Plant Archives Vol. 26, No. 1, 2026 pp. 157-163 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.020

INFLUENCE OF LIMING ON FERTILIZER-INDUCED SOIL ACIDITY AND NUTRIENT UPTAKE BY MAIZE (*ZEA MAYS* L.) IN *ALFISOLS*

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(Date of Receiving-20-11-2025; Date of Revision-28-12-2025; Date of Acceptance-04-02-2026)

ABSTRACT

Continuous use of acid-forming fertilizers leads to soil acidification, which adversely affects nutrient availability and uptake by crops. Liming is an effective soil management practice for neutralizing fertilizer-induced acidity and improving the availability of essential nutrients in acidic soils, particularly *Alfisols* under intensive maize cultivation. A field experiment was conducted during the *Kharif* season of 2021-22 at the College of Agriculture, V.C. Farm, Mandya, to evaluate the effect of lime and granulated dolomite on nutrient content and uptake of maize (*Zea mays* L.) grown on *Alfisols*. Treatments included neutralization of 100% and 50% of fertilizer acidity using lime and granulated dolomite, standard checks of lime (500 kg ha^{-1}) and granulated dolomite (250 kg ha^{-1}), recommended dose of fertilizers (RDF), and an absolute control. Farmyard manure (FYM) was applied along with RDF in relevant treatments. Neutralization of 100% fertilizer acidity using lime along with FYM and RDF recorded significantly higher nitrogen (1.50 and 1.45%), phosphorus (0.29 and 0.26%), and potassium (1.15 and 1.32%) contents in kernel and stover, respectively. Application of lime at 500 kg ha^{-1} along with FYM and RDF resulted in significantly higher calcium content in kernel (0.89%) and stover (0.94%), while 100% neutralization with granulated dolomite recorded the highest magnesium content in kernel (0.58%) and stover (0.69%). Nutrient uptake of maize was significantly higher under liming treatments compared to RDF alone, whereas the lowest uptake was observed in the absolute control. The correlation results indicated that higher nutrient availability and uptake under liming treatments were strongly and positively associated with improved maize yield.

***Key words*: Soil acidification, Lime, Granular dolomite, Neutralization**

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in India, valued for its versatility as food, feed, and industrial raw material. Its productivity largely depends on efficient nutrient management and soil health. In many intensive cropping systems, continuous use of high-analysis and acid-forming fertilizers, particularly nitrogenous fertilizers such as urea and ammonium-based sources, has led to progressive soil acidification, especially in *Alfisols*. Soil acidity adversely affects nutrient availability by converting essential nutrients such as phosphorus, calcium, magnesium, and nitrogen into forms that are less available to plants, thereby limiting crop growth and yield.

Alfisols, which are widely distributed in southern India, are inherently susceptible to acidification due to low base saturation, leaching of basic cations, and repeated application of chemical fertilizers. A decline in soil pH adversely affects nutrient availability by increasing phosphorus fixation and reducing the availability of nitrogen, calcium, magnesium, and potassium. Acidic soil conditions also enhance aluminium toxicity, restrict root growth, and impair microbial activity, thereby reducing nutrient uptake and crop productivity (Subba Rao and

Srivastava 2001; Sharma *et al*., 2013).

Liming is a proven soil management practice for ameliorating soil acidity and improving nutrient availability. Application of liming materials neutralizes exchangeable acidity, raises soil pH, and improves the availability of both macro- and secondary nutrients. Lime and dolomite are commonly used liming materials in Indian agriculture, supplying calcium and magnesium in addition to correcting soil acidity. Liming has also been reported to improve phosphorus availability by reducing its fixation in acidic soils (Verma *et al*., 2005). Several studies under Indian conditions have demonstrated improvements in soil chemical properties, nutrient uptake, and yield of maize following lime application in acidic soils (Singh *et al*., 2015; Kumar *et al*., 2019).

Granulated dolomite has recently gained importance due to its ease of application, uniform distribution, and simultaneous supply of calcium and magnesium. However, information on the comparative effectiveness of lime and granulated dolomite in neutralizing fertilizer-induced acidity and their influence on nutrient content and uptake of maize under *Alfisol* conditions is limited. Hence, the present study was undertaken to evaluate the effect of different liming strategies on nutrient content and uptake of maize.

Materials and Methods

The field experiment was conducted at the College of Agriculture, V.C. Farm, Mandya, which falls under Region III and Agro-Climatic Zone VI (Southern Dry Zone) of Karnataka, located at 12° 34' 03'' N latitude and 76° 49' 08'' E longitude with an altitude of 705 meters above mean sea level. The soil at the experimental site was classified as *Alfisols* with a red loamy sand texture, a neutral soil reaction (pH 7.19), low electrical conductivity (0.14 dS m^{-1}), and low organic carbon content (4.84 g kg^{-1}). The available nitrogen (241.06 kg ha^{-1}), phosphorus (25.56 kg P_2O_5 ha^{-1}), and potassium (182.45 kg K_2O ha^{-1}) were found to be in the medium range. The experiment was conducted using a Randomized Complete Block Design (RCBD) with eight treatments, each replicated three times. The treatments included the application of 500 kg lime (T_3) and 250 kg granular dolomite (T_4) along with farmyard manure (FYM) and the recommended dose of fertilizers (RDF), 100% and 50% neutralization of fertilizer acidity using lime (T_5 and T_6) and granular dolomite (T_7 and T_8) in combination with FYM and RDF, along with absolute control (T_1) and FYM + 100% RDF (T_2).

Maize (*Zea mays* L.), variety MAH-14-05, was used as the test crop. The experimental field was prepared by ploughing with a tractor-drawn disc plough, followed by disc harrowing and two passes of a cultivator to obtain a fine tilth. The experiment was laid out with a gross plot size of 5.1 m × 3.6 m and a net plot size of 3.9 m × 2.4 m. A spacing of 0.5 m between plots and 0.6 m between replications was maintained. Earthen bunds of 30 cm height were constructed between plots and replications to prevent lateral movement of water and nutrients. The recommended dose of fertilizers (150:75:40 kg N:P_2O_5 :K_2O ha^{-1}), farmyard manure (10 t ha^{-1}), and zinc sulphate (10 kg ha^{-1}) was uniformly applied to all treatments, except the absolute control. Furrows were opened at 60 cm row spacing using bullock-drawn furrow openers. Basal application consisted of 50% of the recommended nitrogen and 100% of phosphorus and potassium, which were placed along the seed rows and incorporated into the soil. Urea, diammonium phosphate (DAP), and muriate of potash (MOP) were used as sources of nitrogen, phosphorus, and potassium, respectively. The remaining 50% nitrogen was applied as top dressing in two equal splits at 30 and 60 days after sowing. Liming materials for treatments T_3 to T_8 were applied 15 days prior to sowing, broadcast uniformly on a plot-wise basis, and thoroughly incorporated into the soil. Adequate soil moisture was maintained through irrigation to facilitate effective reaction of the liming materials. Sowing was done by dibbling seeds at 30 cm plant spacing, with two seeds per hill. Standard agronomic practices, including timely irrigation and weeding, were followed throughout the crop growth period.

Based on the yield from each net plot, the amount of grain and straw was estimated and expressed as q ha^{-1}. Following the suggested set of practises allowed the crop to be maintained and plant samples were obtained at random to assess the crop's nutrient content at harvest. Then randomly selected destructive plant samples were taken to determine the nutrient content of crop at harvest, washed and rinsed with distilled water and dried in an oven at 60 °C to constant weight. Further nutritional analysis was carried out using the same samples. Both the grain and straw of maize were examined for major (N, P, K, Ca, Mg and S) and micronutrients (Fe, Mn, Zn and Cu). A modified micro Kjeldahl method and a Vanadomolybdate yellow colour method, respectively, were used to evaluate the nitrogen (N) and phosphorus (P) contents of straw and grain (Jackson, 1973). Potassium (K) content of grain and straw was estimated by flame photometric method and the titration method was adopted for the estimation of calcium (Ca) and magnesium (Mg). The turbidimetric approach was used to estimate the sulphur (S) content (Bradsley and Lancester, 1965). Micronutrient samples (Fe, Mn, Zn and

Table 2: Effect of liming material on N, P and K content and total uptake by maize.

Treatment	N			P			K		
	Content (%)		Total uptake (kg ha^{-1})	Content (%)		Total uptake (kg ha^{-1})	Content (%)		Total uptake (kg ha^{-1})
	Kernel	Stover		Kernel	Stover		Kernel	Stover	
T_1	0.41	0.32	22.76	0.09	0.06	4.58	0.68	0.82	49.31
T_2	1.39	1.30	198.07	0.25	0.21	33.76	1.10	1.29	177.09
T_3	1.40	1.32	207.32	0.19	0.16	26.60	0.99	1.16	172.01
T_4	1.41	1.33	223.86	0.23	0.19	34.21	1.09	1.28	186.70
T_5	1.50	1.45	253.82	0.29	0.26	47.23	1.15	1.32	213.48
T_6	1.45	1.36	237.44	0.27	0.23	42.13	1.13	1.30	206.52
T_7	1.42	1.34	231.31	0.26	0.22	40.10	0.92	1.15	174.92
T_8	1.47	1.38	242.58	0.28	0.24	44.15	0.83	1.13	168.45
S.Em±	**0.05**	**0.05**	**8.27**	**0.01**	**0.01**	**1.40**	**0.04**	**0.05**	**6.75**
CD @ 5 %	**0.16**	**0.15**	**25.11**	**0.03**	**0.03**	**4.26**	**0.12**	**0.15**	**20.48**

Cu) were measured using an atomic absorption spectrophotometer (AAS) after being initially digested using a di-acid mixture (Lindsay and Norwell, 1978).

Methods for measuring fertilizer acidity

The potential acidity of fertilizers is estimated using Pierre's Method, which expresses acidity in terms of calcium carbonate equivalents (CCE) per unit weight of fertilizer. This value indicates the amount of CCE needed to neutralize the acidity generated by the application of the fertilizer (Pierre, 1933). To determine the acidity of individual salts, the following equations are applied:

$$\frac{\text{Molecular weight of element} \times \text{equivalent acidity for element} \times 1000 \text{ kg}}{\text{Molecular weight of salt}}$$

$= \text{kg of } CaCO_3$ acidity for element per 1000 kg metric tonne of fertilizer salt

Statistical Analysis

Pearson's correlation coefficients (r) were computed to assess relationships among yield and nutrient parameters of maize. The significance of correlations was tested at $p \geq 0.05$, $p < 0.05$, $p < 0.01$, and $p < 0.001$. A correlation heat map was generated for visual interpretation. All analyses were performed using R statistical software (version 4.2.2). The data obtained from various characters under study were analyzed by the method of analysis of variance as described by (Gomez and Gomez, 1984).

Results and Discussion

Yield of maize

Maize kernel and stover yields were significantly influenced by liming materials applied with RDF and FYM (Table 1). The highest kernel yield was recorded in T_5 (100% RDF + FYM + 100% acid neutralization with lime; 81.57 q ha^{-1}), which was significantly higher than RDF alone (T_2, 69.65 q ha^{-1}) and RDF + FYM + 500 kg lime (T_3, 72.54 q ha^{-1}), but statistically at par with treatments receiving partial lime or granulated dolomite (GD) applications (T_4, T_6, T_7, T_8). Absolute control (T_1) recorded the lowest kernel yield (24.35 q ha^{-1}). Liming at 100% neutralization increased kernel yield by 17.11% over RDF alone. A similar trend was observed for stover yield, with T_5 producing the maximum yield (90.67 q ha^{-1}), significantly outperforming T_2 and T_3, while remaining on par with other lime and GD treated plots. The lowest stover yield was recorded in the control (T_1, 39.95 q ha^{-1}). RDF alone (T_2) was statistically on par with the application of 500 kg lime along with RDF and FYM (T_3), indicating limited yield advantage at lower lime doses.

Enhanced kernel and stover yields under RDF + FYM with lime or granulated dolomite (GD) were associated with improved growth and yield attributes (Table 1). Application of liming materials improved Ca and Mg availability and enhanced uptake of major nutrients, particularly nitrogen and phosphorus, resulting in better nutrient use efficiency and yield improvement. Calcium plays a key role in root elongation, cell division, and nutrient uptake, while lime application improves soil chemical balance and reduces nutrient fixation, thereby enhancing crop performance. Similar yield improvements due to enhanced Ca^{2+} and Mg^{2+} supply and improved phosphorus availability have been reported by Achalu *et al*., (2012). Improved uptake of K, Ca, and Mg following liming was also documented by Crusciol *et al*., (2016). Granulated dolomite performed comparably to lime due to its dual role as a Ca and Mg source. Its slow solubility ensures sustained nutrient availability throughout crop growth. Magnesium-mediated improvements in chlorophyll synthesis, photosynthesis, and N and P uptake contributed to increased biomass and grain yield, as reported by Raboin *et al*., (2016) and The *et al*., (2006).

Nutrient content and Uptake

The primary nutrient content and uptake by maize kernel and stover differed significantly among treatments

Table 3: Effect of liming material on Ca, Mg and S content and total uptake by maize.

Treatment	Ca			Ms			S		
	Content (%)		Total uptake	Content (%)		Total uptake	Content (%)		Total uptake
	Kernel	Stover	(kg ha^{-1})	Kernel	Stover	(kg ha^{-1})	Kernel	Stover	(kg ha^{-1})
T_1	0.39	0.41	25.87	0.18	0.19	11.97	0.09	0.07	4.98
T_2	0.57	0.69	93.44	0.38	0.41	58.40	0.10	0.08	13.19
T_3	0.89	0.94	139.88	0.45	0.49	71.90	0.13	0.11	18.24
T_4	0.60	0.74	110.10	0.53	0.63	95.20	0.15	0.13	22.83
T_5	0.80	0.86	137.24	0.47	0.53	86.39	0.19	0.18	31.81
T_6	0.78	0.82	129.95	0.49	0.57	90.11	0.17	0.15	26.99
T_7	0.69	0.79	124.74	0.58	0.69	107.16	0.16	0.14	25.08
T_8	0.65	0.76	120.71	0.55	0.65	102.76	0.17	0.15	27.19
S.Em±	**0.03**	**0.03**	**4.45**	**0.02**	**0.02**	**3.27**	**0.005**	**0.005**	**0.84**
CD @ 5 %	**0.09**	**0.09**	**13.56**	**0.06**	**0.07**	**9.93**	**0.01**	**0.01**	**2.57**

(Table 2). The highest N content in kernel (1.50%) and stover (1.45%) was recorded in T_5 (100% RDF + FYM + 100% fertilizer acidity neutralization with lime), which was significantly superior to the absolute control and statistically on par with other fertilized treatments. Correspondingly, total N uptake was maximum in T_5 (253.82 kg ha^{-1}), significantly exceeding T_1, T_2, and T_3, but remaining comparable with other lime- and GD-treated treatments. Under neutral soil conditions, this increase was mainly due to improved Ca and Mg nutrition and enhanced nitrogen use efficiency rather than soil acidity correction. Calcium-mediated improvements in root growth and microbial activity likely enhanced nitrogen mineralization and uptake (Bhemaiah, 1980; Ranjit *et al*., 2007), as also reported by Gerroh and Gascho (2004), Bhat *et al*., (2010), and Ramesh *et al*., (2012). Phosphorus content in kernel (0.29%) and stover (0.26%) was highest in T_5 and significantly superior to T_1, T_2, T_3, and T_4. Total P uptake was also maximum in T_5 (47.23 kg ha^{-1}), statistically at par only with T_8, while the lowest uptake was observed in the control. The enhanced P uptake under lime and FYM application in neutral soil may be attributed to improved fertilizer use efficiency and organic acid-mediated mobilization of Ca-bound P during FYM decomposition, which maintained P in plant-available forms (Whalen *et al*., 2002).Similarly, T_5 recorded the highest K content in kernel (1.15%) and stover (1.32%) and the maximum total K uptake (213.48 kg ha^{-1}), which was statistically on par with T_6 but significantly superior to the remaining treatments. The increased K uptake may be explained by improved cation balance and displacement of K^+ from exchange sites by Ca^{2+} supplied through lime and GD, thereby increasing K availability in the soil solution (Ranjit *et al*., 2007).

The secondary nutrients *viz*., Calcium, magnesium, and sulphur content and uptake by maize kernel and stover were significantly influenced by the application of liming materials along with RDF and FYM (Table 3). The highest Ca content in kernel (0.89%) and stover (0.94%) was recorded in T_3which was statistically on par with T_5 and significantly superior to the remaining treatments. Correspondingly, total Ca uptake was highest in T_3 (139.98 kg ha^{-1}) and remained at par with T_5 and T_6, indicating that Ca uptake closely followed grain and stover yield as well as Ca concentration. The increased Ca content and uptake were mainly due to the direct supply of Ca through lime application, which increased Ca concentration in the soil solution and enhanced root uptake. Early application of lime allowed sufficient time for interaction with soil colloids, improving Ca availability throughout crop growth. Similar increases in Ca uptake following lime application were reported by Mason (1979) and Moreira and Fageria (2010). Magnesium content in kernel (0.58%) and stover (0.69%) was highest in T_7, which was statistically at par with T_8 and T_4. Total Mg uptake was also maximum in T_7 (107.16 kg ha^{-1}), followed by T_8. The superior performance of dolomite-treated plots

Table 1: Kernel and stover yield of maize as influenced by the effect of liming material.

Treatments	Kernel yield (q ha^{-1})	Stover yield (q ha^{-1})
T_1 Absolute control	24.35	39.95
T_2 100% RDF + FYM	69.65	77.89
T_3 T_2 + 500 kg lime	72.54	80.13
T_4 T_2 + 250 kg GD	78.33	85.28
T_5 T_2 + 100 % neutralization with lime	81.57	90.67
T_6 T_2 + 50 % neutralization with lime	79.86	89.45
T_7 T_2 + 100 % neutralization with GD	79.00	88.91
T_8 T_2 + 50 % neutralization with GD	80.76	89.76
S.Em±	**2.87**	**3.27**
CD @ 5%	**8.70**	**9.93**

RDF- Recommended dose of fertilizer; FYM- Farm yard manure; GD- Granular dolomite was attributed to its dual role as a Ca and Mg source and its slow solubility, ensuring sustained Mg availability throughout the crop growth period. Sulphur content in kernel (0.19%) and stover (0.18%) and total S uptake (31.81 kg ha^{-1}) were significantly higher in T_5 compared to all other treatments. The enhanced S uptake may be attributed to improved Ca nutrition, which increases sulphate (SO_4^{2-}) availability in soil solution and promotes sulphur mineralization. Similar synergistic effects of Ca and Son sulphur uptake have been reported by Bolan *et al*., (1988), Grego *et al*., (2000), and Prabhakumari (1992).

Micronutrient (Fe, Mn, Cu, and Zn) content and uptake in maize kernel and stover varied significantly with the application of liming materials along with RDF and FYM (Fig. 1). Treatment T_5 recorded the highest Fe content in kernel (99.12 mg kg^{-1}) and stover (73.50 mg kg^{-1}) and the maximum Fe uptake (1474.94 g ha^{-1}), remaining statistically on par with other lime and dolomite-amended treatments. Similarly, Mn content and uptake were highest in T_5 (75.56 and 62.77 mg kg^{-1} in kernel and stover; 1185.47 g ha^{-1} uptake), comparable with T_6, T_7, and T_8 but significantly superior to RDF alone and control treatments. Copper and zinc content and uptake followed a similar trend, with T_5 recording the highest Cu (15.14 and 10.67 mg kg^{-1}) and Zn (46.94 and 40.44 mg kg^{-1}) content in kernel and stover and the maximum uptake (220.24 and 749.56 g ha^{-1}, respectively), statistically at par with other Ca-Mg-amended treatments. Application of lime and dolomite improved Ca and Mg nutrition, which enhanced root activity and nutrient absorption efficiency, thereby facilitating greater uptake of Fe, Mn, Cu, and Zn. Since total micronutrient uptake is a function of nutrient concentration and yield, treatments with higher kernel and stover yield recorded greater uptake. Similar improvements in micronutrient uptake following lime application within the optimal pH range have been reported by Hunter and Yapa (1996) and Buni (2015). The levels of these nutrients were lowest in the control treatment, as expected, due to nutrient uptake

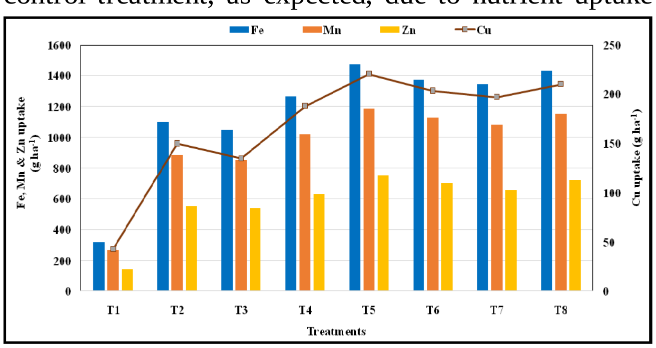

Fig. 1: Effect of liming material on Fe, Mn, Cu and Zn uptake by maize.

being solely dependent on native soil reserves.

Correlation analysis of yield and nutrient uptake in maize

Pearson's correlation analysis revealed strong and significant positive relationships among growth parameters, yield, and nutrient uptake in maize (Fig. 2). Grain yield showed a highly significant positive correlation with growth attributes ($r \approx 0.96$-1.00, $p < 0.001$), indicating that improved vegetative growth directly contributed to higher productivity. Yield was also strongly correlated with macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Mn, Cu, and Zn), with correlation coefficients mostly exceeding 0.90, suggesting that balanced nutrient availability played a key role in determining yield performance.

Nitrogen exhibited a strong positive association with growth and yield, highlighting its central role in biomass production and grain formation. Similarly, significant correlations of P, K, Ca, Mg, and S with yield indicate their importance in energy transfer, enzyme activation, structural development, and metabolic processes. Micronutrients such as Fe, Mn, Zn, and Cu were also positively and significantly correlated with yield and growth, reflecting their involvement in photosynthesis, chlorophyll synthesis, and enzymatic reactions.

The strong interrelationships among nutrients further indicate synergistic nutrient interactions under integrated nutrient management practices. Overall, the correlation results suggest that improvements in nutrient availability and uptake enhanced crop growth, which in turn translated

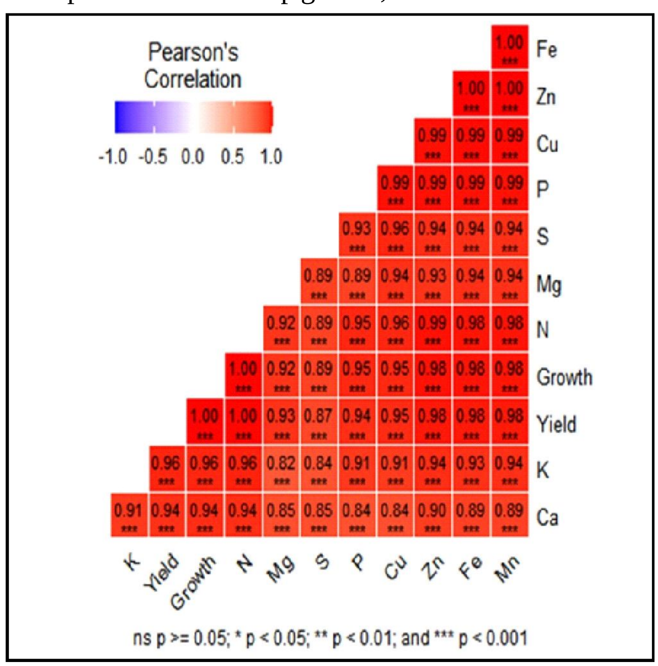

Fig. 2: Pearson's correlation matrix showing relationships among yield and nutrient uptake in maize.

into higher maize yield. Similar positive relationships between nutrient uptake, growth and yield in maize have been reported by Fageria *et al*., (2011), Ramesh *et al*., (2012), and Crusciol *et al*., (2016).

Conclusion

The study demonstrated that liming, either through lime or granulated dolomite, effectively mitigated fertilizer-induced soil acidity in *Alfisols* and significantly enhanced nutrient content and uptake in maize. Neutralization of 100% fertilizer acidity with lime along with FYM and RDF resulted in the highest N, P, K, Ca, Mg, and S concentrations in both kernel and stover, while also improving micronutrient (Fe, Mn, Cu, Zn) uptake. Liming treatments significantly increased maize yield compared to RDF alone, highlighting the positive relationship between improved nutrient availability and crop productivity. Pearson's correlation analysis confirmed strong and significant associations between nutrient uptake, growth parameters, and grain yield, emphasizing the role of balanced nutrition in achieving higher productivity. Overall, the integrated use of lime or granulated dolomite with FYM and RDF can be recommended as an effective strategy for correcting soil acidity, enhancing nutrient use efficiency, and maximizing maize yield in *Alfisols*.

Acknowledgements

The authors gratefully acknowledge the Department of Soil Science and Agricultural Chemistry, College of Agriculture, V.C. Farm, Mandya and the University of Agricultural Sciences, Bangalore, for providing the necessary research facilities, continuous support and encouragement for the successful completion of this study. The first author sincerely expresses her heartfelt gratitude to Late Ramanji Sir for his invaluable guidance and assistance in conducting the correlation studies.

Conflict of Interest: The authors declare no conflict of interest.

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