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EFFECT OF INTEGRATED NITROGEN MANAGEMENT AND NITRIFICATION INHIBITOR ON NUTRIENT CONTENT AND UPTAKE BY WETLAND PADDY (*ORYZA SATIVA* L.)

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ABSTRACT

A research work was carried out on field during two consecutive *kharif* seasons of 2022 and 2023 at Anand Agricultural University, Anand. The experiment included thirteen treatments and was laid out in Randomized Block Design with 3 replications. Gurjari variety of paddy was taken as test crop. The soil of the experimental plot was loamy sand in texture. Application of treatment T_8 recorded significantly higher N content in grain and straw of paddy which remained at par with all treatment except absolute control during both the year. A higher P content in grain and straw was noted in T_{13}, which remained at par with all treatments except absolute control during both the year. Potassium content in grain and straw was found non-significant during the year 2022, 2023 and on base of pooled analysis. Significantly higher N uptake by grain and straw (111 kg ha^{-1} and 60.81 kg ha^{-1}) was observed under T_8, respectively. Treatment T_{13} recorded significantly higher P and K uptake by both grain and straw of paddy in pooled results.

Key words : Integrated nitrogen management, Nitrification inhibitor, Sustainability.

Introduction

The intensive cultivation of crops, combined with the continuous and imbalanced application of synthetic fertilizers to meet the demands of high-yielding, fertilizer-responsive varieties, has resulted in significant declines in soil organic carbon (SOC) levels (Singh *et al.*, 1999) and overall soil health (Kumar *et al.*, 2018). Integrated nutrient management (INM) or integrated nutrient supply (INS) systems offer a viable solution by promoting the efficient and synergistic use of synthetic fertilizers alongside organic nutrient sources (Mahajan *et al.*, 2008). Developed with a deep understanding of crop-soil-climate interactions, INM emphasizes the balanced integration of inorganic, organic and biological nutrient sources. This approach seeks to maintain optimal plant nutrition, ensuring sustainable crop yields while leveraging the potential of all nutrient sources cohesively, tailored to specific cropping systems and farming conditions (Mahajan *et al.*, 2005). The incorporation of organic manures within INM strategies enhances nutrient uptake efficiency, improves soil quality (physical, chemical, and biological properties) and fosters a synergistic effect on crop growth and productivity (Yadav *et al.*, 2000). By judiciously combining organic, inorganic and biological inputs, INM optimizes nutrient supply and demand, harmonizing crop nutritional requirements with environmental discharge (Wu *et al.*, 2015).

Rice is one of the most important cereals globally and is the staple food for more than half of the world population (Savitha and Ushakumari, 2016) and provides 19% of dietary energy (Ray *et al.*, 2013). To achieve food security by 2050, global agricultural productivity should be increased by 60-110% (Ray *et al.*, 2013). India cultivates about 44.4 Mha of rice under four major agro-ecosystems and is one among the top three rice-growing nations with a yield growth rate of only 1.0% per year which cannot ensure global food security by 2050 (Ray *et al.*, 2013). Intensive farming practice with high fertilization is widely adopted to increase crop productivity and therefore, the dependence on fertilizers has continually increased in the rice cropping industry (Mosier *et al.*, 2002; Dobermann and Cassman, 2005).

Materials and Methods

An experiment on effect of integrated nitrogen management and nitrification inhibitor on nutrients content and uptake by wetland paddy was carried out at Regional Research Station Farm, AAU, Anand. The experiment was laid out in Randomized Block Design with 3 replications. The thirteen treatments on INM and NI *viz*., T_1: Absolute control; T_2: 150% RDN through ammonium sulphate (AS); T_3: 100% RDN through AS; T_4: 75% RDN through AS + 25% RDN through FYM; T_5 : 75% RDN through AS + 25% RDN through vermicompost; T_6 : 75% RDN through AS + 25% RDN through FYM + Seedling dip application of Bio NP liquid Biofertilizer; T_7 : 75% RDN through AS + 25% RDN through vermicompost + Seedling dip application of Bio NP liquid Biofertilizer; T_8: T_2 + dicyandiamide (DCD) mixed with AS @ 5%; T_9: T_3 + DCD mixed with AS @ 5%; T_{10}: T_4 + DCD mixed with AS @ 5%; T_{11}: T_5 + DCD mixed with AS @ 5%; T_{12}: T_6 + DCD mixed with AS @ 5% and T_{13}: T_7 + DCD mixed with AS @ 5% were studied. Gurjari variety of paddy was taken as test crop. The soil of the experimental plot was loamy sand in texture. The depth of soil is very deep and has moderate moisture retentive capacity.

Approximately 500 g of grain and straw of paddy was collected randomly from each treatment and bring into the laboratory in well labelled brown paper bag for analysing nutrient content *viz*., N, P and K from each treatment. Subsequently, the collected samples were dried in oven at 65°C for 24 hours. Oven dried plant samples were ground by a grinding mill, sieved through a 20-mesh sieve and put into paper bags then kept into the desiccators for further plant chemical analysis. Dried plant samples (straw and grain) were digested with sulphuric acid (H_2SO_4) for N and nitric acid (HNO_3) used for digestion for P and K in microwave digester and volume was made with double distilled water. The extract was filtered through Whatman filter paper No. 42. The filtrate of plant samples analysed for total P as per vanadomolybdo phosphoric acid yellow colour method (Spectrophotometry) and K content as per flame photometry method.

Macro nutrient uptake by grain and straw was calculated using below given formula.

$$\text{Major nutrient uptake by grain or straw (kg ha}^{-1}) = \frac{\text{Content in grain/straw (\%)} \times \text{grain/straw yield (kg ha}^{-1})}{100}$$

Results and Discussion

Effect of treatments on Nutrient Content (%) in grain of paddy

Nitrogen content (%)

The significantly higher nitrogen content in grain (1.84, 1.83 and 1.83%) was recorded in T_8 (150% RDN through AS + DCD) during the year 2022, 2023 and on base of pooled analysis, respectively (Table 1). This was statistically at par with all the treatments except absolute control (T_1) during both the years while it was at par with all the treatment except T_1 and T_3 in pooled analysis. Significantly lowest nitrogen percentage (1.40, 1.35 and 1.37%) was recorded in T_1 (absolute control), during *kharif*-2022, *kharif*-2023 and in pooled results. All treatments involving either 100% RDN or INM (T_3 to T_7) showed a significant increase in grain nitrogen content over the control. By reducing nitrogen losses by leaching and volatilization, the application of 150% RDN in conjunction with DCD (T_8) considerably outperformed all other treatments, indicating that nitrification inhibitors improve NUE (Shamsuzzaman *et al*., 2015; Zaman *et al*., 2009). Despite being statistically equivalent to T_8, treatments T_2 and T_{13} show that higher nitrogen levels and combinations of organic and biofertilizers can yield results that are comparable. When combined with chemical and microbiological amendments, this validates the promise of integrated nutrient management.

In line with findings from Sharma *et al*. (2016), who highlighted the function of microbial inoculants in promoting nitrogen uptake and fixation, biofertilizer treatments (T_6, T_7, T_{12}, and T_{13}) significantly increased nitrogen assimilation when paired with either FYM or VC. Improved nitrogen efficiency was demonstrated by treatments such as T_7 and T_{12}, which used just 75% RDN but had nitrogen contents comparable to 100-150% RDN treatments. Additionally, compared to purely inorganic treatments at lower rates, the addition of organic sources (FYM, VC) during T_4-T_7 enhanced soil health and nutrient cycling, with a higher nitrogen content. This is in line with earlier research by Ali *et al*. (2019) and Ramesh *et al*. (2017), which found that integrated nutrient management enhanced grain quality and nutrient uptake.

Phosphorus content (%)

Significantly higher phosphorus concentration was obtained in T_{13} (0.477, 0.475 and 0.476%), where 75% RDN was applied through AS, 25% through VC,

Table 1 : Effect of treatments on nutrients content (%) in grain of paddy.

Tr. no.		**N (%)**			**P (%)**			**K (%)**		
		2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1		1.40^{c}	1.35^{c}	1.37^{d}	0.357^{c}	0.343^{c}	0.350^{e}	0.302	0.295	0.299
T_2		1.81^{ab}	1.80^{ab}	1.81^{ab}	0.432^{ab}	0.431^{ab}	0.431^{cd}	0.306	0.303	0.305
T_3		1.69^{ab}	1.68^{ab}	1.69^{bc}	0.428^{ab}	0.428^{ab}	0.428^{d}	0.304	0.301	0.302
T_4		1.71^{ab}	1.69^{ab}	1.70^{ab}	0.462^{ab}	0.458^{ab}	0.460^{abcd}	0.314	0.312	0.313
T_5		1.72^{ab}	1.69^{ab}	1.71^{ab}	0.466^{ab}	0.460^{ab}	0.463^{abcd}	0.320	0.314	0.317
T_6		1.75^{ab}	1.74^{ab}	1.75^{ab}	0.470^{ab}	0.468^{ab}	0.469^{ab}	0.325	0.322	0.323
T_7		1.78^{ab}	1.75^{ab}	1.77^{ab}	0.475^{ab}	0.472^{ab}	0.473^{ab}	0.326	0.325	0.326
T_8		1.84^{a}	1.83^{a}	1.83^{a}	0.435^{ab}	0.433^{ab}	0.434^{bcd}	0.311	0.308	0.310
T_9		1.71^{ab}	1.69^{ab}	1.70^{ab}	0.430^{ab}	0.429^{ab}	0.429^{cd}	0.306	0.301	0.304
T_{10}		1.73^{ab}	1.69^{ab}	1.71^{ab}	0.463^{ab}	0.460^{ab}	0.462^{abcd}	0.321	0.315	0.318
T_{11}		1.75^{ab}	1.73^{ab}	1.74^{ab}	0.467^{ab}	0.463^{ab}	0.465^{abc}	0.322	0.315	0.319
T_{12}		1.79^{ab}	1.78^{ab}	1.79^{ab}	0.472^{ab}	0.471^{ab}	0.471^{ab}	0.329	0.325	0.327
T_{13}		1.80^{ab}	1.80^{ab}	1.80^{ab}	0.477^{a}	0.475^{a}	0.476^{a}	0.330	0.328	0.329
S. Em. ±	T	0.07	0.08	0.048	0.02	0.02	0.011	0.01	0.02	0.010
	Y	-	-	0.021	-	-	0.005	-	-	0.004
	T × Y	-	-	0.076	-	-	0.018	-	-	0.015
CD (P = 0.05)	T	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	NS	NS
	Y	-	-	NS	-	-	NS	-	-	NS
	T × Y	-	-	NS	-	-	NS	-	-	NS
CV (%)		7.27	8.01	7.64	7.41	6.49	6.96	7.18	9.25	8.27

Note: Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

combined with a seedling dip in Bio NP liquid biofertilizer, and the inclusion of DCD during both the years as well as in pooled results, respectively (Table 1). This was remained statistically at par with all treatments except T_1 (absolute control) during both the years while it was found at par with treatments T_7, T_{12}, T_6, T_{11}, T_5, T_{10} and T_4 in pooled result. During both years and in pooled result, treatments T_7, T_{12} and T_6 followed closely and were statistically at par with T_{13}. These results indicate the benefit of integrating organic amendments and biofertilizers along with chemical nitrogen sources. In contrast, significantly lowest phosphorus content (0.357, 0.343 and 0.350%) was observed in T_1 (absolute control) during both season and in pooled results, respectively, then all nutrient-supplemented treatments.

In addition to directly supplying nutrients, organic materials like FYM and VC can enhance soil microbial activity and structure, which increases phosphorus availability and solubilization (Patra *et al.*, 2012). Furthermore, the PSB in Bio NP liquid biofertilizer probably made it easier for the crop to mobilize and absorb phosphorus. Since DCD help reduce nitrogen loss and indirectly support phosphorus assimilation by promoting balanced nutrient uptake, the superior performance of T_{13} and T_{12} highlights the effectiveness of INM in rice, especially when supplemented with biological inputs (Shamsuzzaman *et al.*, 2017; Kumar *et al.*, 2018).

Potassium content (%)

The data presented in Table 1 indicated that effect of INM on potassium content in grain was found non-significant during both the years; 2022, 2023 as well as in pooled result. The lack of significant differences among treatments may be attributed to the relatively narrow variation in potassium content across treatments and the inherent buffering capacity of potassium in soil, which often leads to less pronounced changes in grain potassium concentration (Marschner, 2012). Furthermore, potassium content was not significantly impacted by the use of DCD,

Table 2 : Effect of treatments on nutrients content (%) in straw of paddy.

Tr. no.		N (%)			P (%)			K (%)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1		0.700[c]	0.688[c]	0.694[d]	0.160[c]	0.149[c]	0.155[d]	1.10	1.09	1.09
T_2		0.875[ab]	0.870[ab]	0.873[ab]	0.223[ab]	0.220[ab]	0.222[bc]	1.12	1.09	1.10
T_3		0.820[ab]	0.817[ab]	0.818[bc]	0.222[ab]	0.220[ab]	0.221[c]	1.09	1.08	1.09
T_4		0.828[ab]	0.828[ab]	0.828[ab]	0.230[ab]	0.230[ab]	0.230[abc]	1.17	1.14	1.16
T_5		0.830[ab]	0.829[ab]	0.830[ab]	0.235[ab]	0.234[ab]	0.235[abc]	1.18	1.15	1.17
T_6		0.856[ab]	0.854[ab]	0.855[ab]	0.240[ab]	0.239[ab]	0.240[abc]	1.20	1.19	1.19
T_7		0.861[ab]	0.855[ab]	0.858[ab]	0.248[ab]	0.242[ab]	0.245[ab]	1.22	1.21	1.22
T_8		0.884[a]	0.878[a]	0.882[a]	0.225[ab]	0.220[ab]	0.223[bc]	1.13	1.09	1.11
T_9		0.830[ab]	0.827[ab]	0.828[ab]	0.222[ab]	0.218[ab]	0.220[c]	1.12	1.08	1.10
T_{10}		0.836[ab]	0.830[ab]	0.833[ab]	0.233[ab]	0.232[ab]	0.233[abc]	1.18	1.17	1.18
T_{11}		0.842[ab]	0.837[ab]	0.839[ab]	0.238[ab]	0.235[ab]	0.237[abc]	1.20	1.17	1.18
T_{12}		0.866[ab]	0.862[ab]	0.864[ab]	0.243[ab]	0.241[ab]	0.242[abc]	1.23	1.21	1.22
T_{13}		0.872[ab]	0.870[ab]	0.871[ab]	0.250[a]	0.243[a]	0.247[a]	1.24	1.23	1.24
S. Em. ±	T	0.03	0.03	0.019	0.01	0.01	0.007	0.07	0.07	0.043
	Y	-	-	0.008	-	-	0.003	-	-	0.019
	T × Y	-	-	0.031	-	-	0.010	-	-	0.067
CD (P = 0.05)	T	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	NS	NS
	Y	-	-	NS	-	-	NS	-	-	NS
	T × Y	-	-	NS	-	-	NS	-	-	NS
CV (%)		6.10	6.56	6.33	8.71	6.83	7.84	9.98	10.23	10.10

Note: Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

which is in line with research by Kumar *et al*. (2019), who found that nitrification inhibitors mainly affect nitrogen transformations rather than potassium availability.

Effect of treatments on Nutrient Content (%) in straw of paddy

Nitrogen content (%)

Significantly higher nitrogen content in paddy straw (0.884, 0.878 and 0.881%) was observed in T_8, during both the years as well as in pooled analysis respectively, where 150% RDN was supplied through AS along with 5% DCD (Table 2). This treatment remained at par to all treatments except absolute control (T_1) during both year and at par with all treatment except T_1 and T_3. The information showed that the nitrogen content of straw strongly responds favourably to the type of nutrient inputs used as well as the nitrogen dosage. Higher nitrogen rates (T_2, T_8) or the addition of the DCD produced consistently better results, suggesting better nitrogen uptake and conservation. This conclusion is in line with research by Shamsuzzaman *et al*. (2015), which found that by postponing nitrification, nitrification inhibitors dramatically lower nitrogen losses and increase plant nitrogen availability. Combining chemical fertilizers with organic and biofertilizer components can substantially increase NUE, as demonstrated by the synergistic effect of organic amendments and microbial inputs in treatments T_6, T_7, T_{12} and T_{13}. As previously shown by Sharma *et al*. (2016) and Ramesh *et al*. (2017), such combinations enhance soil biological activity and nutrient cycling, improving nitrogen assimilation in both grain and straw.

Phosphorus content (%)

The significantly higher phosphorus content was recorded in T_{13} treatment with value of 0.250, 0.243 and 0.247% in 2022, 2023 and in a pooled analysis, respectively (Table 2). This was remained statistically at par with all treatments except T_1 (absolute control) during both the years while it was found at par with treatments T_7, T_{12}, T_6, T_{11}, T_5, T_{10} and T_4 in pooled result. On the other hand, lower phosphorus values were found in T_1 (0.160, 0.149 and 0.155%), the unfertilized control, which significantly lowest from all fertilized treatments.

Vermicompost and FYM treatments, either by themselves or in combination with Bio NP liquid biofertilizer, increased rhizosphere microbial activity and enzymatic activities, which are essential for the mineralization and solubilization of phosphorus (Sharma *et al*., 2016). Through microbial action, specifically by phosphate-solubilizing bacteria (PSB), which convert insoluble phosphorus into forms that plants can use, biofertilizers like Bio NP directly contribute to increased phosphorus availability (Zaidi *et al*., 2009). Vermicompost, a rich source of humic compounds and enzymes, has a synergistic impact that further encourages root growth and nutrient uptake (Kumar *et al*., 2020). By reducing nitrogen loss through nitrification, DCD probably made an indirect contribution by enhancing the plant's nutritional balance, which in turn promotes more efficient phosphorus absorption (Kiran and Patra, 2018). Although chemical nitrogen increases yield, it might not be enough for the best phosphorus feeding in the absence of organic matter and microbial activity, as seen by the comparatively lower phosphorus contents in groups that solely received inorganic fertilizers. This supports previous research showing that the long-term use of chemical fertilizers alone can lower soil microbial biomass and enzyme activity (Zhao *et al*., 2014), which will have a detrimental effect on phosphorus cycling.

Potassium content (%)

The lack of significant variation in potassium content across treatments suggests that potassium uptake by the crop's straw is less influenced by different nitrogen management strategies or biofertilizer application under the conditions tested. Potassium is a mobile nutrient within the plant, and its concentration can be influenced by soil K availability more than by nitrogen forms or amendments (Marschner, 2012). The slight increases observed in treatments incorporating organic sources like FYM and VC, along with biofertilizers, may be attributed to improved soil health and nutrient availability, which could have facilitated better K uptake (Bhattacharyya and Jha, 2016).

Effect of treatments on Nutrient Uptake (kg ha^{-1}) by grain of paddy

Nitrogen uptake (kg ha^{-1})

During first year, significantly higher nitrogen uptake (111.64 kg ha^{-1}) was recorded in T_8 (150% RDN through AS + DCD @ 5%), which was remained at par with T_2, T_{13}, T_{12}, T_7, T_6, T_{10} and T_{11} (Table 3). Significantly the lowest uptake (61.64 kg ha^{-1}) was observed in the absolute control (T_1), which was significantly inferior to all other treatments. The trend remained consistent in 2023. T_8 again recorded significantly higher nitrogen uptake (109.95 kg ha^{-1}), were statistically at par with T_{13} (105.68 kg ha^{-1}), T_2 (106.07 kg ha^{-1}) and T_{12} (104.41 kg ha^{-1}). Significantly lowest uptake was again found in the control (56.38 kg ha^{-1}). The pooled data also revealed statistically significant differences among treatments. T_8 recorded significantly higher nitrogen uptake (110.80 kg ha^{-1}), which remained at par with T_{13}, T_{12}, T_7 and T_6. Control (T_1) continued to show the lowest uptake (59.01 kg ha^{-1}), significantly lower than all other treatments. The superior performance of T_8 (150% RDN with DCD) can be attributed to both the increased availability of nitrogen and reduced losses due to volatilization or leaching, a known benefit of nitrification inhibitors (Aulakh *et al*., 2001). Due to enhanced microbial nitrogen fixation and phosphorus solubilization, which enhance nutrient availability and uptake, the use of Bio NP liquid biofertilizer further enhanced performance in T_6-T_7 and their corresponding combinations with DCD (T_{12}-T_{13}) (Meena *et al.*, 2013; Tilak *et al*., 2005).

Phosphorus uptake (kg ha^{-1})

Significantly higher uptake was noted under T_{13} (75% RDN through AS + 25% RDN via VC + seedling dip with Bio NP + DCD), which recorded 28.21 kg ha^{-1} in the first year (Table 3). This was statistically remained at par with all the treatments except T_1 (absolute control), T_3 (100% RDN) and T_9 (100% RDN + DCD). On the lower end, the control (T_1) recorded the least phosphorus uptake (15.61 kg ha^{-1}), significantly lowest than all nutrient-enriched treatments. During the second year, T_{13} again recorded significantly higher phosphorus uptake (27.75 kg ha^{-1}), than most of the treatments. This was statistically remained at par with all the treatments except T_1, T_3 and T_9. The control treatment (T_1) remained significantly lowest performer (14.47 kg ha^{-1}). Upon averaging across both years, significantly higher mean phosphorus uptake was recorded under T_{13} (27.98 kg ha^{-1}), closely followed by T_{12} (27.80 kg ha^{-1}) and T_7 (27.10 kg ha^{-1}). These remained at par with T_2, T_{13}, T_{12}, T_7, T_6, T_{11} and T_{10}. On the contrary, T_1 recorded significantly lowest uptake (15.04 kg ha^{-1}), then all nutrient-enriched treatments.

The potential of INM strategies is shown by the improved phosphorus uptake seen in treatments T_{13}, T_{12}, T_7, and T_6, particularly when combined with DCD and biofertilizers. The synergy between organic amendments and microbial inoculants like Bio NP, which typically

Table 3 : Effect of treatments on nutrients uptake (kg ha^{-1}) by grain of paddy.

Tr. no.		N (%)			P (%)			K (%)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1		61.64^{d}	56.38^{c}	59.01^{f}	15.61^{d}	14.47^{d}	15.04^{e}	13.44	12.46	12.95^{d}
T_2		108.10^{ab}	106.07^{ab}	107.08^{ab}	25.78^{abc}	25.24^{abc}	25.51^{abc}	18.32	17.81	18.07^{abc}
T_3		87.28^{c}	84.72^{b}	86.00^{e}	22.31^{c}	21.82^{c}	22.07^{d}	15.83	15.33	15.58^{c}
T_4		92.49^{bc}	89.56^{ab}	91.03^{cde}	25.03^{abc}	24.30^{abc}	24.67^{bcd}	17.10	16.67	16.88^{abc}
T_5		94.16^{abc}	90.83^{ab}	92.49^{bcde}	25.47^{abc}	24.60^{abc}	25.03^{abc}	17.42	16.84	17.13^{abc}
T_6		101.68^{abc}	99.51^{ab}	100.60^{abcd}	27.15^{ab}	26.46^{ab}	26.80^{ab}	18.80	18.33	18.57^{abc}
T_7		103.47^{abc}	99.39^{ab}	101.43^{abcd}	27.54^{a}	26.66^{ab}	27.10^{ab}	18.95	18.50	18.72^{ab}
T_8		111.64^{a}	109.95^{a}	110.80^{a}	26.37^{abc}	26.01^{abc}	26.19^{ab}	18.86	18.49	18.67^{ab}
T_9		90.82^{bc}	87.85^{ab}	89.33^{de}	22.91^{bc}	22.41^{bc}	22.66^{cd}	16.31	15.73	16.02^{bc}
T_{10}		97.48^{abc}	94.04^{ab}	95.76^{abcde}	26.13^{abc}	25.60^{abc}	25.87^{ab}	18.05	17.61	17.83^{abc}
T_{11}		99.15^{abc}	96.11^{ab}	97.63^{abcde}	26.41^{abc}	25.72^{abc}	26.07^{ab}	18.25	17.53	17.89^{abc}
T_{12}		105.88^{ab}	104.41^{ab}	105.14^{abc}	27.91^{a}	27.69^{a}	27.80^{a}	19.48	18.99	19.23^{a}
T_{13}		107.23^{ab}	105.68^{ab}	106.46^{ab}	28.21^{a}	27.75^{a}	27.98^{a}	19.64	19.29	19.47^{a}
S. Em. ±	T	5.34	7.10	4.44	1.33	1.25	0.91	1.19	1.39	0.92
	Y	-	-	2.09	-	-	0.43	-	-	0.43
	T × Y	-	-	6.28	-	-	1.29	-	-	1.30
CD (P = 0.05)	T	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	NS	Sig.
	Y	-	-	NS	-	-	NS	-	-	NS
	T × Y	-	-	NS	-	-	NS	-	-	NS
CV (%)		9.53	13.05	11.38	9.19	8.83	9.02	11.67	14.03	12.87

Note: Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

consists of phosphorus-solubilizing bacteria (e.g., *Bacillus* and *Pseudomonas* species), can improve phosphorus availability in the rhizosphere by mineralizing insoluble phosphates (Sharma *et al*., 2013). This explains the superior uptake performance in biofertilizer-treated plots. Additionally, using DCD probably decreased nitrogen losses, which helped improve root growth and phosphorus uptake. The findings of Subbarao *et al*. (2006), who emphasized the advantages of nitrification inhibitors in lowering nitrogen loss and enhancing overall nutrient use efficiency, lend support to this.

Potassium uptake (kg ha^{-1})

The pooled data over two years showed that potassium uptake by paddy grain ranged from 12.95 kg ha^{-1} in T_1 to 19.47 kg ha^{-1} in T_{13}. The significantly higher K uptake was observed in T_{13}, which remained at par with all the treatments except T_1, T_3, and T_9. As a nitrification inhibitor (T_{12} and T_{13}), DCD probably decreased nitrogen loss, improving NUE and allowing the plant to absorb more potassium (Singh *et al*., 2019). By improving soil structure and nutrient retention, FYM and VC might increase potassium availability and uptake (Rani *et al*., 2020). Additionally, microbial formulations such as Bio NP may assist increased K absorption by improving nutrient mobilization through biological mechanisms (Thakur *et al*., 2021; Rao *et al*., 2018).

Effect of treatments on Nutrient Uptake (kg ha^{-1}) by straw of paddy

Nitrogen uptake (kg ha^{-1})

In the first year, significantly higher uptake (61.89 kg ha^{-1}) was recorded in T_8 (150% RDN via AS along with DCD), which remained at par with T_2, T_{13}, T_{12}, T_7, T_6, T_{11} and T_{10} (Table 4). Significantly lowest nitrogen uptake (35.71 kg ha^{-1}) was observed in the untreated control (T_1). The trend in the second year closely mirrored the previous season. Treatment T_8 again recorded significantly higher uptake (59.73 kg ha^{-1}), remained at par with T_2, T_{13}, T_{12}, T_7, T_6, T_{11} and T_{10}. Control treatment T_1, with a

Table 4 : Effect of treatments on nutrients uptake (kg ha^{-1}) by straw of paddy.

Tr. no.		N (%)			P (%)			K (%)		
		2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1		35.71^{d}	31.78^{d}	33.75^{e}	8.21^{c}	6.91^{c}	7.56^{f}	57.00	50.14^{d}	53.57^{d}
T_2		60.44^{ab}	59.38^{a}	59.91^{ab}	15.40^{ab}	14.92^{ab}	15.16^{abcde}	77.35	74.09^{abc}	75.72^{abc}
T_3		48.77^{c}	47.50^{c}	48.13^{d}	13.18^{b}	12.84^{b}	13.01^{e}	65.09	62.72^{cd}	63.90^{c}
T_4		51.64^{bc}	50.39^{abc}	51.02^{cd}	14.30^{ab}	13.98^{ab}	14.14^{cde}	72.93	69.65^{abc}	71.29^{abc}
T_5		52.13^{bc}	50.54^{abc}	51.34^{cd}	14.82^{ab}	14.35^{ab}	14.58^{bcde}	74.20	69.83^{abc}	72.02^{abc}
T_6		57.21^{abc}	55.99^{abc}	56.60^{abc}	16.04^{ab}	15.67^{a}	15.86^{abc}	80.25	77.38^{abc}	78.81^{ab}
T_7		57.72^{abc}	56.27^{abc}	56.99^{abc}	16.63^{ab}	15.92^{a}	16.27^{abc}	82.25	80.12^{ab}	81.18^{a}
T_8		61.89^{a}	59.73^{a}	60.81^{a}	15.81^{ab}	15.07^{ab}	15.44^{abcd}	79.12	74.76^{abc}	76.94^{ab}
T_9		51.26^{bc}	48.85^{bc}	50.06^{d}	13.72^{ab}	12.89^{b}	13.30^{de}	69.18	64.09^{bcd}	66.64^{bc}
T_{10}		54.17^{abc}	52.69^{abc}	53.43^{bcd}	15.18^{ab}	14.58^{ab}	14.88^{abcde}	76.75	73.81^{abc}	75.28^{abc}
T_{11}		54.75^{abc}	52.84^{abc}	53.79^{bcd}	15.57^{ab}	14.90^{ab}	15.24^{abcd}	77.96	74.20^{abc}	76.08^{abc}
T_{12}		59.52^{ab}	58.04^{ab}	58.78^{ab}	16.75^{ab}	16.26^{a}	16.51^{ab}	84.71	81.88^{a}	83.29^{a}
T_{13}		60.20^{ab}	58.93^{a}	59.56^{ab}	17.26^{a}	16.51^{a}	16.88^{a}	85.44	83.51^{a}	84.48^{a}
S. Em. ±	T	2.72	2.79	1.95	1.07	0.81	0.67	5.86	5.06	3.87
	Y	-	-	0.92	-	-	0.32	-	-	1.82
	T × Y	-	-	2.76	-	-	0.95	-	-	5.47
CD (P = 0.05)	T	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	Sig.	Sig.
	Y	-	-	NS	-	-	NS	-	-	NS
	T × Y	-	-	NS	-	-	NS	-	-	NS
CV (%)		8.68	9.21	8.95	12.48	9.92	11.33	13.43	12.17	12.85

Note: Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

value of 31.78 kg ha^{-1}, recorded significantly lowest nitrogen uptake. The superiority of T_8, in both years and in pooled data, demonstrates the benefit of higher N dosage along with the application of DCD, known to reduce nitrogen losses through leaching and volatilization, thereby extending nitrogen availability in the soil (Subbarao *et al*., 2006). These tactics are consistent with research by Pathak *et al*. (2002) and Ramakrishna *et al*. (2007), which showed that nitrification suppression can greatly increase rice ecosystems' nitrogen use efficiency (NUE).

Phosphorus uptake (kg ha^{-1})

Significantly lowest uptake (8.21 kg ha^{-1}) was recorded in the absolute control (T_1), while significantly higher P uptake (17.26 kg ha^{-1}) was observed in T_{13}, which remained statistically at par with all the treatments except T_1, T_3 and T_9 during 2022 (Table 4). Treatment T_{13} again showed significantly higher phosphorus uptake (16.51 kg ha^{-1}), which was at par with all treatments except T_1, T_3, T_4 and T_9 during 2023. The absolute control (T_1) recorded significantly lowest uptake (6.91 kg ha^{-1}), than all other treatments. The pooled analysis further corroborated the trend observed in individual years. The treatment T_{13} registered the highest P uptake (16.88 kg ha^{-1}), which was significantly at par with T_2, T_6, T_7, T_{11}, T_{12} and T_{13}. Control (T_1) recorded significantly lowest pooled phosphorus uptake (7.56 kg ha^{-1}), then all other treatments.

This improvement is attributable to the increased phosphate solubilization and microbial activity brought about by the use of biofertilizer (Reddy *et al.*, 2020). In addition to adding to the nutrient pool, organic additions like FYM and VC also improve soil structure, microbial biomass and enzyme activity all of which increase the availability of phosphorus (Sharma *et al*., 2019). By reducing nitrogen losses and maintaining a more synchronized nutrient availability throughout crop growth, the addition of the DCD to treatments such as T_{13} and

T_{12} may have indirectly improved phosphorus uptake (Shamsuzzaman *et al*., 2017; Subbarao *et al*., 2013).

Potassium uptake (kg ha^{-1})

In the second year, treatment T_{13} recorded significantly higher K uptake which remained at par with all the treatments except T_1, T_3 and T_9, while significantly lowest was again observed under the control. Across both years, the potassium uptake ranged from 53.57 kg ha^{-1} (T_1) to 84.48 kg ha^{-1} (T_{13}). Treatment T_{13} noted significantly higher K uptake by straw of paddy and at par with T_{12}, T_7, T_6, T_{11} and T_{10}. Significantly lowest K uptake was recorded in absolute control (T_1). The simultaneous benefits of increased biological activity from the organic amendments and biofertilizers and better nutrient retention from the nitrification inhibitor are responsible for T_{12} and T_{13} excellent performance. These findings are consistent with those of Rao *et al.* (2018) and Mishra *et al*. (2018), who noted that the use of biofertilizers enhances nutrient absorption and lowers leaching losses.

Conclusion

This studied demonstrates the efficacy of integrated nitrogen management (INM) in conjunction with nitrification inhibitors in promoting the sustainability of wetland rice cultivation in terms of nutrients content and uptake. The synergistic application of organic, inorganic nitrogen sources and biofertilizer coupled with nitrification-suppressing agents, resulted in marked nutrient assimilation. These outcomes highlight the potential of INM as an effective strategy for maximizing nitrogen utilization, boosting plant composition productivity, and minimizing the ecological footprint of rice farming. This approach offers a resilient and environmentally responsible alternative to conventional nitrogen fertilization, aligning with the principles of climate-smart and sustainable agriculture.

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