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Impact of long-term integrated nutrient management on productivity, profitability, soil microbial activity and nutrient content of rice (*Oryza sativa*) in Assam

RISHBH KUMAR DIDAWAT[1], VINOD KUMAR SHARMA[1], D J NATH[2], SANDEEP KUMAR[3]*, ABIR DEY[1], PRAVEEN KUMAR[1], KRIPA SHANKAR[1], INDU CHOPRA[1], Y S SHIVAY[1], C M PARIHAR[1] and SHIV PRASAD[1]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

A study was carried out during 2021 to 2022 at Assam Agricultural University, Jorhat, Assam to study the effect of long-term integrated nutrient management on productivity, profitability, soil microbial activity and nutrient content of rice (*Oryza sativa* L.) in Assam. The experiment was conducted in a randomized block design (RBD) comprised of 5 nutrient management practices, viz. T_1, Absolute control; T_2, 100% recommended dose (RD) through chemical fertilizers (CF); T_3, 50% RD through CF + liquid biofertilizers; T_4, 50% RD through CF + solid biofertilizers; and T_5, 50% RD through CF + enriched compost (EC) (@1 t/ha), with 4 replications. The results showed higher grain yield and profitability in treatment T_2 (5.23 t/ha and $1472.29/ha) followed by T_5 (5.23 t/ha and $1446.29/ha), T_3 (4.90 t/ha and $1362.29/ha), T_4 (4.87 t/ha and $1346.69/ha), and the lowest in T_1 (3.21 t/ha and $897.85/ha). Notably, treatment T_5 delivered comparable yield and returns to T_2. However, treatment T_5 significantly increased the essential nutrients (N, P, K, Zn, Cu, Mn, Fe) in grain compared to T_2 or T_3/T_4. In addition, soil microbial activity such as dehydrogenase activity, phospho-monoesterase activity, microbial biomass carbon, fluorescein diacetate hydrolase, and arylsulphatase activity were significantly higher under treatment T_5. These findings highlight that treatment T_5 i.e 50% CF + EC (@1 t/ha) not only matches conventional 100% fertilizer application in yield and returns but also enhances soil microbial activity. Study highlights the potential of integrated nutrient management practices with 50% RD through CF + enriched compost (EC) (@1 t/ha) to address micronutrient deficiencies, improve crop productivity, profitability, and promote sustainable agriculture in the region.

Keywords: Enriched compost, INM, Micronutrients, North-east, Rice, Soil microbial activity

In Assam, rice (*Oryza sativa* L.) cultivation dominates agricultural lands, with three main types: Sali, Ahu, and Boro rice (Bhowmick *et al.* 2006). Covering ~2.36 million hectares during the rainy (*kharif*) and winter (*rabi*) cropping seasons, paddy occupies about 80% of the state's agricultural area (Directorate of Economics and Statistics 2021). However, continuous rice monoculture in these regions has led to productivity and profitability problems as the soil is depleted of nutrients, yields have decreased and susceptibility to pests and diseases has increased (Zhao *et al.* 2018). Malnutrition in NEH regions persists due to the dominance of rice as a staple food, which deficient in essential micronutrients, leading to anemia and health problems related to deficiencies in iron, zinc, vitamin B_{12}, vitamin A, and folate (Anand *et al*. 2014, Abbaspour *et al*. 2014, Longvah *et al.* 2021). The inefficiency of chemical fertilizers further exacerbates these challenges, with significant amounts contributing to soil imbalances and environmental pollution (Dwivedi *et al.* 2017). In response, Long-Term Integrated Nutrient Management (LTINM) is emerging as a sustainable approach, integrating organic and inorganic nutrients, crop residue management, and eco-friendly techniques to enhance soil fertility, crop yield, and ecological balance (Gogoi *et al*. 2021).

However, despite LTINM's potential, research on its effectiveness in NEH regions is limited, and requires tailored strategies. To address this gap, a study was carried out with the aim to provide insights into integrated nutrient management practices to improve productivity, profitability, soil microbial activity, and nutritional composition of rice in Assam.

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]Assam Agricultural University, Jorhat, Assam; [3]ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Jorhat, Assam. *Corresponding author email: sk0097411@gmail.com

MATERIALS AND METHODS

Experimental site: A study was carried out during from 2021 to 2022 at Assam Agricultural University, Jorhat, Assam. The long-term integrated nutrient management experiment started in 2006 at the Instructional-cum-Research (ICR) farm of Assam Agricultural University, Jorhat, Assam. Study site experiences a humid subtropical climate with hot, humid summers and mild, dry winters, receiving an average annual rainfall of 2000 mm. Soil samples collected at a depth of 0–15 cm revealed a composition of 48.23% sand, 19.07% silt and 32.70% clay, with a bulk density of 1.38 Mg/m^3. The soil has a *p*H of 5.15 and electrical conductivity of 0.35 dS/m. Organic carbon content was11.6 g/kg, while available nitrogen, phosphorus, and potassium were 215, 27.0, and 159.0 kg/ha, respectively. DTPA-extractable micronutrients include zinc (9.74 mg/kg), iron (16.67 mg/kg), manganese (2.9 mg/kg), and copper (1.79 mg/kg).

Experimental design: The experiment was laid out in a randomized block design (RBD) comprised of five treatments, viz. T_1, Absolute control; T_2, 100% recommended dose (RD) through chemical fertilizers (CF); T_3, 50% RD through CF + liquid biofertilizers; T_4, 50% RD through CF + solid biofertilizers; and T_5, 50% RD through CF + enriched compost (EC) (@1 t/ha) having 4 replications with the plot size 3 m × 4 m. The recommended dose (RD) was 60:40:20 kg/ha of N, P_2O_5, and K_2O, respectively.

Enriched compost: Rice straw and fresh biomass of azolla were used in a 10:1 (v/v) to prepare enriched compost material (ECM) in an aerobic composting facility. A 1% rock phosphate containing 19.5% P_2O_5 was thoroughly mixed into the mature compost. After three days, the enriched compost was primed with 1% (v/w) *Azospirillum* broth ($10^{-8} – 10^{-9}$ CFU/ml) and cured for 30 days. The ECM was applied 15 days before the rice transplanting. The compost had a *p*H of 7.3, an electrical conductivity of 3.7 dS/m, high organic carbon content (192 g/kg), and significant amount of nitrogen, phosphorus, and potassium. The analysis of the enriched compost revealed the following properties: a *p*H of 7.3, an electrical conductivity of 3.7 dS/m, and an organic carbon content of 19.2%. It also contains 1.7% total nitrogen, 1.15% total phosphorus, and 0.91% total potassium.

Crop establishment: The rice variety 'Ranjit' was sown in the first fortnight of June, at 20 cm × 20 cm plant spacing. Fertilizers application included urea for nitrogen (N), single superphosphate for phosphorus (P), and muriate of potash for potassium (K). The full doses of P and K were applied at the basal stage, whereas N was applied at three stages: 50, 25 and 25% at the basal, tillering, and panicle initiation, respectively. Biofertilizers *Azospirillum* and PSB (@3.5 kg/ha), applied as overnight immersion treatments for the roots of seedlings. The enriched compost was applied @1 t/ha before sowing. To ensure optimal growth and development, recommended agronomic practices were followed.

Soil analysis: Soil samples, systematically collected from 3 representative places within each experiment. The analysis of OC, *p*H, N, P, K, and micronutrients was carried out using the methodologies (Singh *et al*. 2013). For soil microbial activity, fresh samples were refrigerated at 4°C. Enzyme activities were assessed: FDA hydrolysis for fluorescein formation (Adam and Duncan 2001), DHA by TTC reduction (Casida *et al*. 1964), PMA activity using p-nitrophenyl phosphate (Tabatabi and Bremner 1969), and MBC via chloroform fumigation extraction (Nunan *et al*. 1998).

Plant analysis: For nitrogen estimation, plant samples were digested in sulfuric acid, for other nutrients, the plant samples were digested using a di-acid mixture. P, K, and micronutrients such as Fe, Zn, Cu, and Mn were measured in the resulting diluted acid digest using a spectrophotometer for the vanadomolybdate yellow colour method, a flame photometer, and atomic absorption spectroscopy, respectively (Singh *et al*. 2013).

Crop productivity and profitability: Grain yield was determined by weighing the threshed grains, and straw yield was calculated by subtracting grain yield from the total bundle weight. Straw yield was converted into tonnes per hectare (t/ha). Additionally, reported grain yield was adjusted to account for moisture content of 14%. Profitability was determined by combining rice grain and straw yield. The price paddy was fixed at 20,400 ₹/t, as per the minimum support price (MSP) of the Government of India, while the price of paddy straw at 2,000 ₹/t. The calculated values were then expressed in ($/ha), with a conversion rate of $1 = ₹83.

Statistical analysis: Data analysis and visualization were carried out in R-Studio version 4.3.2 (http://www.rstudio.com/).

RESULTS AND DISCUSSION

Productivity: The study evaluated the effects of different fertilization treatments on grain and straw yields in two consecutive years, 2021 and 2022 (Fig. 1). The absolute control (T_1) consistently yielded 3.2 t/ha for grain and 4.48 t/ha for straw. In terms of grain yield, the 100% recommended dose (T_2) resulted in significant increases, with a 65.31% improvement in 2021 and 65% in 2022 compared to the control. The treatments involving 50% of the recommended dose combined with either liquid biofertilizers (T_3) or solid biofertilizers (T_4) both led to a consistent 53.13% increase in grain yield across both years, highlighting the potential of biofertilizers to enhance yields when used alongside reduced chemical inputs. The treatment with 50% recommended dose plus enriched compost (T_5) showed a 62.5% increase in grain yield in 2021 and an even higher 68.75% increase in 2022, indicating the growing efficacy of enriched compost over time.

For straw yield, the 100% recommended dose (T_2) led to a 77.15% increase in 2021 and a 76.79% increase in 2022, further demonstrating the effectiveness of complete chemical fertilization. The 50% recommended dose treatments, combined with either liquid (T_3) or solid biofertilizers (T_4), resulted in a 64.06% increase in straw yield across both years, similar to their impact on grain yield. The 50% recommended dose plus enriched compost (T_5) treatment led to a 76.45% increase in 2021 and a notable

83.21% increase in 2022, suggesting enhanced soil health and nutrient availability with compost use.

These findings have important implications for sustainable agriculture. While the consistently high yields achieved with 100% chemical fertilizers (T_2) demonstrate their effectiveness, there are concerns regarding micronutrient imbalances and long-term sustainability. The significant yield improvements observed with enriched compost (T_5), particularly in 2022, suggest it as a viable alternative or supplement to chemical fertilizers, promoting a more sustainable nutrient management strategy. Integrating organic sources, such as enriched compost, can improve nutrient availability and soil health. Studies by Gruhn *et al*. (2000), Shukla *et al*. (2014), Kumar *et al*. (2019), and Tyagi *et al*. (2022) have shown that enriched compost enhances yields, microbial activity, and nutrient absorption. The synergy between organic and inorganic fertilizers underscores the importance of balanced nutrient supply for sustainable agriculture, as supported by research from Nath *et al*. (2011), Gogoi *et al*. (2013), and Patra *et al*. (2020).

Soil microbial activity: The study demonstrated significant increases in soil microbial activity in response to various nutrient management treatments, as evidenced by enhanced enzymatic activities (Fig. 2). Key indicators of microbial activity, such as dehydrogenase, phosphomonoesterase, microbial biomass carbon, fluorescein diacetate hydrolase, and arylsulphatase showed notable improvements compared to the control, with an increase ranging from approximately 15.88–73.52%.

Dehydrogenase activity (DHA): This is a critical measure of microbial activity, reflecting the capability of micro-organisms to catalyze redox reactions. Higher DHA levels are indicative of improved soil health and enhanced nutrient cycling. The treatments exhibited varying increases in DHA compared to the control, with T_2 (100% RD through fertilizers) showing an increase of about 15.88%, T_3 (50% RD with liquid biofertilizers) a 40.00% increase, T_4 (50% RD with solid biofertilizers) a 42.35% increase, and T_5 (50% RD with enriched compost) a substantial 57.06% increase (170 µg TPF g/soil/day).

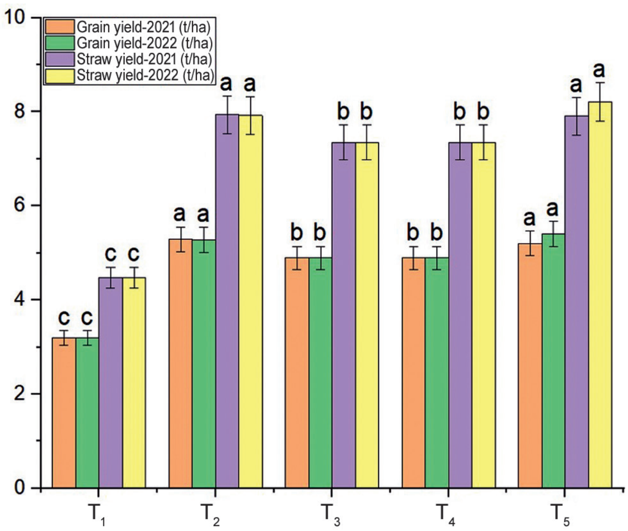

Fig. 1 Effect of integrated nutrient management practices on grain yield in rice.

Treatment details are given under Materials and Methods.

Phosphomonoesterase activity (PMA): This enzyme reflects the microbial ability to hydrolyze organic phosphorus compounds, serving as an indicator of soil fertility and phosphorus cycling. The treatments resulted in significant increase with T_2 showing a 14.61% increase, T_3 a 46.12% increase, T_4 a 49.32% increase, and T_5 a significant 73.52% increase (219 µg p-nitrophenol/g/day).

Microbial biomass carbon (MBC): MBC quantifies the carbon content in living microbial biomass, with higher levels indicating increased microbial activity and nutrient availability. T_2 showed a 15.63% increase, T_3 a 43.75% increase, T_4 a 49.38% increase, and T_5 a 56.25% increase compared to the control (160 µg C g/soil).

Fluorescein diacetate hydrolase (FDA): This enzyme measures microbial activity by assessing the hydrolysis of fluorescein diacetate, with elevated levels indicating active microbial breakdown of organic compounds. T_2 exhibited a 6.36% increase, T_3 a 13.33% increase, T_4 a 17.88% increase, and T_5 a 25.76% increase compared to the control.

Arylsulphatase activity (ASA): ASA evaluates the microbial ability to hydrolyze arylsulfate esters, reflecting sulfur mineralization activity. Higher ASA is associated with improved sulfur transformation. T_2 showed a 7.81% increase, T_3 a 13.75% increase, T_4 a 17.81% increase, and T_5 a substantial 26.56% increase as compared to the control (320 µg p-nitrophenol/g/day). The enhanced microbial properties observed under T_5 (50% RD with enriched compost) can be attributed to the increased organic material in the soil, which provides a food source for microbes. Additionally, enriched compost supplies essential nutrients, further boosting enzymatic activities (Nath *et al*. 2011, 2012, Gogoi *et al*. 2013, Patra *et al*. 2020). The results clearly showed that both T_3 and T_4 outperform T_2 in improving microbial activity and soil health. The use of biofertilizers, whether liquid or solid, offers a more sustainable and effective approach to nutrient management. These treatments not only improve enzymatic activities, but also support a more diverse and active microbial community, which is essential for long-term soil fertility and plant productivity.

Nutrient content: The prevalence of anaemia and related diseases resulting from micronutrient deficiencies in staple crops such as rice, has led to targeted efforts to enhance grain micronutrient content. Results of this study revealed that micronutrient concentrations are higher in rice straw compared to husk and grain, with iron (Fe) being the most abundant followed by zinc (Zn), manganese (Mn), and copper (Cu) (Table 1, 2). The average micronutrient content in rice grain and straw is notably lower than in straw. Various treatments, including fertilizers and enriched compost, significantly increase micronutrient levels compared to controls. For instance, 100% recommended dose (RD) fertilizers raise micronutrient content by approximately 6.34–11.75%. In comparison, combinations like 50% RD

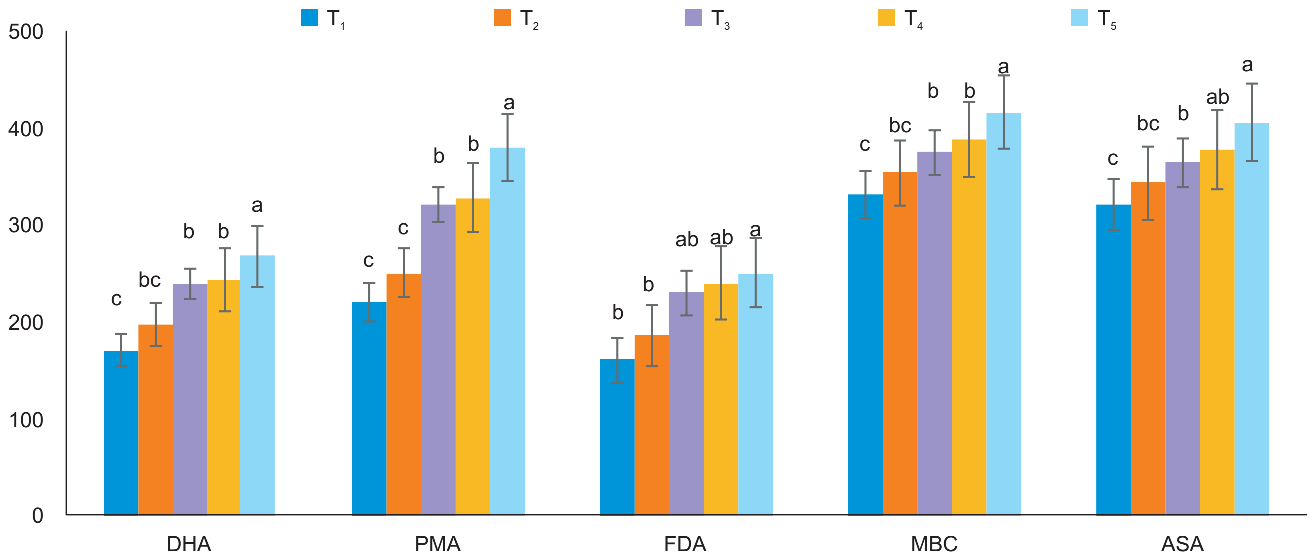

Fig. 2 Effect of integrated nutrient management practices on soil microbial activity in rice.

DHA, Dehydrogenase activity (µg TPF/g soil/day); PMA, Phospho-monoesterase activity (µg p-nitrophenol/g/day); MBC, Microbial biomass carbon (µg C/g soil); FDA, Fluorescein diacetate hydrolase (µg fluorescein/g/day); ASA, Arylsulphatase activity (µg p-nitrophenol/g/day).

Treatment details are given under Materials and Methods.

fertilizers with liquid or solid biofertilizers (BF) or enriched compost (@1 t/ha) exhibit more substantial increases, up to 28.24% for Mn, 23.70% for Fe, 21.39% for Zn, and a remarkable 96.68% for Cu. Notably, 50% RD fertilizers combined with enriched compost surpass 100% RD fertilizers in enhancing micronutrient content, increasing 15.71–76.02%. Moreover, this approach enhances N, P and K concentrations in grains and straw, with the order of NPK being N>K>P in grains and K>N>P in straw. The enriched compost's organic matter acts as a nutrient reservoir, enabling gradual release aligned with crop growth stages, ensuring sustained nutrient supply. This slow-release mechanism harmonizes with the concept of optimizing nutrient release rates for prolonged plant nutrient availability, as highlighted in prior studies (Nath *et al*. 2011, 2012, Gogoi *et al*. 2013, Didawat *et al*. 2022).

Gross return: The highest gross yields were observed in treatment T_5 (₹123,670) in which 50% RD of fertilizers was implemented in combination with enriched compost (EC) at 1 t/ha. This treatment also had a relatively high

Table 1 Effect of integrated nutrient management practices on N, P, K and Cu content of paddy

Treatment	N concentration (%)		P concentration (%)		K concentration (%)		Cu concentration (mg/kg)		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Husk	Straw
Control	1.56^{b}	0.45^{c}	0.24^{b}	0.22^{c}	0.25^{b}	1.62^{c}	2.50^{c}	6.52^{c}	8.21^{c}
100% CF	1.68^{a}	0.54^{a}	0.39^{a}	0.27^{a}	0.36^{ab}	1.82^{b}	2.80^{c}	6.82^{c}	8.55^{c}
50% CF + Liquid BF	1.64^{ab}	0.51^{b}	0.37^{ab}	0.25^{ab}	0.35^{b}	1.77^{ab}	3.45^{b}	7.42^{b}	9.13^{b}
50% CF + Solid BF	1.65^{ab}	0.51^{b}	0.37^{ab}	0.25^{ab}	0.32^{b}	1.75^{ab}	3.59^{b}	7.58^{b}	9.28^{b}
50% CF + EC (@1 t/ha)	1.67^{a}	0.54^{a}	0.40^{a}	0.27^{a}	0.38^{a}	1.83^{a}	4.93^{a}	8.90^{a}	10.51^{a}

CF, Chemical fertilizer; BF, Biofertilizer; EC, Enriched component.
Treatment details are given under Materials and Methods.

Table 2 Effect of integrated nutrient management practices on Zn, Fe and Mn content of paddy

Treatments	Zn concentration (mg/kg)			Fe concentration (mg/kg)			Mn concentration (mg/kg)		
	Grain	Husk	Straw	Grain	Husk	Straw	Grain	Husk	Straw
Control	13.63^{c}	40.90^{c}	54.52^{b}	14.04^{c}	42.48^{c}	144.52^{c}	10.25^{c}	21.24^{c}	46.62^{c}
100% NPK CF	14.28^{c}	41.00^{b}	55.82^{ab}	14.69^{c}	43.13^{bc}	145.82^{c}	10.90^{c}	21.56^{b}	47.92^{c}
50% CF + Liquid BF	15.16^{b}	42.27^{ab}	57.42^{ab}	15.57^{b}	43.85^{b}	157.42^{b}	11.78^{b}	21.92^{ab}	59.52^{b}
50% CF + Solid BF	15.33^{b}	42.87^{ab}	57.58^{ab}	15.74^{b}	44.45^{b}	157.58^{b}	11.95^{b}	22.22^{ab}	59.68^{b}
50% CF + EC (@1 t/ha)	16.52^{a}	45.37^{a}	60.90^{a}	15.93^{a}	46.95^{a}	160.90^{a}	13.14^{a}	23.48^{a}	63.00^{a}

CF, Chemical fertilizer; BF, Biofertilizer; EC, Enriched component.
Treatment details are given under Materials and Methods.

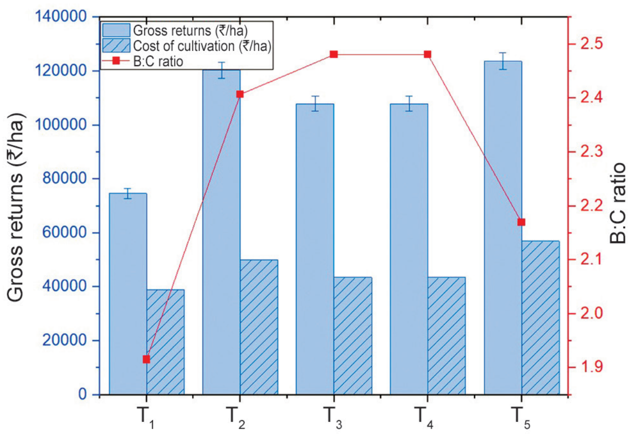

Fig. 3 Effect of integrated nutrient management practices on gross returns in rice.
Treatment details are given under Materials and Methods.

benefit-cost ratio (B:C) of 2.17, indicating favourable economic returns, although the cultivation cost (₹57,600) is higher as compared to other treatments. Treatment T_2, which followed 100% RD of fertilizers (CF), yielded gross yield of ₹120,350 and incurred cultivation cost of ₹50,530. Although this approach had highest ratio of 2.40, the highest of all treatments, it implies a purely chemical approach and may not be as sustainable in the long term given environmental factors.

The 50% RD fertilizer treatments combined with liquid (T_3) and solid biofertilizers (T_4) both resulted in equal gross yields of ₹107,900 and identical B:C ratios of 2.48, reflecting their cultivation cost of ₹43,500. These treatments demonstrate the effectiveness of integrating biofertilizers with reduced chemical inputs to achieve not only high yields but also cost effectiveness (Fig. 3). The Absolute Control (T_1) had the lowest gross return (₹74,700) and a relatively lower B:C ratio of 1.91, but also the lowest cultivation cost (₹39,000), which was expected since no fertilizers or amendments were used. The 100% RD of fertilizers resulted in high B:C ratio. The integration of reduced chemical inputs with organic inputs such as enriched compost or biofertilizers not only provided comparable economic returns but could also result in improved microbial activity and nutrient uptake of crops. These integrative approaches, evidenced by high B:C ratios in treatments T_3, T_4, and T_5, support the notion that sustainable agricultural practices can be both economically viable and environmentally sustainable.

The study showed that integrated nutrient management methods, particularly those using enriched compost and biofertilizers, significantly increased rice grain yield, soil microbial activity, micronutrient content and economic returns compared to conventional chemical fertilizers. While 100% chemical fertilizers initially increased yields, combining 50% recommended fertilizer dose with enriched compost resulted in comparable improvements, especially in the second year. This approach supports long-term soil health and nutrient cycling while increasing micronutrient content and maintaining economic viability. The results encourage the adoption of INM practices for sustainable agriculture that integrate organic and inorganic fertilizers to optimize productivity and environmental sustainability.

REFERENCES

Abbaspour N, Hurrell R and Kelishadi R. 2014. Review on iron and its importance for human health. *Journal of Research in Medical Sciences* **19**(2): 164.

Adam G and Duncan H. 2001. Development of a sensitive and rapid method for the measurement of total microbial activity using fluorescein diacetate (FDA) in a range of soils. *Soil Biology and Biochemistry* **33**: 943–51.

Anand T, Rahi M, Sharma P and Ingle G K. 2014. Issues in prevention of iron deficiency anaemia in India. *Nutrition* **30**(7–8): 764–70.

Bhowmick C B, Barah C B and Borthakur N. 2006. Changing pattern of agriculture in Assam with special reference to rice production system. *Changing Agricultural Scenario in North-East India, Concept* **2006**: 240–68.

Casida L, Klein D and Santoro T. 1964. Soil dehydrogenase activity. *Soil Science* **98**(6): 371–76.

Didawat R K, Sharma V, Kumar S, Chobhe K, Bandyopadhyay K, Kumar P, Kumar S, Yadav S P, Roy A and Gangwar K. 2022. Effect of long-term organic practices on yield and nutrients uptake by rice (*Oryza sativa* L.) in an acid Inceptisol. *Annals of Plant and Soil Research* **24**(4): 547–51.

Directorate of Economics and Statistics. 2021. *Statistical Handbook Assam.* Directorate of Economics and Statistics, Govt. of Assam, Guwahati, India.

Dwivedi B S, Singh V K, Shekhawat K, Meena M C and Dey A. 2017. Enhancing use efficiency of phosphorus and potassium under different cropping systems of India. *Indian Journal of Fertilizers* **13**(8): 20–41.

Gogoi B, Borah N, Baishya A, Nath D J, Dutta S, Das R, Bhattacharyya D, Sharma K K, Valente D and Petrosillo I. 2021. Enhancing soil ecosystem services through sustainable integrated nutrient management in double rice-cropping system of north-east India. *Ecological Indicators* **132**: 108262.

Gogoi D, Nath D J and Borah D K. 2013. Augmentation of the fertilizer values of compost through beneficial microbes amid rock phosphate amendments during curing stage. *Indian Journal of Agricultural Research* **47**(4): 304–10.

Gruhn P, Goletti F and Yudelman M. 2000. Integrated nutrient management, soil fertility, and sustainable agriculture: Current issues and future challenges. *International Food Policy Research Institute.*

Kumar R, Kumar R and Prakash O. 2019. Chapter-5 the impact of chemical fertilizers on our environment and ecosystem. *Chief Ed* **35**(69): 1173–89.

Longvah T, Mangthya K, Subhash K, Sen S and Rathi S. 2021. Comprehensive nutritional evaluation of popular rice varieties of Assam, north-east India. *Journal of Food Composition and Analysis* **101**:103952.

Nath D J, Ozah B, Baruah R, Barooah R C and Borah D K. 2011. Effect of integrated nutrient management on soil enzymes, microbial biomass carbon and bacterial populations under rice (*Oryza sativa*)-wheat (*Triticum aestivum*) sequence. *The Indian Journal of Agricultural Sciences* **81**(12): 1143.

Nath D J, Ozah B, Baruah R, Barooah R C, Borah D K and Gupta M. 2012. Soil enzymes and microbial biomass carbon under rice-toria sequence as influenced by nutrient management. *Journal of the Indian Society of Soil Science* **60**(1): 20–24.

Nunan N, Morgan M A and Herlihy M. 1998. Ultraviolet absorbance (280 nm) of compounds released from soil during chloroform fumigation as an estimate of the microbial biomass. *Soil Biology and Biochemistry* **30**(12): 1599–1603.

Patra A, Sharma V K, Purakayastha T J, Barman M, Kumar S, Chobhe K A, Chakraborty D, Nath D J and Anil A S. 2020. Effect of long-term integrated nutrient management (INM) practices on soil nutrients availability and enzymatic activity under acidic Inceptisol of north-eastern region of India. *Communications in Soil Science and Plant Analysis* **51**(9): 1137–49.

Shukla A K, Tiwari P K and Prakash C. 2014. Micronutrients deficiencies *vis-a-vis* food and nutritional security of India. *Indian Journal of Fertilizers* **10**(12): 94–112.

Singh D, Chhonkar P K and Dwivedi B S. 2013. Manual on soil, plant and water analysis. Westville Publishing House **155**.

Tabatabai M A and Bremner J M. 1969. Use of *p*-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochem*istry **1**: 301–07.

Tyagi J, Ahmad S and Malik M. 2022. Nitrogenous fertilizers: Impact on environment sustainability, mitigation strategies, and challenges. *International Journal of Environmental Science and Technology* **19**(11): 11649–72.

Zhao Q, Xiong W, Xing Y, Sun Y, Lin X and Dong Y. 2018. Long-term coffee monoculture alters soil chemical properties and microbial communities. *Scientific Report* **8**: 6116.