity in crop plants (Waraich *et al.*, 2011). Limited researchers have also opined that the integrated use of organic and inorganic nutrient sources in rice cultivation has the advantage in terms of higher yield and water use efficiency of the rice (Singh and Shivay, 2003).

Among different moisture regimes, the maximum value of grain yield was recorded under 5 cm depth at tillering, panicle initiation and flowering stages, which was statistically at par with continuous flooding. Similarly, treatment 5 cm depth at tillering, panicle initiation and flowering stages gave the statistically highest value of straw yield among all treatments. However, the harvest index remained significantly unaffected under varying moisture regimes. The highest value of water use efficiency was noted under maintenance of 5 cm depth at tillering, panicle initiation and flowering stages. Alternate wetting and drying irrigation practice, including flooding only in certain growth stages consumes less quantity of water than conventional method of flooding throughout the season due to reduction in percolation losses. On the other hand, meeting the moisture demand under recommended submergence at specific growth stages provide favourable growing environment with better nutrient availability, thus leading to better yield and WUE as compared to conventional methods (Pandey *et al.*, 2010; Xu *et al.,* 2020).

Table 5: Results of PCA of soil chemical properties and nutrient status of rice

Principal components		**PC 1**	**PC 2**	**PC 3**
Initial Eigenvalues	Total	5.07	3.27	1.58
	% of Variance	46.11	29.70	14.33
	Cumulative %	46.11	75.80	90.13
Rotation Sums of Squared Loadings	Total	4.38	3.01	2.53
	% of Variance	39.80	27.36	22.97
	Cumulative %	39.80	67.16	90.13
Eigen vectors[b]		***Factor loadings***[a]		
		PC 1	**PC 2**	**PC 3**
Plant height		-0.040	0.922	0.101
Number of tillers/hill		**0.960**	-0.017	0.045
Number of leaves/hill		**0.863**	-0.069	0.088
Leaf length		0.215	-0.545	0.795
Leaf width		0.696	-0.551	0.071
Flag leaf length		-0.705	0.297	0.576
Effective Tillers/hill		**0.950**	-0.053	0.106
Spikelets/panicle		-0.008	0.991	-0.009
Filled grains/ panicle		-0.032	0.932	0.081
Panicle length		0.215	0.453	0.826
Test weight		**0.948**	0.229	0.169

Extraction Method: *Principal Component Analysis,*
Rotation Method: *Varimax with Kaiser Normalization.*
[a]*Rotation converged in 5 iterations and*
[b]*Boldfaced factor loadings are considered highly weighted*

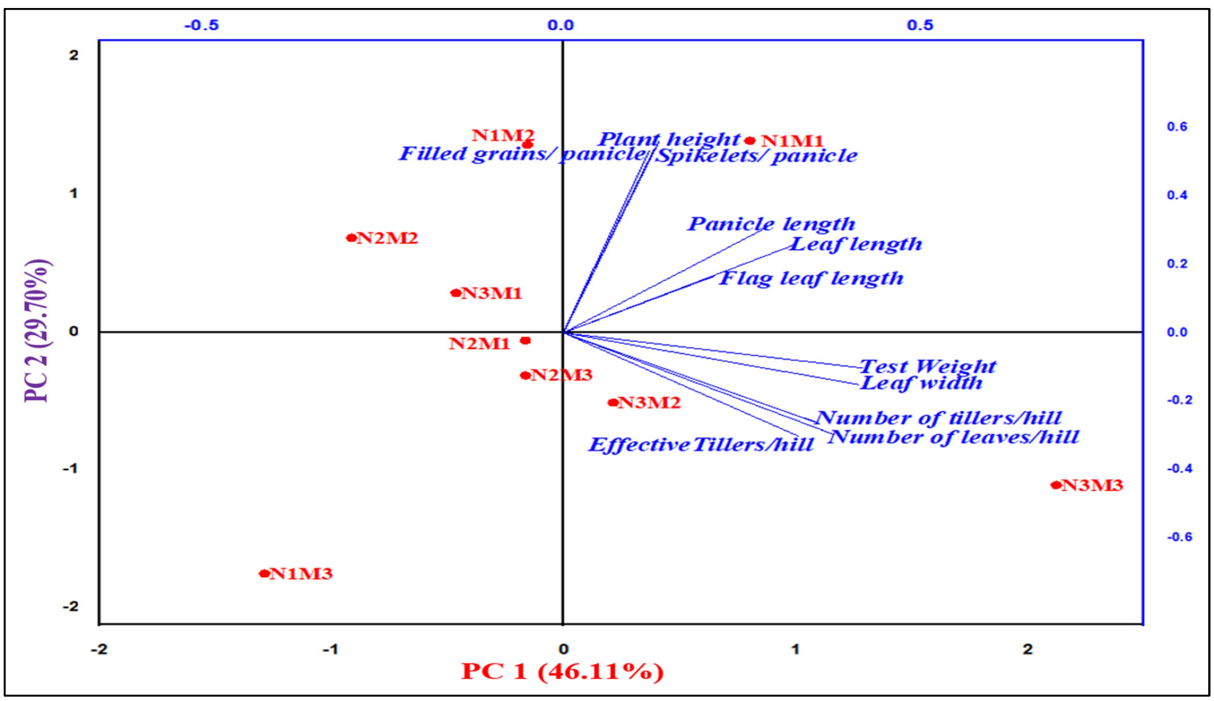

Figure 2: Two dimensional graphical biplot formed by PC 1 and 2 of growth and yield attributing characters of rice

Zhang *et al*. (2009) observed that a moderate wetting and drying regime could augment root growth which aids other physiological processes and upshot in higher grain yield and WUE in rice.

Various combinations of N management practice and moisture regimes rendered significant effect on grain yield, and water use efficiency, except straw yield of rice (Table 3). Application of 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under 5 cm depth at tillering, panicle initiation and flowering stages led to marked enhancement of grain yield of rice which was 26.95% higher than that of 100% RDN through Urea under continuous flooding. The highest harvest index was recorded under both 100% RDN through Urea under continuous flooding and 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under no standing water, which was statistically at par with 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under 5 cm depth at tillering, panicle initiation and flowering stages and 66.67% RDN through Urea + 33% RDN through FYM under 5 cm depth at tillering, panicle initiation and flowering stages. The treatment combination 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under 5 cm depth at tillering, panicle initiation and flowering stages showed to have an edge in term of water use efficiency among all the treatment combinations. Higher yield level rice under the combination of 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under 5 cm depth at tillering, panicle initiation and flowering stages could be attributed to improved growth and yield attributes under integrated N management practice with standing water at critical stages of rice. Further, the higher production level with lesser water consumption caused enhancement in its WUE under this treatment combination.

Correlation study between yield attributing characters of rice and with crop yield

The Pearson's correlation coefficients analysis was performed to evaluate the relationships between the diverse growth and yield attributing characters of rice and its grain yield (Table 4). In general, there existed positive correlation amongst the yield attributing characters of rice and with crop yield. However, few selected parameters revealed the existence of non-significant and negative correlation between them and with crop yield. Specifically, there was an existence of highly and significant positive correlation of plant height with spikelets/panicle ($r = 0.874$, $p < 0.01$) and filled grains/ panicle ($r = 0.816$, $p < 0.01$) but it showed non-significant negative correlation with number of tillers/hill ($r = -0.111$), number of leaves/hill (-0.072) and effective tillers/hill ($r = -0.091$). The number of tillers/hill was found to correlate (highly and significant positive correlation) with number of leaves/hill ($r = 0.739$, $p < 0.01$), Leaf width ($r = 0.769$, $p < 0.01$), effective tillers/hill ($r = 0.893$, $p < 0.01$), test weight ($r = 0.905$, $p < 0.01$) and grain yield (g/hill) ($r = 0.815$, $p < 0.01$) while it revealed non-significant negative correlation with spikelets/ panicle ($r = -0.010$) and filled grains/ panicle ($r = -0.023$). Similarly, the number of leaves/hill exhibited a significant positive correlation correlated with leaf width ($r = 0.815$, $p < 0.05$), effective tillers/hill ($r = 0.866$, $p < 0.01$), test weight ($r = 0.786$, $p < 0.01$), and grain yield ($r = 0.833$, $p < 0.01$), however it was found to correlative negatively with spikelets/ panicle ($r = -0.068$) and filled grains/ panicle ($r = -0.097$). There existed a significant positive correlation of leaf length with leaf width ($r = 0.584$, $p < 0.05$), Flag leaf length ($r = 0.887$, $p < 0.01$), panicle length ($r = 0.737$, $p < 0.01$) and test weight ($r = 0.532$, $p < 0.01$). Also, effective tillers/hill revealed a highly and significant positive correlation with test weight ($r = 0.913$, $p < 0.01$) and grain yield ($r = 0.913$, $p < 0.001$) and grain yield ($r = 0.959$, $p < 0.001$) but it exhibited a non-significant negative correlation with spikelets/panicle ($r = -0.049$) and Filled grains/ panicle ($r = -0.134$). While, pikelets/ panicle exhibited a highly and significant positive correlation with filled grains/ panicle ($r = 0.918$, $p < 0.01$) while it revealed non-significant negative correlation with spikelets/ panicle ($r = -0.010$). And finally, test weight showed the existence of a highly and significant positive correlation with grain yield ($r = 0.934$, $p < 0.01$). Similar findings were also reported by Jat *et al.* (2016) and (2020).

Principal component analysis

The results of principal component analysis (PCA) exercised on growth and yield attributing characters of rice grain yield explicated the data variation to the tune of 90.15% of the total variability (Table 5).

Three dominant principal components with Eigenvector less than 1 are extracted viz, PC1, PC 2 and PC3 accounting for 44.16%, 31.32% and 14.68% of cumulative variance in the available data set were extracted as an outcome of PCA (Table 5). Biplot (Fig. 1) generated in respect of rice elucidated that first principal component had large positive loadings number of tillers/hill, followed by effective tillers/hill, test weight and number of leaves/hill and these soil parameters exhibited high correlation between them since the variables of 0 or 180◦ reveals a correlation of 1 or -1, respectively (Kohler and Luniak, 2005). Growth and yield attributes (parameters) are superimposed on various N management practices (N) and moisture regimes (treatments) on the biplots (Fig. 1) to figure out the best treatment combination affecting the growth and yield attributing characters and grain yield rice. The outcome of the superimposition showed that treatment N3M3 (50% RDN through Urea + 25% RDN through FYM + 25% RDN through *Azolla)*+ 5 cm water depth at tillering, panicle initiation and flowering stages) was realized to be the best treatment combination followed by treatment combinations 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under no standing water and 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* under continuous flooding, respectively in influencing the growth and yield attributing characters and rice grain yield.

Stepwise multiple linear regressions (MLR) for predicting the best model for rice crop yield

For implementing MLR model on rice crop, the growth and yield attributing parameters were assigned as predictor variables and yield of rice crop were assigned as response variable to evaluate the main factors as the determinants of rice yield. Upon iteration, the following regression equation (Table 6) was generated after screening out the redundant predictor variables which were not involved directly in increasing rice crop yield. From the stepwise regression variances analysis (Table 7), it can be inferred that the yield attributing character i.e., number of tillers/hill was realized to be the best predictor variable impacting in augmenting the rice yield thereby contributing 66.46% followed by effective tillers/hill (25.46%), test weight (4.21%) and number of leaves/hill width ((3.44%), respectively.

Table 6: Multiple stepwise linear regressions (MLR) equation for crops

Grain yield= 16.18 + 1.05 Number of tillers/hill + 6.85 Test weight + 3.37 Effective Tillers/hill + 0.04 Number of leaves/hill
R^2= 99.57%
R^2 adjusted = 99.13%
R^2 predicted= 88.29%
Durbin-Watson Statistic =1.84

Table 7: Stepwise regression variances analysis

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-Value	P-Value
Regression	4	6.22	99.57%	6.22	1.55	229.11	0.00
Number of tillers/hill	1	4.15	66.46%	0.10	0.10	14.24	0.02
EffectiveTillers/hill	1	1.59	25.46%	1.79	1.79	264.08	0.00
Test weight	1	0.26	4.21%	0.26	0.26	38.75	0.00
Number of leaves/hill width	1	0.21	3.44%	0.03	0.03	3.72	0.13
Error	4	0.03	0.43%	0.03	0.01		
Total	8	6.24	100.00%				

Where, Seq. SS = Sequential sums of squares, Adj. SS = Adjusted sum of squares, Adj. MS = Adjusted mean squares
Stepwise selection of terms: ***α to enter = 0.15, α to remove = 0.15***

Conclusion

Based on the above findings of pot experiment, it can be concluded that integrated approach of N management markedly improved growth and yield attributes and subsequently yield and water use efficiency of rice as compared to conventional method of N supplementation through fertilizer. Also, maintenance of 5 cm water depth at tillering, panicle initiation and flowering stage displayed a strong potential to replace the traditional practice of continuous flooding without affecting growth and yield of rice. So, it can be inferred that application of 50% RDN through Urea + 25% RDN through FYM + 25% through *Azolla* with maintenance of 5 cm depth at tillering, panicle initiation and flowering stages appears to be promising resource conserving practices for sustainable management of N and moisture in rice without comprising in terms of its growth and yield. However, to reach a specific conclusion and recommendation, the experiment should be tested under different agro-climatic situations and under open field conditions, with some due considerations on irrigation water quality and detailed study on the effect of nutrients on moisture stress tolerant capacity of rice.

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