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Effect of liming and nutrient management on productivity and profitability of maize (*Zea mays* L.) in the Northeast region of India

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Abstract

India's main cereal crop, maize (*Zea mays* L.), is limited in its yield by acidic soils and inadequate fertilizer management, especially in the Northeast region. In order to assess the impact of liming and integrated nutrient management (INM) on maize growth, yield, and economics in acidic environments, a field experiment was carried out at the ICAR–IARI in Assam during the 2024 *kharif* season. Three levels of lime (Control, 250 kg ha^{-1}, and 300 kg ha^{-1} based on soil test (ST)) and five nutrient management treatments (Control, 100% recommended dose of fertilizer (RDF), 50% RDF combined with 50% recommended dose of nitrogen (RDN) from farmyard manure (FYM), 50% RDF combined with 50%RDN from vermicompost (VC) and 50% RDF combined with 50% RDN from poultry manure (PM)) were used in the experiment, which was conducted using a split-plot design. Among the different levels of lime, liming at 300 kg ha^{-1} considerably increased growth parameters, such as plant height, leaf area index (LAI), dry matter accumulation (DMA), grain yield (4.43 t ha^{-1}), stover yield (8.6 t ha^{-1}), and biological yield (13.03 t ha^{-1}) in comparison to the control and 250 kg ha^{-1} of lime. Among nutrient management treatments, 50% RDF + 50% RDN (PM) showed highest plant height, LAI,DMA, grain yield (4.55 t ha^{-1}), stover yield (8.59 t ha^{-1}), and biological yield (13.14 tha^{-1}) compared to other treatments. Lime at 300 kg ha^{-1} improved gross returns (105,738 ₹ ha^{-1}), net returns (69,030₹ha^{-1}), and the net B:C ratio (1.90) in comparison to the control, but it also marginally raised cultivation costs (36,708 ₹ha^{-1}). Nutrient management treatments were more profitable; the maximum gross returns (108,200 ₹ ha), net returns (72,673 ₹ha^{-1}) and net B:C ratio (2.04) were obtained with 50% RDF + 50% RDN (PM).

Key words: Acidic soil, FYM, lime, nutrient management, poultry manure, vermicompost

Introduction

Maize (*Zea mays* L.) is Often referred to as the Queen of Cereals. It is a prominent crop in the *Poaceae* family of grasses and ranks third in the world behind rice and wheat. Approximately 1,200 million metric tons (MT) were produced globally in 2023–2024, with America and Asia accounting for 49.1% and 32.5% of total output, respectively (FAOSTAT, 2024). India produces about 3% of the world's maize, with 11 million hectares yielding 36 million MT (GOI, 2024). Together, the top five states that produce maize—Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Uttar Pradesh—account for 57% of the nation's total production. Maize generates more than 2% of the entire value of crop output, sustains the livelihood of around 15 million Indian farmers, and creates over 650 million person-days of employ-

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ment yearly. Maize is a C4 day-neutral crop that can grow in a variety of seasons, has a high potential yield, and uses less water. It is utilized for food, feed, and fodder. While food-grade maize depends on traditional cultivars, hybrid maize currently occupies 65–70% of the land, primarily for feed and industry (USDA FAS, 2023; ICAR-IIMR, 2022). India's maize production is still below the global average, despite its potential (FAOSTAT, 2024), highlighting the need for improved crop and soil management.

Maize needs a balanced supply of nutrients because it is a nutrient-intensive crop. Although chemical fertilizers have traditionally increased yields, overuse of them has weakened soil quality. It has been demonstrated that INM, which blends inorganic fertilizers, biofertilizers, and organic manures, maintains productivity while enhancing soil quality (Kumar *et al*., 2016; Gundlur *et al*., 2015). Although the climate and soils in Assam are conductive to maize cultivation, the cropped area (1.04 lakh ha) and productivity (5.14 t ha^{-1})(ICAR-IIMR, 2022). Although maize is primarily farmed for food, the growth of commercial livestock production is driving up demand for fodder and poultry feed. However, productivity is constrained by soil fertility issues. Soil acidity results from heavy rainfall that leaches vital base cations like calcium and potassium. Thus, it is crucial to implement efficient soil management techniques such as liming and INM (ICAR-IIMR, 2022). Almost half of the world's arable land is affected by the global issue of soil acidity. In Assam, about 4.7 million ha (59.4%) of soils are acidic, constraining crop growth through *aluminum* (Al) and manganese (Mn) toxicity, phosphorus (P) fixation, and suppression of microbial activity (Borgohain *et al.,* 2020*)*.

The most advised method for reducing soil acidity is liming. Lime increases soil pH, decreases Al and Mn toxicity, and improves microbial activity and nutrient availability by neutralizing hydrogen ions. In comparison to control fields, Meghalaya's maize production improved by 32% after 300 kg ha^{-1} of lime was applied in furrows (Sharma *et al*., 2005). Lime also decreases fixation with Al and Fe oxides, increasing phosphorus availability. The synergistic effects of organic and inorganic nutrient sources were demonstrated by the fact that lime enhanced maize yields by 147% when paired with approved NPK and by up to 291% when FYM was added (Sharma *et al*., 2005). Productivity is further increased by integrated nutrition management. Lime application (500 kg ha^{-1}) combined with 50% suggested NPK and 1 t ha^{-1} vermicompost increased maize production to 4.17 t ha^{-1} in the Ri-Bhoi area of Meghalaya, as opposed to 2.31 t ha^{-1} under conventional practice (Bordoloi, 2020). By raising the soil pH from 4.45 to 5.12 and its organic carbon content by 130%, this treatment also increased soil fertility. In addition to neutralizing acidity, lime and INM promote the breakdown of organic waste, releasing phosphate and nitrogen.

Therefore, inadequate nutrient management and soil acidity are the main factors limiting maize output in Northeast India. Lime can greatly increase yields and improve soil health when combined with balanced organic and inorganic nutrient sources, according to evidence. However, there are still few systematic studies assessing lime and nutrient combinations in Assam, which emphasizes the need for more study to create sustainable farming practices for maize in the region's acidic soils.

Materials and Methods

The field experiment was conducted during the *kharif* season of 2024 at the Experimental Farm of the ICAR–Indian Agricultural Research Institute (IARI), Assam, India, with the objective of evaluating the effect of liming and integrated nutrient management on maize productivity and soil health under acidic soils. The site is located at a latitude of 27°242 N and a longitude of 94°202 E, with an elevation of 72.53 meters above mean sea level, and falls under a humid subtropical climate. The initial soil was sandy loam in texture, comprising 68.96% sand, 12.74% silt, and 18.3% clay, with a bulk density of 1.31 g cm^{-3}. The soil reaction was strongly acidic with pH 5.02 and low electrical conductivity (0.12 dS m^{-1}), while organic carbon content was high (1.14%). Available nitrogen (201.6 kg ha^{-1}) waslow, and phosphorus (21.23 kg ha^{-1}) was medium, whereas available potassium (125.8 kg ha^{-1}) was in the medium range. The experiment was laid out in a split-plot design with three replications, where liming consisted the 3 main plot factors and nutrient management consisted the 5 subplot factors. A total of 45 plots were maintained, each of 20 m² size (5 m × 4 m). The maize hybrid 'HQPM-5' was used at a spacing of 60 cm × 20 cm. The recommended fertilizer dose for maize was 80:60:40 kg N, P_2O_5, and K_2O per hectare, respectively, applied as basal and top-dressing. In liming treatments, T_1 was the control without lime, T_2 involved lime application at 250 kg ha^{-1}, and T_3 was soil test-based liming at 300 kg ha^{-1}, calculated using the formulas ΔpH × buffer factor × 1000, where ΔpH was 0.20 and the buffer factor was considered 1.5 t ha^{-1} per pH unit. Nutrient management practices consisted of five treatments: S_1, absolute control without nutrient addition; S_2, 100% RDF through fertilizers; S_3, 50% RDF combined with 50% recommended nitrogen (RDN) supplied through FYM; S_4, 50% RDF with 50% RDN from VC; and S_5, 50% RDF with 50% RDN from PM). In all integrated treatments, organics were incorporated one week before sowing, and fertilizers were applied as per the treatment plan. For RDF and integrated treatments, a full dose of phosphorus and potassium along with half of nitrogen was applied basally, while the remaining half of nitrogen was top-dressed at the knee-high stage of the crop. The experiment thus combined liming with different nutrient management practices to assess their interactive influence on maize growth, yield, and soil properties under acidic soil conditions prevalent in Northeast India.

Other agronomic practices such as weed management, irrigation, and pest control were kept uniform across all treatments. Observations on crop growth parameters, including plant height, dry matter accumulation (DMA), leaf area index (LAI), and yield, were recorded using standard methods. Soil samples were analyzed for available nitrogen, phosphorus, and potassium using established procedures (Subbiah and Asija, 1956; Bray and Kurtz; Jackson, 1973). The experimental data were subjected to statistical analysis through analysis of variance (ANOVA) using OPSTAT software. For each parameter, the standard error of the mean (S.Em±) and the least significant difference (LSD) at a 5% probability level were calculated, and treatment means were compared accordingly.The amount of fertilizer applied to each subplot is detailed in Table 1.

Table 1. The fertilizer application for each treatment

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
N_1 Control	0	0	0
$N_2$100%RDF	80	60	40
N_3 50% RDF	40	30	20
N_4 50% RDF	40	30	20
N_5 50% RDF	40	30	20

Results and Discussion

Growth attributes

Plant height, LAI and DMA were significantly affected at all growth stages due to application of lime and INM levels (Table 2). The maximum plant heights across all growth phases were achieved with 300 kg of lime per hectare. At 30 DAS, the plant had grown to a height of 47.8 cm, 15.5% higher than the control (41.4 cm) and weighing more than 250 kg of lime per hectare. The plant height at 60 DAS with 300 kg of lime per hectare was 181.6 cm, a 4.4% increase over the control (174.0 cm) and a little increase over 250 kg of lime per hectare. The plants reach a height of 187.7 cm at harvest, when the ideal lime dosage was 300 kg ha^{-1} and higher than the control. As a result, growth was steady throughout the crop season with the optimum dosage of lime. These outcomes are consistent with the findings of Kumar (2014). Kumar *et al*. (2012) also emphasized the role of liming, alone or with nitrogen management, in enhancing maize plant height. Similarly, Kavya *et al*. (2024) observed that lime application in acidic alfisols of Karnataka markedly improved plant height, LAI, and dry matter accumulation due to better calcium and magnesium availability.

Among nutrient management levels, the tallest plants were found when 50% RDF (NPK) + 50% RDN from PM were applied together. These plants grew to 50.7 cm at 30 DAS, 190.0 cm at 60 DAS, and 196.6 cm at 90 DAS, respectively. Comparisons with the control showed increases in plant height of 27.7% at 30 DAS, 12.8% at 60 DAS, and 12.7% at 90 DAS (39.7, 168.5, and 174.5 cm, respectively). The results unequivocally demonstrate that the combination of comprehensive nutrition management and proper liming greatly enhances plant growth at all developmental stages. These outcomes are consistent with the findings of Patil *et al*. (2024) reported that liming, when combined with FYM and NPK, significantly enhanced maize–wheat productivity and soil health in Jharkhand by raising pH and reducing exchangeable acidity.

The synergistic supply of nutrients under INM, particularly from poultry manure, enriched the soil with nitrogen, phosphorus, and potassium, which enhanced root development and nutrient uptake efficiency. Nitrogen promoted cell division and elongation, contributing to taller plants and greater leaf expansion. A larger canopy facilitated higher photosynthetic rates, crop growth rate (CGR), and relative growth rate (RGR), leading to sustained biomass accumulation. These favourable outcomes under integrated lime and nutrient management are consistent with the findings of Suthar *et al*. (2014), Choudhary *et al*. (2014), and Kumar (2009). Collectively, the results emphasize that the combined use of lime and INM significantly improves growth attributes of maize under acidic soil conditions.

Yield

In the present investigation, most yield attributes and overall yield, i.e., yield components and grain yield, were superior in lime-applied treatments compared to the control (Figure 1). The application of soil test-based liming at 300 kg ha^{-1} resulted in significantly higher grain yield (4.43 t ha^{-1}), stover yield (8.60 t ha^{-1}), and biological yield (13.03 t ha^{-1}) than the liming at 250 kg ha^{-1} and control. These findings agree with Majhi *et al*. (2024). Liming in acidic soils improved soil moisture retention, nutrient availability, and uptake, along with better soil structure, which contributed to higher stover yield and among yield components, 1000-grain weight and grains per cob were crucial, as they directly influence productivity. Liming enhanced microbial activity, enzyme functions, and photosynthetic efficiency by increasing soil pH, which also improved hormone activity and nutrient cycling (Kavya *et al*., 2024).

Integrated Nutrient Management led to a gradual increase in grain output, stover yield, and biological yield as well as a rise in nutrient levels (Figure 1). By applying 50% RDF (NPK) + 50% RDN (PM), the highest grain yield (4.55 t ha^{-1}) was attained. The grain yield increased by 3.41, 7.31, 10.44, and 16.67 percent when 50% RDF (NPK) + 50% RDN (PM) was used instead of 50% RDF (NPK) + 50% RDN (VC), 50% RDF (NPK) + 50% RDN (FYM), 100% RDF, and control. Figure 1 show that the application of 50% RDF (NPK) in conjunction with 50% RDN (PM) produced the highest stover yield (8.59 t ha^{-1}) and biological yield (13.14 t ha^{-1}). The stover and biological yields were 9.15% and 11.53% higher, respectively, than the control, since multiple yield components affect grain yield, the treatment's notable increase in grain yield (80:60:40 kg N, P_2O_5, K_2O kg/ha) can be explained. The balanced and consistent fertilizer supply from both organic and inorganic sources, which increased soil fertility, stimulated vigorous vegetative growth in the early stages,

Table 2. Effect of liming and integrated nutrient management levels on plant height at different stages

Treatment	Plant height (cm) 30 DAS	60 DAS	At harvest (90 DAS)
Liming			
Control	41.4	174.0	180.1
Lime at 250 kg ha^{-1}	44.7	179.1	185.5
Liming based on ST (300 kg ha^{-1})	47.8	181.6	187.7
S.Em±	1.18	0.93	0.99
LSD ($P \leq 0.05$)	4.63	3.65	3.88
Integrated nutrient management levels			
Control	39.7	168.5	174.5
RDF	42.1	172.9	178.8
50% RDF (NPK) + 50% RDN (FYM)	44.1	177.2	183.3
50% RDF (NPK) + 50% RDN (VC)	46.7	182.5	188.8
50% RDF (NPK) + 50% RDN (PM)	50.7	190.0	196.6
S.Em±	1.17	2.53	2.55
LSD ($P \leq 0.05$)	3.42	7.37	7.44

and improved nutrient-use efficiency, is responsible for the superior performance. These improvements were primarily due to soil acidity correction, which enhanced nutrient uptake, optimized root growth, and promoted biomass accumulation, resulting in better grain formation, heavier cobs, and higher maize yield (Quaggio *et al*., 1991; Pfülb *et al*., 2025; Kibet *et al*., 2023; Ao and Sharma, 2020). These improvements are attributed to the balanced and sustained supply of nutrients from both organic and inorganic sources, enhancing soil fertility, nutrient-use efficiency, and vegetative growth, which in turn increased dry matter accumulation, LAI, and photosynthetic efficiency (Sairam *et al*., 2024).

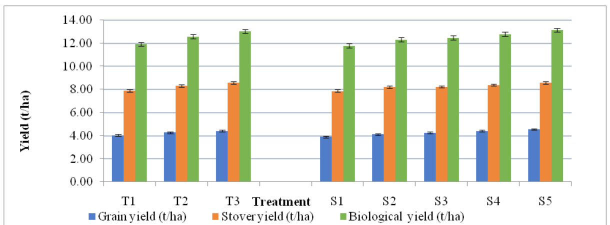

Fig. 1. Effect of liming and integrated nutrient management levels on maize grain yield, stover yield, and biological yield (t ha^{-1})

(T_1 was the control without lime, T_2 involved lime application at 250 kg ha^{-1}, and T_3 was soil test-based liming at 300 kg ha^{-1}, S_1, absolute control without nutrient addition; S_2, 100% RDF through fertilizers; S_3, 50% RDF combined with 50% recommended nitrogen (RDN) supplied through FYM; S_4, 50% RDF with 50% RDN from VC; and S_5, 50% RDF with 50% RDN from PM)

Economics

In the present investigation (Table 3), applying lime at 300 kg ha^{-1} slightly increased the cost of cultivation to 36,708 ₹ha^{-1} compared to 250 kg ha^{-1} (36,458₹ha^{-1}) and control (35,126₹ha^{-1}). However, it substantially enhanced economic returns, with gross returns of 105,738₹ha^{-1}, net returns of 69,030₹ha^{-1}, and a B:C ratio of 1.896, outperforming control and lower lime levels. Liming at this rate increased gross returns by 9.7%, net returns by 12.7%, and improved the B:C ratio by 7.5%, demonstrating that the increased productivity and profitability outweighed the additional investment and significant yield increases with lime application, supporting the economic benefits of optimal liming in maize cultivation. These outcomes are consistent with the findings of Bordoloi *et al*. (2020).

In the present study (Table 3), integrated nutrient management (INM) treatments showed superior economics compared to the control. Among nutrient management treatments, the control had the lowest cultivation cost (31,347 ₹ha^{-1}) but lower returns, whereas 50% RDF (NPK) + 50% RDN (PM) delivered the highest net return (72,673 ₹ha^{-1}) and B:C ratio (2.04). These results confirm that integrating organic and inorganic fertilizers, along with liming, significantly boosts maize yields and farm profitability, making them effective and economically sound strategies for sustainable maize

Table 3. Effect of liming and nutrients management levels on the economics of maize

Treatment	Cost of Cultivation (× 10^3 ₹ha^{-1})	Gross returns (×10^3 ₹ha^{-1})	Net returns (× 10^3 ₹ha^{-1})	Net B:C
Liming				
Control	35.12	96.37	61.24	1.76
Lime @ 250 kg ha^{-1}	36.46	102.11	65.66	1.81
Liming based on ST (300 kg ha^{-1})	36.70	105.74	69.03	1.90
S. Em±	-	0.26	0.26	0.007
LSD (P ≤ 0.05)	-	1.02	1.02	0.027
Integrated nutrient management levels				
Control	31.35	93.83	62.48	1.99
RDF	40.78	98.78	58.00	1.42
50% RDF (NPK) + 50% RDN (FYM)	36.50	101.35	64.85	1.78
50% RDF (NPK) + 50% RDN (VC)	36.33	104.87	68.54	1.88
50% RDF (NPK) + 50% RDN (PM)	35.52	108.20	72.67	2.04
S.Em±	-	0.27	2027	0.007
LSD (P ≤ 0.05)	-	0.78	078	0.021

production (Jamakhandi *et al*. 2025) and 50% RDF with 1 t ha^{-1} vermicompost increased maize yield by 180%, highlighting strong economic viability with a maximum B:C ratio of 2.10 (Bordoloi *et al*. 2020). Combined applications improved soil pH, nutrient availability, and productivity, enhancing net returns and profitability.

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