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RESEARCH ARTICLE

Effect of organic manures and silicon nutrition on the productivity and profitability of rice

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Abstract

Field experiments were conducted in 2022 and 2023 during the *Kharif* season at experimental farm, Department of Agronomy, Annamalai University, Tamil Nadu, India to study the effect of organic manures and silicon nutrition on the productivity and profitability of rice. The treatments included both organic manures (farmyard manure (FYM), green manure (GM), poultry manure (PM)) and recommended doses of fertilizers (RDF)). Silicon through Diatomaceous earth (DE) was tested in combination with the above nutrient sources. The treatments were arranged in randomized block design with three replications. The highest growth parameters (plant height, number of tillers hill^{-1}, leaf area index and dry matter production), yield parameters (number of panicles m^{-2}, number of filled grains panicles^{-1} and Test weight) and rice yields (grain and straw yields) were found in both seasons with RDF + GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1}. However, applying RDF + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE increased net income and benefit cost ratio in 2022 and 2023. Based on the results of two-year field experiment, it can be concluded that rice productivity and profitability can be improved through the application of RDF + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE.

Keywords: economics; growth; organic manures; rice; silicon; yield

Introduction

Rice is one of the most important food crops all over the world. Over half of the world's population depends on rice. With 60 % of the world's population native to Asia, the region produces and consumes more than 90 % of the world's rice. Since rice is vital to India's food security and supports millions of people, the slogan "rice is life" is the most appropriate. Around 14.29 Mt of India's total rice production is derived from the dry season (*rabi*) and the rest from the wet season (*kharif*) (1). Rice yields are declining due to deteriorating soil health, imbalance in fertilizer use, lack of suitable rice varieties, pest infestation, frequent floods and drought. Among these, insufficient macro and micronutrient availability has an impact on rice output and growth (2). After the green revolution, the addition of inorganic fertilizers became a common practice to improve rice production in India. However, employing chemical fertilizers alone is not a viable ecological strategy for maintaining sustainable rice production. Furthermore, organic nutrient management enhances yields and significantly impacts the physico-chemical characteristics of the soil (3). Therefore, it is imperative to include organic manures/agro industrial wastes in the nutrient management practices to get stable yield, income and to maintain health and conserve biodiversity. FYM is a commonly used organic input in India, readily available as a farm-derived waste that provides essential nutrients for agricultural practices. When FYM is applied to soil, its physical-chemical and biological qualities are enhanced. FYM is made up of both micro and macronutrients (4) and increased crop yields. PM is an inexpensive source of micronutrients (Cu, Fe, Mn, B) and macronutrients (N, P, K, Ca, S). It also exhibits a high degree of resistance to microbial breakdown and is essential for creating and maintaining an ideal soil structure, which in turn has a major effect on plant growth (5). By adding green manures, the soil's physio-chemical reactions, organic matter content, soil structure, water-holding ability, aeration, colloidal complex, permeability and infiltration capacity are all improved. It lowers soil loss from erosion and runoff while preserving the pH of the soil. The addition of green manure may have contributed organic matter and biologically fixed nitrogen to the soil, allowing nutrients to gradually and continuously enter the soil solution (6). Silicon (Si) is the second most abundant element in the Earth's surface and plays a vital role in imparting biotic, abiotic stress resistance and enhancing crop productivity (7). It is also crucial in preventing or minimizing lodging in cereal crops, a matter of great importance in agricultural productivity (8). Si is not known to be an essential element, but it is agronomically beneficial for crop growth and yield and improves crop quality, boosts plant nutrition and reduces the toxicity of heavy metals in acidic soils (9). The silicon is the only element that doesn't damage the crop even in cases of excess accumulation (10). Applying Si greatly increases rice growth and yield and reduces the incidence of rice blast and stem borer (11). Si improves the uptake of NPK in rice by making them more available in the soil. Si is supplemented to the crops through calcium silicate, potassium silicate, diatomaceous earth, fly ash and rice hull ash. Among the different sources, DE supplies more of plant available silicon to the crops. Thus, for sustained rice production, it is imperative to study the combined effect of organic manure and silicon nutrition with the necessary inorganic fertilizer dosage.

Materials and Methods

Experimental site

Field experiments were conducted during the *kharif* seasons of 2022 and 2023 at the N Block of wetland, Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India. The experimental field soil was classified as clay loam, characterized by an electrical conductivity (EC) of 0.89 dS m^{-1}, a slightly alkaline pH of 8.4 and organic carbon content of 0.52 %. The nutrient status of the soil indicated low available nitrogen (248 kg ha^{-1}), medium phosphorus (17.31 kg ha^{-1}), high potassium (310 kg ha^{-1}) and moderate levels of available silicon (68.4 kg ha^{-1}).

Climatic conditions

During the crop growth period, 1037.6 mm of rainfall was received in 2022 and 1010.6 mm in 2023. Detailed weather parameters such as temperature, humidity and pest/disease pressure can be supplemented if recorded during the study.

Experimental treatments and design

The experiment included eleven treatments combining recommended fertilizer doses, various organic manures and silicon through diatomaceous earth (DE). The treatments were:

T_1: RDF (150:50:50 kg NPK ha^{-1})

T_2: RDF + FYM @ 12.5 t ha^{-1}

T_3: RDF + GM @ 6.25 t ha^{-1}

T_4: RDF + PM @ 2 t ha^{-1}

T_5: RDF + FYM @ 12.5 t ha^{-1} + PM @ 2 t ha^{-1}

T_6: RDF + GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1}

T_7: RDF + FYM @ 12.5 t ha^{-1} + Si @ 200 kg ha^{-1} (via DE)

T_8: RDF + GM @ 6.25 t ha^{-1} + Si @ 200 kg ha^{-1} (via DE)

T_9: RDF + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} (via DE)

T_{10}: RDF + FYM @ 12.5 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} (via DE)

T_{11}: RDF + GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} (via DE)

The experiment was laid out in a Randomized Block Design (RBD) with three replications.

Nutrient and crop management

Entire P_2O_5 and Si (via DE) were applied basally. Nitrogen (N) and Potassium (K_2O) were applied in four equal splits at Basal, Active tillering, Panicle primordial initiation, Heading stage. FYM and PM were incorporated during the final ploughing. Green manure was grown and incorporated at the flowering stage before transplanting.

Crop details

The rice variety 'Sigappi', known for its medium duration and adaptability to the local agro-climatic conditions, was chosen for the study due to its favorable response to integrated nutrient management practices, especially the application of organic manures and Si supplementation. 35 - day old seedlings were transplanted in the main field at a spacing of 20 cm × 15 cm, with two seedlings per hill.

Data collection and observations

Growth attributes were recorded at critical crop stages. Yield attributes and final yields were measured at harvest. Observations were taken from a net plot size of 4.5 m × 3.5 m.

Statistical analysis

All data were subjected to statistical analysis (12). Results from both years were pooled and treatment differences were tested using analysis of variance (ANOVA).

Results and Discussion

Growth attributes

The growth attributes of rice were greatly altered by the addition of organic manures Si nutrition, both in *kharif*, 2022 and 2023 (Table 1). The higher values for plant height, number of tillers/hills, leaf area index and dry matter production of rice were observed under incorporation of GM @ 6.25 t/ha + PM @ 2 t/ha + application of Si @ 200 kg/ha through DE combined with RDF. This was comparable to T_{10}. Application of RDF + FYM @ 12.5 t /ha + PM @ 2 t/ha +Si @ 200 kg/ ha via DE (T_9) was next in order. An increase on plant height could be because of integrated nutrient management techniques made nutrients more available to crops, which in turn led to a greater conversion of carbohydrates to protein. This increased protein synthesis promotes meristematic cellular activity, such as cell division and elongation, which expresses morphologically in terms of increasing measured variables like plant height (13). The addition of organic matter that contains nitrogen improved N availability, aids in stimulating plant cells and keeps the process of photosynthesis going, all of which will have an impact on the height of the plants. Auxin and gibberellic acid, two plant hormones that are crucial for cell division and growth and eventually control the length of the shoot and give the crop stiffness, are produced mostly by nitrogen (14). Phosphorus contributed to internodel growth through cell elongation. Plant height was indirectly regulated by potassium, which maintained turgor pressure, supported stress tolerance and supported several metabolic activities within the plant system (15, 16). Application of Si gives erectness to rice plants and was effective in preventing lodging in rice by increasing the thickness of the culm and size of vascular bundles, enhancing the strength of the culm. The combined application of Si nutrition, inorganic fertilizers and organic manures had a greater impact on the number of tillers $hill^{-1}$. Tiller production, which is associated with the culm's nutritional requirements since, in the early phases, the culm supplies nutrients and carbohydrates that were augmented, is the outcome of auxiliary bud growth caused by the addition of both organic and inorganic nutrients. The nutrients N, P and K raise the soil's fertility because nitrogen helps plants by encouraging the growth of leaves, tillers and roots (17). Potassium is essential for the synthesis of carbohydrates and protein, but it also fortifies plants by promoting the growth of

Table 1. Effect of organic manures and silicon nutrition on growth attributes at different growth stages of rice (Pooled data)

Treatments	Plant height (cm)			No. of tillers $hill^{-1}$	Leaf area index		DMP (kg ha^{-1})		
	Active tillering	Flowering	Harvest		Active tillering	Flowering	Active tillering	Flowering	Harvest
T_1	36.51	62.09	81.64	12.59	4.05	4.26	3752	5623	7161
T_2	38.16	65.25	85.28	13.07	4.17	4.58	4039	5934	7680
T_3	39.27	66.78	87.56	13.23	4.31	4.69	4193	6107	7987
T_4	40.72	70.05	91.81	13.76	4.50	4.97	4447	6410	8492
T_5	43.51	73.09	95.21	14.32	4.80	5.23	4672	6674	8994
T_6	44.96	74.59	98.17	14.58	4.92	5.31	4833	6884	9117
T_7	47.20	77.71	101.72	15.17	5.10	5.57	5177	7169	9549
T_8	48.07	79.07	104.26	15.43	5.18	5.69	5320	7399	9732
T_9	50.03	81.81	107.90	15.99	5.35	5.91	5517	7692	10144
T_{10}	51.62	85.28	111.63	16.52	5.58	6.16	5715	7957	10522
T_{11}	51.78	86.57	114.32	16.70	5.62	6.23	5803	8125	10862
CD (p=0.05)	**1.44**	**2.52**	**3.25**	**0.50**	**0.14**	**0.15**	**165.76**	**252.51**	**345.99**
Sem ±	**0.60**	**1.06**	**1.37**	**0.20**	**0.06**	**0.06**	**71.24**	**105.22**	**148.36**

more tillers. Moreover, the addition of Si may have improved the mother culms' access to Si and other nutrients and raised the number of tillers $hill^{-1}$. Similar results showed by early works (18). Increased leaf area per plant may have resulted from the synergistic effects of nitrogen and phosphorus in cell division and cell elongation. Nitrogen is the fundamental component for chlorophyll, protein, cellulose and tissue formation. Better nutritional quality and a favourable nutrient balance were provided by poultry manure when combined with NPK supplements. When combined with inorganic and organic fertilizers and Si nutrients, increased availability and uptake of macro and micronutrients, as well as active participation in the processes of starch formation, translocation of protein and sugar, photosynthesis and carbohydrate assimilation, may result in increased leaf area (19). The physical and chemical quality of the soil may have been improved by applying organic manure, which would have given the crop enough nutrients to support greater growth and metabolism. This would have increased the amount of leaf area and leaves per plant. These outcomes concur with the research (20). Additionally, silicon added to rice enhanced the quantity of leaves on each plant, the leaves erectness and the amount of light intercepted by the leaves' prolonged erectness, all of which boosted canopy photosynthesis and increased the leaf area index. These outcomes concur with those of previous works (21). The crop's dry matter was positively impacted by the macronutrients' synergistic effects on root formation, vegetative growth and reproductive growth. The enhanced dry matter accumulation may be a result of the blending effect of nutrients in organic manures, which releases nutrients continuously and gradually during several stages of growth and lowers nitrogen depletion. This increases the amount of N available for rice absorption and assimilation patterns. These outcomes are in line with the previous studies (22). Specific growth metrics, such as height increases in plants, tillers, $hill^{-1}$ and LAI, may be associated with higher dry matter output. Because of the increased formation of secondary and tertiary endodermal cells, rice with Si fertilization had the longest roots and tallest shoots, indicating improved root tolerance in soils and faster root growth. It might be caused by the high photosynthetic activity, effective use of light energy, transfer of absorbed products from source to sink and decreased prevalence of illnesses and pests because of silicon treatment. These outcomes are consistent with early findings (18). Si sources significantly influenced on blast and leaf folder incidence and percent leaf damage in rice crop. Among the methods of establishment transplanted rice recorded lesser incidence and per cent leaf damage for blast and leaf folder at tillering and flowering stage when compared to wet seeded rice and dry seeded rice. This could be due to improper arrangement of plants in row, clumpy growth and intermingling of leaves may provide favourable conditions for higher incidence of leaf folder, folding of leaves and easy leaf to-leaf movement of the larvae. Si absorbed by the crop and offered higher protection against rice blast in low land condition (10, 23). Higher accumulation Si in the leaf breaks the mandibles of leaf folder when it feeds the leaves and caused functionless mandibles, therefore leaf folder dies without food. (23).

Yield attributes and yield

Addition of FYM, green manures, poultry manures and Si nutrition greatly influenced on yield attributes and yield of rice (Table 2). Among the various treatments imposed in this study, application of GM @ 6.25 t ha^{-1}+ PM @ 2 t ha^{-1}+ Si @ 200 kg ha^{-1} through DE along with RDF (T_{11}) registered higher values for no. of panicles m^{-2}, no. of filled grains $panicle^{-1}$ and the test weight of rice in both the season. However, the test weight of rice was not significantly affected by organic manures and Si application, possibly due to genetic nature of this variety. This was on par with T_{10}. This was followed by T_9. Application of T_8: RDF + GM @ 6.25 t ha^{-1}+ Si @ 200 kg ha^{-1} through DE was next in order. The above treatment recorded significantly higher grain and straw yields of 5688 and 7922 kg ha^{-1}, respectively. The increased crop yield might have resulted from the lush vegetative development brought by the application of silicon, green manure and poultry manure in addition to RDF during the crop season. This improves the translocation of the source to the reproductive sink and displays an increase in yield-attributing features. These results are confirmed by the previous works (22 - 25). Together with macronutrients (N, P and K), green manure also contains micronutrients (such as calcium, magnesium, silica, zinc and others). These nutrients support the preservation of the nutrient supply in the soil. Furthermore, green manure decreased N losses, absorbed N in the soil during the first stage of decomposition and made sure there was enough nutrition available for later stages of reproduction. This is in accordance with the previous study (26). Higher rice grain and straw yields could also have been caused by the addition of

Table 2. Effect of organic manures and silicon nutrition on yield attributes and yields of (pooled data)

Treatments	No. of panicles m^{-2}	No. of filled grains panicle^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	213	87.45	22.31	3967	5858
T_2	225	90.01	22.38	4340	6678
T_3	230	90.64	22.41	4372	6805
T_4	242	92.21	22.47	4538	7010
T_5	251	93.79	22.54	4779	7244
T_6	257	94.52	22.56	4887	7376
T_7	267	96.02	22.62	5132	7590
T_8	272	96.35	22.64	5228	7739
T_9	281	98.05	22.70	5422	7932
T_{10}	290	99.33	22.74	5593	8138
T_{11}	295	100.32	22.75	5658	8275
CD (p=0.05)	**7.66**	**1.31**	**NS**	**120**	**166.5**
Sem +	**2.60**	**0.44**	**-**	**40.82**	**56.63**

organic manures, a more aeration-friendly physical environment, increased soil moisture retention, increased root activity and improved nutrient absorption (27). Application of DE is used as a source of Si for plants. It is a good choice because of its distinct amorphous form, which increases solubility and bioavailability. DE large surface area enhances Si uptake by encouraging interaction with beneficial microbes and plant roots. Furthermore, DE provides a gradual release of Si, ensuring a steady supply for plant growth. In contrast, because of their crystalline structure, other silicon sources, such as calcium and potassium silicates, might have restricted availability and solubility. Furthermore, compared to calcium silicate, this natural form of Si is more affordable and readily available on the market as well as potalum silicate (28). The maximum grain and straw yield by reducing biotic and abiotic stress and enhancing plant growth and photosynthetic activity in rice by improving nutrient uptake of the crop. These findings are consistent with those of early results (12, 29).

Economics

The economics of rice were noticeably impacted through the application of organic manures and Si nutrition in addition to inorganic fertilizers (Table 3). GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE combined with RDF achieved greater gross income and net income of rice in both the seasons compared to other treatment combinations. The combined use of Si and organic and inorganic nutrient sources encouraged synchronization between nutrient release and crop utilisation, which enhanced crop production and helped to raise rice's gross and net income. This could be the reason for the increased yield. The higher grain yield and higher market value of the produce enhanced the gross income and net income. These outcomes were consistent with the previous research (25, 15). When comparing T_9 - RDF + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through diatomaceous earth along with RDF to GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE along with RDF, the benefit cost ratio was higher due to lesser cultivation costs. Due to lower grain and straw yields compared to other treatments, application of RDF alone recorded lesser gross income, net income and BCR in rice.

Conclusion

Based on the results of the two-year field experiment, it can be concluded that the combined application of RDF + GM @ 6.25 t ha^{-1} + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE (T11) resulted in the highest grain yield and net income. However, RDF + PM @ 2 t ha^{-1} + Si @ 200 kg ha^{-1} through DE (T9) recorded the highest benefit-cost ratio (BCR) due to lower cultivation costs. Therefore, depending on the grower's objective-whether to maximize yield or enhance economic return either treatment can be recommended. Both options represent technically feasible and environmentally sustainable strategies for improving rice productivity and profitability.

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Table 3. Effect of organic manures and silicon nutrition on economics of rice (Pooled data)

Treatments	Total cost of cultivation Rs. ha^{-1}	Gross income Rs. ha^{-1}	Net income Rs. ha^{-1}	BCR
T_1	51092	93027	41935	1.82
T_2	57742	106389	48647	1.84
T_3	55042	106565	51523	1.94
T_4	53292	109269	55977	2.05
T_5	59942	115513	55571	1.93
T_6	57242	117602	60360	2.05
T_7	66742	124066	57324	1.86
T_8	64042	125667	61625	1.96
T_9	62492	130485	67993	2.09
T_{10}	68942	134860	65918	1.96
T_{11}	66242	136415	70173	2.06

Authors' contributions

Conceptualization, data curation, writing the original draft was done by CR. SJ performed the conceptualization, supervision, funding acquisition, writing the review and editing. Writing the original draft, methodology and validation was done by CK. Writing the original draft was editing was also performed by DE. SK and DS collects the resources and visualization. Methodology, writing the review and editing was done by ES, PV and SSS. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical issues: None

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