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RESIDUAL EFFECT OF NUTRIENT MANAGEMENT IN RICE ON GROWTH OF POPCORN (*ZEA MAYS L. VAR. EVERTA*) IN A RICE–POPCORN CROPPING SEQUENCE

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ABSTRACT:
A two-year field experiment was conducted during 2024-25 and 2025-26 at the Agronomy Main Research Farm, Odisha University of Agriculture and Technology, Bhubaneswar to examine the effect of nutrient management in kharif rice and fertility levels on growth of rabi popcorn (cv. BPCH 6). The experiment was laid out in a split-plot design with three replications. Four nutrient management practices to rice were assigned to main plots (T1: 100% soil test based fertilizer (STBF); T2: 75% STBF + FYM + neem cake + Azospirillum + PSB; T3: 50% STBF + FYM + neem cake + Azospirillum + PSB; T4: FYM + neem cake + Azospirillum + PSB) and five fertility levels to popcorn (F1 – 0:0:0, F2 – 40:20:20, F3 – 80:40:40, F4 – 120:60:60 and F5 – 160:80:80 kg N:P_2O_5:K_2O ha-1) as sub-plots. Plant height, leaf area index (LAI) and dry matter accumulation were significantly influenced by both the factors. Pooled over two years, popcorn grown after T2 recorded the tallest plants at 90 days after sowing (DAS) (185.3 cm), the highest LAI at 75 DAS (4.48) and the highest dry matter accumulation at harvest (994.5 g m^{-2}). Application of 160:80:80 kg N:P_2O_5:K_2O ha-1 (F5) produced the tallest plants (205.8 cm) and the highest dry matter at harvest (1028.5 g m^{-2}), which were 47.4 and 19.2 per cent higher than the unfertilized control plots. The interaction effect was significant for plant height and dry matter and T2F5 recorded the tallest plants at 90 DAS (224.6 cm) and the highest dry matter at 60 DAS (659.8 g m^{-2}) and at harvest (1042.3 g m^{-2}). Rice provided with 75% STBF and organic sources along with 120:60:60 to 160:80:80 kg N:P_2O_5:K_2O ha-1 to popcorn, therefore supported vigorous growth of popcorn in the rice–popcorn sequence.

KEYWORDS: Popcorn, residual effect, integrated nutrient management, fertility level, plant height, leaf area index, dry matter accumulation

INTRODUCTION

Rice (Oryza sativa L.) based cropping systems dominate the irrigated and rainfed lowlands of India and rice–rice, rice–wheat and rice–maize are the major sequences in these areas. Rice–maize systems are emerging as a viable and remunerative option across South Asia because maize fits well into the post-rainy season and makes efficient use of residual soil moisture. However, the gap between attainable and actual yield of maize in these systems still varies from 25

to 50 per cent, which indicates considerable scope for improving crop management (Ahirwar & Khan, 2019). Rice–maize systems already occupy about 3.5 Mha in Asia, including 1.5 Mha in South Asia. The potential yields of the system are as high as 15 t ha^{-1} for rice and 22 t ha^{-1} for maize, but high-yielding maize removes large quantity of nutrients, which makes integrated nutrient management essential for sustaining it (Timsina et al., 2010).

Popcorn (Zea mays L. var. everta) is a special type of maize with a hard, moisture-sealed hull that expands into a fluffy, edible flake on heating. In India, maize is used mainly as poultry feed, animal feed and food in various forms and popcorn enjoys wide acceptance as a snack (Meena et al., 2012). Popcorn is rich in dietary fibre and antioxidants, low in calories and fat, sugar-free and a good source of thiamine, manganese and magnesium (Iqbal et al., 2020). Popcorn nevertheless remains one of the less explored crops in India and is cultivated mainly in Madhya Pradesh, Maharashtra, Rajasthan, Karnataka and Andhra Pradesh. Kernel size and popping expansion volume determine its commercial value (De Oliveira et al., 2020), whereas information on scientific crop management is still scarce (Jele et al., 2014).

Under Odisha conditions, popcorn can be grown during rabi after harvest of kharif rice, which offers farmers an additional source of income from the same land. As both rice and popcorn are exhaustive cereals, continuous cropping with chemical fertilizers alone may not sustain soil fertility and crop productivity. Integrated nutrient management with combination of inorganic fertilizers, organic manures and biofertilizers; is therefore a more sustainable option. Integrated nutrient management has also improved soil fertility, productivity and economics of maize-based sequences, including rice–maize systems (Chandravanshi et al., 2014; Maruthupandi & Jayanthi, 2017). In a sequential cropping system, the nutrient sources applied to the first crop influence the second crop as well. Organic manures such as FYM and neem cake release nutrients slowly and biofertilizers such as Azospirillum and PSB improve the availability of nitrogen and phosphorus in the soil. Part of the benefit of these inputs applied to rice is therefore expected to remain available to the succeeding popcorn. Such a carry-over has been demonstrated in rice-based sequences. Blackgram grown in rice fallows yielded 1118 and 1210 kg ha^{-1} in two years where the preceding rice had received 50% RDN + 25% N through FYM + 25% N through neem cake + Azospirillum + PSB, compared with 917 and 1096 kg ha^{-1} after rice fertilized with 100% RDN alone (Latha et al., 2020). At the same time, popcorn responds markedly to the fertility level applied directly to it (Meena et al., 2017) and its productivity and quality are also influenced by the source of nutrients (Meena et al., 2016). In the mid hills of Nepal, plant height and leaf area index of popcorn increased with nitrogen up to 175 kg N ha^{-1}, while the highest grain yield (4.97 t ha^{-1}) was obtained at 150 kg N ha^{-1} (Regmi et al., 2024). Yet most growers manage popcorn in the same way as other maize types, without a specific nutrient recommendation (Dada et al., 2023).

Growth parameters such as plant height, leaf area and dry matter accumulation determine the source capacity of the crop and form the basis of yield. Leaf area index is a measure of the photosynthetic surface available to the crop (Watson, 1952) and the dry matter produced by this surface is later partitioned to the grain. Inorganic nutrients have been reported to improve the source–sink relationship of popcorn through greater plant height and dry matter accumulation (Iqbal et al., 2020). The present investigation was undertaken to evaluate the residual effect of nutrient management in rice and the direct effect of fertility levels on the growth of popcorn in a rice–popcorn sequence under the East and South Eastern Coastal Plain agro-climatic zone of Odisha.

MATERIALS AND METHODS

The field experiment was conducted for two consecutive years (kharif rice followed by rabi popcorn during 2024-25 and 2025-26) at the Agronomy Main Research Farm, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India. The soil of the experimental site was sandy loam with pH 6.00, EC 1.239 dS m-1, organic carbon 0.73% (medium), available N 290.56 kg ha-1 (medium), available P 21.19 kg ha^{-1} (low) and available K 113.59 kg ha-1 (low). Available N was estimated by the alkaline permanganate method (Sahrawat & Burford, 1982), available P by Olsen's method and available K by neutral normal ammonium acetate extraction followed by flame photometry (Sparks, 1996). The experiment was laid out in a split-plot design with three replications. The main plots comprised four nutrient management practices applied to rice T1: 100% soil test based fertilizer (STBF); T2: 75% STBF + FYM + neem cake + Azospirillum + PSB; T3: 50% STBF + FYM + neem cake + Azospirillum + PSB; T4: FYM + neem cake + Azospirillum + PSB. Wherever included, FYM was applied at 5 t ha-1, neem cake at 250 kg ha-1 and Azospirillum and PSB at 5 kg ha-1 each. The sub-plots comprised five fertility levels applied to popcorn: F1 – 0:0:0, F2 – 40:20:20, F3 – 80:40:40, F4 – 120:60:60 and F5 – 160:80:80 kg N:P_2O_5:K_2O ha-1, each with FYM at 5 t ha-1. Popcorn was therefore influenced by the residual effect of the main-plot treatments and the direct effect of the sub-plot treatments. Rice variety Mahendragiri was transplanted at 20 cm × 15 cm and popcorn hybrid BPCH 6 was sown at 60 cm × 20 cm. Plant height, leaf area index (LAI) and dry matter accumulation of popcorn were recorded at 15-day intervals from 15 days after sowing (DAS) to harvest.

RESULTS AND DISCUSSION

Plant height

Plant height of popcorn was significantly influenced by the residual effect of rice nutrient management and by the fertility levels at both stages in both years and in the pooled analysis (Table 1). At 45 DAS, popcorn grown after T2 recorded the tallest plants (86.9 cm), which were on par with T1 (84.8 cm). T4 produced significantly the shortest plants (73.2 cm). At 90 DAS, T2 again recorded the maximum plant height (185.3 cm), on par with T3 (181.8 cm) and significantly taller than T1 (172.4 cm). Popcorn plant height after T2 were 25.1 per cent taller than after the purely organic T4 (148.1 cm). Plant height increased with each increment in fertility level. At 45 DAS, F5 (102.4 cm) was on par with F4 (98.3 cm), while F2 (63.2 cm) and F1 (60.1 cm) did not differ significantly. By 90 DAS, F5 recorded the tallest plants (205.8 cm), 47.4 per cent taller than the unfertilized F1 (139.6 cm) (Fig. 1a). The interaction between rice nutrient management and fertility levels was significant in the pooled analysis at both stages and at 90 DAS in 2024-25 (Table 2). At 45 DAS, T1F5 recorded

the tallest plants (116.6 cm), significantly taller than all other combinations, while T4F1 recorded the shortest (54.1 cm). At 90 DAS, T2F5 produced the tallest plants (224.6 cm), which were on par with T3F5 (221.3 cm), T3F4 (209.9 cm), T1F5 (209.3 cm) and T2F4 (208.2 cm). The shortest plants were recorded under T1F1 (132.3 cm) and T4F2 (132.7 cm). Popcorn after T4 responded only weakly to fertility (132.7 to 167.9 cm at 90 DAS), whereas after T1, T2 and T3 plant height increased sharply up to F5.

Table 1. Residual effect of rice nutrient management and effect of fertility levels on plant height (cm) of popcorn

Treatment	45 DAS			90 DAS		
	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
Residual effect of rice nutrient management						
T_1	84.1	85.5	84.8	173.0	171.8	172.4
T_2	86.1	87.7	86.9	186.8	183.8	185.3
T_3	83.4	82.1	82.7	183.6	179.9	181.8
T_4	73.6	72.9	73.2	153.0	143.3	148.1
SE(m)±	1.60	2.12	1.33	1.95	6.07	3.19
CD (P = 0.05)	5.54	7.35	4.10	6.76	21.01	9.83
Fertility levels to popcorn						
F_1	60.3	59.9	60.1	143.6	135.7	139.6
F_2	62.6	63.8	63.2	153.5	151.7	152.6
F_3	86.4	84.8	85.6	170.6	169.4	170.0
F_4	97.0	99.6	98.3	192.9	190.0	191.5
F_5	102.5	102.3	102.4	209.9	201.7	205.8
SE(m)±	2.09	3.21	1.92	3.19	6.11	3.45
CD (P = 0.05)	6.03	9.24	5.41	9.20	17.60	9.74

Table 2. Interaction effect of residual rice nutrient management and fertility levels on plant height (cm) of popcorn (pooled over two years)

Treatment	**45 DAS**					**90 DAS**				
	F_1	F_2	F_3	F_4	F_5	F_1	F_2	F_3	F_4	F_5
T_1	60.6	62.0	86.0	98.9	116.6	132.3	153.9	175.2	191.1	209.3
T_2	66.0	65.1	96.8	103.6	102.9	146.5	166.5	180.8	208.2	224.6
T_3	59.6	70.2	80.4	103.4	99.9	142.9	157.4	177.4	209.9	221.3
T_4	54.1	55.5	79.2	87.3	90.2	136.8	132.7	146.7	156.7	167.9
SE(m)± (F at same T)	3.83					6.90				
CD (P = 0.05)	10.82					19.48				
SE(m)± (T at same or different F)	3.68					6.94				
CD (P = 0.05)	10.51					19.99				

Leaf area index

Leaf area index (LAI) increased up to 75 DAS, when the crop reached its peak leaf area and declined thereafter owing to the senescence of the lower leaves. The residual effect of rice nutrient management was significant at both stages, except at 75 DAS in 2025 (Table 3). In the pooled analysis, popcorn after T2 recorded significantly the highest LAI at 45 DAS

(3.31) and 75 DAS (4.48). T3 (3.14 and 4.33) was on par with T1 (3.02 and 4.26), whereas T4 recorded the lowest LAI (2.99 and 4.20). The fertility levels had a significant effect on LAI at both stages in both years. At 45 DAS, each fertility level differed significantly from the next and LAI ranged from 2.32 under F1 to 3.88 under F5 in the pooled data. At the peak stage (75 DAS), F5 recorded the highest LAI (4.97), which was on par with F4 (4.87) and 48.4 per cent higher than F1 (3.35) (Fig. 1b). The interaction was not significant at either stage.

Table 3. Residual effect of rice nutrient management and effect of fertility levels on leaf area index of popcorn

Treatment	45 DAS			75 DAS		
	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
Residual effect of rice nutrient management						
T_1	3.26	2.79	3.02	4.27	4.25	4.26
T_2	3.65	2.97	3.31	4.53	4.43	4.48
T_3	3.50	2.78	3.14	4.31	4.34	4.33
T_4	3.28	2.69	2.99	4.23	4.16	4.20
SE(m)±	0.065	0.053	0.042	0.062	0.057	0.042
CD (P = 0.05)	0.223	0.183	0.129	0.214	NS	0.130
Fertility levels to popcorn						
F_1	2.59	2.06	2.32	3.48	3.22	3.35
F_2	3.02	2.43	2.72	3.94	3.76	3.85
F_3	3.34	2.80	3.07	4.59	4.50	4.55
F_4	3.94	3.22	3.58	4.83	4.91	4.87
F_5	4.23	3.53	3.88	4.84	5.09	4.97
SE(m)±	0.093	0.065	0.057	0.102	0.104	0.073
CD (P = 0.05)	0.266	0.189	0.160	0.294	0.299	0.206

Dry matter accumulation

Dry matter accumulation was significantly influenced by both factors at 60 DAS and at harvest in both years and in the pooled analysis (Table 4). In the pooled data, popcorn grown after T_2 accumulated significantly the highest dry matter at 60 DAS (567.8 g m^{-2}) and at harvest (994.5 g m^{-2}). T3 and T4 were on par with each other at both stages, while popcorn after T1 recorded the lowest dry matter (491.9 and 922.9 g m^{-2}). At harvest, T2 accumulated 7.8 per cent more dry matter than T1. Dry matter increased significantly with fertility level. At 60 DAS, every level differed significantly from the next and F_5 recorded the highest dry matter (604.6 g m^{-2}). At harvest, F5 (1028.5 g m^{-2}) remained significantly superior to F4 (1001.8 g m^{-2}), which was on par with F3 (980.6 g m^{-2}). F5 accumulated 19.2 per cent more dry matter than the unfertilized F1 (862.9 g m^{-2}) (Fig. 1c). The year × fertility level interaction was significant at harvest, as the response to fertility was larger in 2024-25 (843.7 to 1047.2 g m^{-2}) than in 2025-26 (882.2 to 1009.7 g m^{-2}). The interaction between rice nutrient management and fertility levels was significant at 60 DAS in both years and at harvest in 2025-26 and in the pooled analysis (Table 5). At 60 DAS, T2F5 recorded the highest dry matter (659.8 g m^{-2}), which was on par only with T2F4 (624.7 g m^{-2}), while T1F1 recorded the lowest (446.4 g m^{-2}). At harvest, T2F5 (1042.3 g m^{-2}) and T3F5 (1042.0 g m^{-2}) recorded the highest dry matter and were statistically comparable with T2F4, T4F4, T4F5, T2F3, T4F3 and T1F5. T4F1 recorded the lowest dry matter (832.9 g m^{-2}). With adequate fertility, the residual differences among the rice treatments narrowed, whereas under low fertility the integrated treatments maintained a clear advantage.

Table 4. Residual effect of rice nutrient management and effect of fertility levels on dry matter accumulation (g m^{-2}) of popcorn

Treatment	60 DAS			Harvest		
	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
Residual effect of rice nutrient management						
T_1	498.19	485.69	491.94	922.61	923.26	922.94
T_2	572.56	562.96	567.76	987.13	1001.91	994.52
T_3	537.96	546.39	542.17	950.47	949.15	949.81
T_4	532.48	541.93	537.20	963.15	963.43	963.29
SE(m)±	6.28	6.61	4.56	9.35	13.60	8.25
CD (P = 0.05)	21.73	22.87	14.05	32.36	47.07	25.43
Fertility levels to popcorn						
F_1	467.69	474.29	470.99	843.65	882.16	862.91
F_2	494.97	498.00	496.49	884.73	944.09	914.41
F_3	528.80	527.79	528.29	981.61	979.65	980.63
F_4	578.35	568.54	573.45	1021.99	981.54	1001.77
F_5	606.65	602.60	604.62	1047.22	1009.74	1028.48
SE(m)±	9.77	7.91	6.29	11.46	9.77	7.53
CD (P = 0.05)	28.15	22.79	17.76	33.00	28.15	21.27

Table 5. Interaction effect of residual rice nutrient management and fertility levels on dry matter accumulation (g m^{-2}) of popcorn (pooled over two years)

Treatment	60 DAS					Harvest				
	F_1	F_2	F_3	F_4	F_5	F_1	F_2	F_3	F_4	F_5
T_1	446.4	465.1	498.1	505.5	544.6	852.4	880.6	914.5	966.5	1000.8
T_2	481.8	538.6	533.9	624.7	659.8	920.5	961.6	1014.7	1033.6	1042.3
T_3	492.7	517.3	522.3	573.4	605.1	845.9	902.0	984.5	974.6	1042.0
T_4	463.1	464.9	558.9	590.1	609.1	832.9	913.5	1008.8	1032.4	1028.8
SE(m)± (F at same T)	12.57					15.06				
CD (P = 0.05)	35.52					42.55				
SE(m)± (T at same or different F)	12.13					15.80				
CD (P = 0.05)	34.72					45.73				

Fig. 1. Effect of fertility levels on (a) plant height at 90 DAS, (b) leaf area index at 75 DAS and (c) dry matter accumulation at harvest of popcorn (pooled over 2024-25 and 2025-26). Bars show means ± SE(m).

The better growth of popcorn after T2 and T3 can be attributed to the residual benefit of FYM, neem cake and biofertilizers applied to the preceding rice. These sources improve soil organic carbon, aggregation and moisture retention and release nutrients slowly (Alluvione et al., 2013; Ghosh et al., 2020; Li et al., 2013), so more nutrients remained available to the succeeding popcorn. The biofertilizers would have further enhanced this benefit as Azospirillum promotes plant growth not only through biological nitrogen fixation but also through the production of plant hormones, improved root growth and better uptake of water and minerals (Bashan & de-Bashan, 2010). Phosphate solubilizing bacteria release organic acids and phosphatases that convert insoluble soil phosphorus into forms available to plants (Rodríguez & Fraga, 1999). Integrated nutrient management has also been shown to increase soil microbial biomass carbon and dehydrogenase activity over conventional chemical fertilization (Paramesh et al., 2023), which favours nutrient cycling for the following crop. A similar residual advantage of integrated nitrogen management in rice was reported for the succeeding rice-fallow blackgram (Latha et al., 2020). Popcorn after the purely organic T_4 had the shortest plants, which suggests that organic sources alone could not meet the early nutrient demand of the preceding rice and left less residual fertility. Similar superiority of integrated over sole chemical or sole organic nutrient sources for growth of maize has been reported earlier (Bal & Chhatwal, 2022; Ewais et al., 2015; Kaur et al., 2023; Walia & Patidar, 2021). The increase in plant height, LAI and dry matter with fertility level reflects the direct role of N, P and K in cell division, leaf expansion and photosynthesis. A larger leaf area under F_4 and F_5 intercepted more radiation, which in turn increased dry matter accumulation. This agrees with the improvement in plant height and dry matter of popcorn under higher inorganic nutrient supply reported earlier (Iqbal et al., 2020; Meena et al., 2017). Regmi et al. (2024) likewise recorded a continuous increase in plant height and leaf area index of popcorn with nitrogen up to 175 kg N ha^{-1}. In rabi maize in Odisha, Sairam et al. (2024) obtained the highest leaf area index and dry matter accumulation with 200:60:60 kg N:P_2O_5:K_2O ha^{-1} and found dry matter to be closely related to leaf area index (R^2 = 0.69 to 0.86), which supports the link between leaf area and dry matter observed in the present study. LAI at F4 and F5 was on par, which indicates that 120:60:60 kg N:P_2O_5:K_2O ha^{-1} was sufficient to reach near-maximum leaf area, while the additional dose mainly added to stem growth and dry matter at later stages. The significant interaction for plant height and dry matter shows that the two factors did not act independently. Under low fertility levels, popcorn depended more on the nutrients left by the preceding rice, so the integrated treatments T_2 and T_3 maintained a clear advantage. At higher fertility levels, fertilizer applied directly to popcorn met most of its needs, narrowing the residual differences among the rice treatments. Popcorn after T_4 responded only weakly to fertility, suggesting that factors beyond the current nutrient supply, such as poorer early growth, limited its response.

CONCLUSION

Both the residual effect of nutrient management in kharif rice and the fertility levels applied to rabi popcorn significantly influenced the growth of popcorn. Integrated nutrient management in rice with 75% STBF + FYM + neem cake + Azospirillum + PSB (T_2) left the most favourable residual effect for plant height, LAI and dry matter accumulation. Growth improved consistently with fertility level and 120:60:60 to 160:80:80 kg N:P_2O_5:K_2O ha^{-1} produced the most vigorous crop. The combination T_2F_5 recorded the tallest plants at 90 DAS and the highest dry matter accumulation. Integrated nutrient management in rice followed by 120:60:60 to 160:80:80 kg N:P_2O_5:K_2O ha^{-1} to popcorn can therefore be suggested for vigorous growth of popcorn in the rice–popcorn sequence.

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