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Integrating soil amendments with micronutrients enhances growth and grain formation of maize (*Zea mays* L.) in the acidic soils of India's Eastern Sub-Himalayan Region

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Abstract

Maize is a major cereal crop valued for its food, feed and industrial use. However, its physiological growth is arrested in soil having acidity and micronutrients deficiency. To address this issue, the present experiment was conducted to investigate maize performance through application of soil amendments and micronutrients (Zn and B) in acid soil. The main plots consisted of treatments with agricultural lime, wood ash, and no amendments, while the sub-plots received four micronutrients (Zn and B) treatments, laid out in a split-plot design with three replications. Integrated application of soil amendments and micronutrients (Zn and B) significantly improved growth and yield attributes across the years. Agricultural lime @ 1.5 t ha⁻¹ recorded tallest plant followed by wood ash @ 5 t ha⁻¹ and control. Among the micronutrient treatments, soil applied micronutrients recorded tallest plant than foliar applied at 30 days after sowing (DAS) while, foliar sprays achieved tallest plant at 60, 90 and 120 DAS. Number of cob plant⁻¹ and number of grains cob⁻¹ significantly improved with integration of amendments and micronutrients, whereas, number of rows cob⁻¹ and seed index observed significant with micronutrients treatments, across the years. The integrated application of soil amendments (Lime and wood ash) along with soil and foliar Zn and B, significantly enhanced maize physiological growth. Lime application consistently outperformed than wood ash. Among micronutrients, two foliar application followed by soil applied micronutrients (Zn and B) proved most effective in boosting physiological functions, cob and grain formation. The synergy between soil amendment and micronutrient strategies led to marked improvements in grain formation. These results confirmed that soil amendments and micronutrients interventions unlocked the near maximum genetic potential of maize under acid soil conditions.

Keywords: Lime, wood ash, zinc and boron, maize, growth and yield attributes grain formation

1. Introduction

Maize (*Zea mays* L.) is widely grown cereal crop, known for its versatile use in food, feed, and industry (Nuss & Tanumihardjo, 2010; Hulmani *et al.*, 2020) ^[12, 5]. It is rich in starch, protein, fats, and micronutrients and high energy value (365 kcal/100 g). Maize plays a dynamic role in India's agriculture, covering 9.38 million hectares and yielding 28.75 million tonnes (IndiaAgristat, 2020) ^[6]. In recent years, maize has rushed across the sub-tropical belt of Eastern India, gradually supplanting traditional jute due to its superior crop establishment, lower irrigation demands and successful feed and industrial-market value. This region marked by heavy monsoon rain and sandy-loam soils, prone to intense leaching of basic cations (calcium and magnesium), repeatedly driving pH levels of soils in acidic reaction. Compounding the issue, long-term use of ammonium and sulphur-based fertilizers further acidifies soils, triggering micronutrients deficiencies, including zinc and boron essential for maize vitality. Maize is sensitive to acidity: grain yield can decline by as much as 11-37% under pH stress condition (Mutimaamba *et al.*, 2020) ^[10], and optimal performance typically requires a more neutral range of pH.

Maize is sensitive to micronutrient scarcities especially zinc (Zn) and boron (B). Zn deficiency in maize manifests as stunted growth, interveinal chlorosis and the notorious “white bud” symptom at the plant apex, severely reducing grain yield and nutritional quality. Boron, largely immobile within the plant, becomes fixed in acidic soils through adsorption to aluminium and iron hydroxides and formation of calcium complexes, hindering its translocation to growing tips. Shortfall in B halts terminal growth and curtails grain set (Singh *et al.*, 2020)^[15].

Application of agricultural lime effectively counteracts soil acidity, sustainably raising pH and replenishing essential base cations in soil: this rises microbial activity, nutrient cycling leading to plant growth and yields, often increasing by 20-40% following liming (Ernani *et al.*, 2002)^[4]. Wood ash offers a compelling alternative or complement to lime, delivering a liming effect (approximately 25-60% of that of pure lime), while simultaneously enhancing soil structure. Wood ash supplies macro and micronutrients- calcium, potassium, phosphorus, magnesium, zinc, manganese, copper and boron (Demeyer *et al.*, 2001)^[3] that are particularly valuable for maize production. Studies revealed that wood ash elevates soil pH and nutrient availability on par with lime, even improving crop performance in maize. Among soil chemical traits, pH remains the linchpin regulating Zn and B mobility; making calculated both liming and wood ash application critical for unlocking micronutrient uptake and maximizing yield, especially in acidic sub-tropical soils.

Therefore, the present field experiment was designed to investigate maize performance through application of soil amendments and micronutrients (Zn and B) in this acidic Sub-Himalayan plain. We aimed to improve the maize response through application of appropriate combination of amendments and micronutrients to meet rising maize productivity in a sustainable way.

2. Materials and Methods

A consecutive two-year field investigation was carried out during the winter (*rabi*) seasons of 2021-22 and 2022-23 to investigate maize performance through application of soil amendments and micronutrients (Zn and B) at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari, Cooch Behar, West Bengal, India. Geographically, the site lies within the Eastern Sub-Himalayan plains, precisely positioned at 26°40'15.80" N latitude and 89°38'64.32" E longitude, at an altitude of 49 meters above mean sea level. The soil is categorised under inceptisol and entisol, having sandy loam in textural class. The soil was acidic in pH and low fertility status. The initial soil analysis showed that the pH value was 5.65; low in - organic carbon (0.66%); available nitrogen (187 kg ha⁻¹); available phosphorus (22.0 kg ha⁻¹) and available potassium (209 kg ha⁻¹) while available zinc (0.48 mg kg⁻¹) and Boron (0.24 mg kg⁻¹) were in critical concentration. The field experiment was meticulously structured using a split-plot design, incorporating a total of 12 treatment combinations to explore the interactive effects of soil amendments and micronutrients. The main plots featured three distinct soil amendment: A₀ = Control (No amendment); A₁ = Lime application @ 1.5 t ha⁻¹ and A₂ = Wood ash @ 5 t ha⁻¹ strategies while the sub-plots included four micronutrient (Zn & B) treatments: M₁ = Control; M₂ = Zn EDTA (12% Zn) @ 5 kg ha⁻¹ + Solubor (20% B) @ 2 kg ha⁻¹ soil application; M₃ = Foliar spray of Zn EDTA (12% Zn) at knee high stage @ 0.5% + Solubor (20% B) spray at tasseling and silking stage @ 0.1% each spray and M₄ = Foliar spray of Zn EDTA (12% Zn) at knee high and tasseling stages @ 0.25% each spray + Solubor (20%

B) spray at tasseling and silking stages @ 0.1% each spray, all assigned randomly and replicated three times to ensure statistical precision. Fertilizers were applied @ 150:75:75 kg ha⁻¹ through urea (46% N), DAP (46% P₂O₅) and MOP (60% K₂O). Micronutrients-Zn and B were applied through Zn-EDTA (12% Zn) and Solubor (20% B). The high-yielding maize hybrid DHM 117 was sown on 10th December, 2021 and 12th December, 2022 and harvested on 25th April, 2022 and 29th April, 2023, respectively. Biometric observation observations were recorded as per treatments taken under study whereas, at harvest yield attributes were recorded plot-wise to ensure accuracy in yield assessment. The data gathered from field and laboratory was analysed through standard statistical procedure using F test. Different levels of main plot and sub-plot treatments mean were compared using least significant difference (LSD) test.

3. Results and Discussion

3.1. Growth parameter

3.1.1. Plant height

Significant improvement observed in plant height (cm) due to effect of soil amendments and micronutrients (Zn and B) application (Table 1). Plant height at 30, 60, 90 and 120 days after sowing (DAS) revealed that treatment A₁ performed better followed by A₂ in both the years. Among the micronutrient treatments M₂ at 30 DAS, M₃ at 60 DAS and M₄ at 90 and 120 DAS recorded highest plant height. Soil amended treatments (A₁ and A₂) outperformed in terms of plant height. The application of lime and wood ash contributes to increased plant height through a multifaceted mechanism involving the neutralization of soil acidity, improvement in nutrient availability, enhancement of soil structure and stimulation of microbial activity. Sharma *et al.* (2024)^[14] worked on organic amendments and micronutrient application found positive effect in plant height and plant health. In micronutrient treatments M₂ received highest plant height at 30 DAS because soil applied Zn is facilitating rapid cell division and elongation in growing shoot meristems during early vegetative stages, it regulates the biosynthesis of indole-3-acetic acid (IAA), promoting cell elongation and apical dominance and B accumulates in growing points and supports root tip cell division and elongation, enhancing root and shoot length at early growth stages. At later stages of crop growth, foliar spray of Zn and B performed better. Treatment M₃ gained highest plant height at 60 DAS whereas, M₄ at 90 and 120 DAS. Zn and B supplementation increased plant height by maintaining enzymatic functions, hormonal balance and supports cell elongation and cell division too (Cakmak, 2008; Bayar *et al.*, 2024)^[2, 1]. Interaction effect statistically non-significance due to simultaneous application of nutrients does not always lead to additive or synergistic effects on vegetative growth.

3.2. Yield Attributes

3.2.1. Number of cobs

The number of cobs per plant was significantly influenced by soil amendments and micronutrient treatments (Table 3). Among the soil amendments, the highest number of cobs per plant was recorded under A₁ treatment (1.31 in 2021-22 and 1.32 in 2022-23) followed by A₂ treatment. Treatment M₄ received the highest number of cobs per plant (1.28 2021-22 and 1.30 in 2022-23) among the micronutrient treatments including control, across the years. The improved cob formation may be attributed to better root growth, higher nutrient availability and favorable soil microbial activity induced by soil amendments, which were known to influence cob initiation. Zinc and boron play a synergistic role in ensuring healthy cob formation in maize by

supporting key physiological and reproductive functions. Together, these micronutrients ensure proper silk receptivity, pollination and assimilate translocation, ultimately leading to well-formed cobs and improved kernel filling. Crop architecture and cob-bearing capacity of the plant enhanced due to organic amendments and micronutrient applications (Njoroge *et al.*, 2018) ^[11]. Kiran and Channakeshava (2017) ^[7] revealed that combining 2% zinc seed priming with 2% foliar spray significantly improved plant height, cob length, 1000-grain weight, and overall grain yield in maize hybrids. Interaction effect of soil amendments and micronutrients on number of cobs per plant was found significant due to synergistic effect of the main and sub plot treatments.

3.2.2. Number of rows per cob

The number of rows per cob did not show significant variation due to soil amendments (Table 3). Moreover, micronutrient treatments had a significant effect, with M₄ recording the maximum number of rows (14.89 and 15.11), followed by M₂ (14.67 and 14.89), while M₁ (13.11 and 13.33) and control recorded lowest, across the years. Significant differences were achieved probably due to improved pollen viability and silk receptivity under balanced micronutrient nutrition, particularly zinc and boron, which are known to affect floral organ development. Tahir *et al.* (2016) ^[16] and Wasaya *et al.* (2017) ^[17] reported that Zn shows very much response on corn growth parameters and yield components when supplied as foliar spray. Proper root development, improved fertilization and good seed yield is the results of B application (Mousavi and Motesharezadeh, 2020) ^[9]. Interactions effect was statistically significant between amendment and micronutrient treated plots. This suggests that near neutral pH reactions positively influenced the effectiveness of micronutrients (especially Zn and B).

3.2.3. Number of grains per cob

Table 5 shows the number of grains per cob was significantly enhanced by both soil amendments and micronutrients application in both years (Table 3). Among soil amendments, A₁ produced the highest number of grains per cob (553.83 in 2021-22 and 566.83 in 2022-23). Similarly, M₄ resulted in the highest grain number (542.89 and 551.44), closely followed by M₂ (536.11 and 544.00), while M₁ (459.11 and 472.00) and control showed the least. The significant increase in the number of maize grains per cob observed across both years can be attributed to the synergistic effects of soil amendments and micronutrient application on improving soil health and reproductive efficiency. The application of lime and wood ash effectively neutralized soil acidity, reduced aluminium toxicity, and enhanced the availability of essential macronutrients,

thereby creating a favourable rhizosphere environment for root growth and nutrient uptake. Concomitantly, addition of Zn and B played a pivotal role in enhancing reproductive development—Zn by promoting auxin synthesis, pollen viability, and grain set and B by facilitating sugar transport, pollen tube growth, and fertilization. Together, these treatments improved nutrient translocation, floral organ function, and assimilate supply to the developing ear, leading to improved cob fertility and a higher number of grains per cob. Ray *et al.* (2024) ^[13] also reported that micronutrients application in cereals, effectively improved nutrient uptake and translocation, leading to enhanced grain quality and final yield of the crop. Interaction effect was found significant in Number of grains per cob during both the years. Both soil amendments and micronutrients positively affected grains number in maize production.

3.2.4. Seed index

Although the seed index (g) was statistically non-significant under soil amendments, noticeable trends were observed (Table 3). Among micronutrient treatments, significant differences were observed. M₄ registered the highest seed index (27.19 g and 27.37 g), followed by M₂ (27.10 g and 27.32 g) and the lowest values were noted under M₁ (25.09 g and 25.46 g) and control. Significant differences among micronutrient treatments reveal that M₄ and M₂ effectively supported grain weight, likely due to enhanced zinc and boron uptake which are vital for starch synthesis and membrane stability during kernel development. Micronutrients regulate root and shoot length, seedling dry weight, seed development and dry matter accumulation (Kumari *et al.*, 2024) ^[8].

The non-significant interaction between soil amendments and micronutrients across both seasons indicated that their effects on maize growth operated independently rather than synergistically. Soil amendments primarily improved soil pH and root environment, while zinc and boron directly enhanced physiological and reproductive processes. Once acidity was corrected, micronutrient uptake improved uniformly, limiting any further interactive advantage. Thus, both inputs contributed additively but not interactively, resulting in significant individual effects without a combined statistical interaction. Soil amendments (Lime and wood ash) might trigger the soil pH towards neutral; as a result it created more nutrients available to the plant. Hence, plants could easily uptake from the soil and soil solution to meet their demands. In contrary, neutral pH might restrict micronutrients availability in soil, therefore its external supply (foliar application) to the crops proven beneficial in plant system. Overall, the results confirmed that soil amendments involving lime or wood ash (A₁ or A₂) along with micronutrient application (M₄, M₃) substantially enhanced the maize growth and grain formation under acid soil conditions.

Table 1: Effect of soil amendments and micronutrients application on plant height of maize

Treatment	Plant height (cm) at 30 DAS		Plant height (cm) at 60 DAS		Plant height (cm) at 90 DAS		Plant height (cm) at 120 DAS	
Soil Amendments	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
A ₀	13.82	14.09	35.49	36.07	167.71	168.42	240.86	243.57
A ₁	15.58	17.10	44.62	47.12	185.93	189.73	270.18	271.22
A ₂	14.85	16.51	40.54	40.09	181.83	183.71	258.82	264.80
LSD (p=0.05)	0.76	1.06	4.34	4.29	13.15	13.44	15.03	12.25
Micronutrients (Zn & B)								
M ₁	13.85	14.19	35.53	36.61	168.11	171.39	241.77	243.81
M ₂	16.34	17.15	41.28	42.49	176.58	180.32	254.63	258.32
M ₃	14.54	16.35	43.27	44.81	185.34	188.94	261.36	266.47
M ₄	14.27	15.91	40.78	40.46	183.94	181.83	268.72	270.85
LSD (p=0.05)	1.12	0.66	2.39	2.77	5.77	5.04	12.62	9.25
Interaction								
A×M (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

NS = Non-significant between treatment means

Table 3: Effects of soil amendments and micronutrients on yield attributes and grain yield of maize

Treatment	Number of cob plant ⁻¹		Number of rows cob ⁻¹		Number of grains cob ⁻¹		Seed index (g)	
Soil Amendments	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
A ₀	1.09	1.10	13.00	13.17	454.25	455.75	26.03	25.81
A ₁	1.31	1.32	15.17	15.17	553.83	566.83	26.76	27.38
A ₂	1.26	1.27	14.33	14.83	537.83	548.75	26.42	27.09
LSD (p=0.05)	0.09	0.09	NS	NS	32.52	30.78	NS	NS
Micronutrients (Zn & B)								
M ₁	1.12	1.11	13.11	13.33	459.11	472.00	25.09	25.46
M ₂	1.24	1.29	14.67	14.89	536.11	544.00	27.10	27.32
M ₃	1.23	1.21	14.00	14.22	523.11	527.67	26.22	26.89
M ₄	1.28	1.30	14.89	15.11	542.89	551.44	27.19	27.37
LSD (p=0.05)	0.09	0.09	1.17	1.32	19.03	14.26	1.03	1.26
Interaction								
A×M (p=0.05)	0.07	0.07	1.18	1.32	17.94	15.05	NS	NS

NS = Non-significant between treatment means

4. Conclusion

The integrated application of soil amendments (Lime and wood ash) along with soil and foliar Zn and B, significantly enhanced maize growth and yield. Lime application consistently outperformed than wood ash. Among micronutrients, two foliar application (M₄) followed by soil applied micronutrients (Zn and B) proved most effective in boosting physiological functions, cob and grain formation. The synergy between soil amendment and micronutrient strategies led to marked improvements in growth and grain formation. These results confirmed that soil amendments and micronutrients interventions unlocked the near maximum genetic potential of maize under acid soil conditions.

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