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Improving Nutrient Availability and Rice Yield in Coastal Sandy Soils through Non-Conventional Soil Ameliorants

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Soil acidity is a major constraint limiting nutrient availability and rice productivity in the coastal sandy soils of Kerala. A field experiment was conducted during the first crop season of 2023 at Thaikadappuram, Kasaragod, Kerala, to evaluate the effectiveness of different soil ameliorants in improving soil properties, nutrient availability, plant nutrient uptake, and rice productivity. The experiment was laid out in a randomized block design with nine treatments and three replications using rice variety Athira. Treatments included lime, dolomite, gypsum, and calcium silicate applied at 100% and 125% calcium equivalent levels along with a control. The results revealed that application of soil ameliorants significantly improved soil pH, electrical conductivity, availability of major nutrients (N, P, and K), plant nutrient concentration, and yield

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attributes compared to the control. Among the treatments, dolomite applied at 125% calcium equivalent (T_7) proved to be the most effective. This treatment recorded the highest soil pH and nutrient availability throughout crop growth stages, along with superior plant nutrient content. Maximum grain yield (8800 kg ha^{-1}), straw yield (18463.09 kg ha^{-1}), and productive tillers were also observed under T_7. The improvement in crop performance was attributed to enhanced soil acidity amelioration, reduced nutrient fixation and toxicity, and increased availability of calcium and magnesium. The study demonstrates that dolomite can serve as an effective and sustainable soil amendment for enhancing soil fertility and rice productivity in acidic coastal sandy soils.

Keywords: Coastal sandy soil; dolomite; liming; rice productivity; soil acidity; soil ameliorants; nutrient availability; acidic soils.

1. Introduction

The coastal area is an interactive interface between terrestrial and marine environments and thus, it experiences terrestrial as well as marine effects (Alongi, 1997). The coastline of the globe is approximately 356,000 km in length, and it occupies almost 10 percent of the Earth's surface (Martínez *et al.,* 2007). Coastal areas typically have sandy soils that are acidic, well-drained, and moderately salty because of intrusion of seawater (Reddy *et al.,* 2022). The soils found in coastal areas are mostly made up of primary minerals, such as quartz (SiO_2), which have low nutrient content, low cation exchange capacity, and are resistant to weathering (Schaetzl and Anderson, 2005).

Acidity of the soil is known to be one of the key factors that limit the growth and productivity of crops because of its impacts on nutrient availability, aluminum toxicity, and soil biological activities (Foy, 1984; Kochian *et al.,* 2004; Agegnehu *et al.,* 2021). The coastal ecosystem of Kerala is spread across the south-western coastline of India bordering the Arabian Sea and comprises sandy beaches, estuaries, backwaters, wetlands, and mangroves (Nair *et al.,* 2019). The heavy rainfall and weathering along with leaching in the region result in the development of acid soils that have poor nutrient holding capacity. The soils of Kerala, are generally acidic, accounting to nearly 94.7 per cent of the soils in the region (Maji *et al.,* 2012) and is often associated with increased iron toxicity (Mandal *et al.,* 2003; Sahrawat, 2004; Fageria *et al.,* 2008). The antagonistic effect of increased ferrous ions in the rhizosphere region results in the reduced uptake of essential nutrients (Rout and Sahoo, 2015), reducing the growth and yield of rice crops (Audebert and Fofana, 2009).

Liming is considered as an effective management practice for improving soil acidity and enhancing the physical, chemical, and biological properties of acid soils (Bolan, 2003). In rice-growing soils of Kerala, low pH, iron toxicity, and reduced nutrient availability are some of the most important soil-related constraints affecting rice yields. However, the high cost and low availability of conventional shell lime have hindered its use by rice-growing farmers, often at levels much lower than recommended. Farmers are forced to use inorganic fertilizers as a compensatory measure for low nutrient availability, making rice production expensive and unsustainable from an environmental perspective (Moossa *et al.,* 2012; Tilman *et al.,* 2002).

However, the expensive nature of conventional lime materials like shell lime reduces its applicability in the state. As a consequence, farmers use less-than-recommended dosages of the same, and this is why they depend more on chemical fertilizers, which raises their expenses and poses hazards to the environment (Moossa *et al.,* 2012). Additionally, ecological barriers further reduce their availability.

Non-conventional soil ameliorants such as calcium carbonate, dolomite, gypsum, and calcium silicate are cost-effective alternatives with potential to improve acidic soils and reducing iron toxicity problems (Shamshuddin *et al*., 2014). In particular, dolomite supplies both Ca^{2+} and Mg^{2+} and helps improve soil chemical properties in acid soils. Nevertheless, there is limited research work conducted on the effectiveness of these amendments to overcome iron toxicity and increase rice production in coastal sandy acidic soils of Kerala. Thus, this research was conducted to assess and compare some soil ameliorants for the improvement of soil properties, nutrient uptake and rice productivity.

2. Materials and Methods

Field experiment was carried out in a farmer's field at Thaikadappuram, Kasaragod, Kerala (12.2° N latitude, 75.11° E longitude), with a humid tropical climate during the first cropping season, i.e., from May to October

2023. The soil type used for the experiment was sandy loam with the initial characteristics: pH of 4.81, EC - 0.16 dS m^{-1}, available N - 225.47 kg ha^{-1}, available P_2O_5 - 9.49 kg ha^{-1}, available K_2O - 33.52 kg ha^{-1}, available Ca - 182 mg kg^{-1}, available Mg - 116 mg kg^{-1}, and available S - 40.38 mg kg^{-1}.

The experiment was conducted following a randomized block design with nine treatments and three replications, with rice variety *Athira* as the test crop. The treatments were: T_1 – Farmer's Practice (control); T_2 – Application of lime as per the Package of Practices (POP) recommended by Kerala Agricultural University (2016); T_3 – Application of Dolomite @ 100% based on calcium equivalent; T_4 – Application of Gypsum @ 100% based on calcium equivalent; T_5 – Application of Calcium Silicate @ 100% based on POP recommended by KAU (2016); T_6 – Application of lime @ 125% based on POP recommended by KAU(2016); T_7 – Application of Dolomite @ 125% based on calcium equivalent; T_8 – Application of Gypsum @ 125% based on calcium equivalent; and T_9 – Application of Calcium Silicate @ 125% based on calcium equivalent. The proposed amendments were applied equally in two splits during the tillering and panicle initiation stages of the crop. The application rate of the amendments was as follows: T_2 – lime @ 1.25 kg/20 m^2, T_3 – dolomite @ 1.15 kg/20 m^2, T_4 – gypsum @ 2.15 kg/20 m^2, T_5 – calcium silicate @ 1.45 kg/20 m^2, T_6 – lime @ 1.50 kg/20 m^2, T_7 – dolomite @ 1.40 kg/20 m^2, T_8 – gypsum @ 2.60 kg/20 m^2, and T_9 – calcium silicate @ 1.80 kg/20 m^2.The fertilizers were uniformly applied to all plots as per the KAU recommendations (KAU, 2016). All other agronomic practices were followed as per the Package of Practices (KAU, 2016). The sprouted seeds were dibbled at a spacing of 20 x 15 cm in plots of 20 m^2. The soil and plant samples were collected at the tillering, panicle initiation, and harvest stages of the crop.

The soil samples were tested for various chemical properties like soil pH and electrical conductivity. The pH and electrical conductivity of the soil were measured by suspending 1:2.5 soil and water mixture and then measuring it with a pH and EC meter, respectively, as described by Jackson (1958). The available nitrogen was estimated with the help of the alkaline permanganate method of Subbiah and Asija (1956), while the available phosphorus was estimated with the help of Bray No. 1 solution and a spectrophotometer (Bray and Kurtz, 1945). Available potassium was estimated by extracting the available potassium with normal neutral ammonium acetate and estimating it with a flame photometer, as suggested by Jackson (1958). Exchangeable calcium and magnesium were estimated by extracting exchangeable Ca and Mg with normal neutral ammonium acetate and estimating it with complexometric titration, as suggested by Goldstein (1959). Available sulfur was estimated by extracting with calcium chloride and estimating it with spectrophotometric analysis, as suggested by Massoumi and Cornfield (1963). Similarly, plant samples were analyzed for total N with the help of a modified Kjeldhal digestion method, as suggested by Jackson (1958). Total phosphorus was estimated with the Vanadomolybdate yellow colour method, as suggested by Piper (1967). Total potassium was estimated with the help of flame photometry, as suggested by Jackson (1958). Similarly, total Ca and Mg were estimated with the help of complexometric titration, as suggested by Goldstein (1959). Total sulfur was estimated with the Turbidimetric method, as suggested by Bhargava and Raghupathy (1993). The biometric parameters such as grain and straw yield were also recorded.

2.1 Statistical Analysis

Statistical analysis of the experimental data was conducted through the application of one-way analysis of variance (ANOVA) using randomized block design as described in GRAPES (Fisher & Yates, 1938; Gopinath *et al.,* 2021). The effects of different treatments were evaluated at the significance level of 5%. In case where the F-test showed significant difference between the means of different treatments, mean separation was done using LSD test at the probability value of 0.05. Data were subjected to statistical tests before conducting any analysis in order to meet the requirements of applying the ANOVA test. Data normality was tested using various statistical tools like the Shapiro-Wilk test. Data homogeneity of variances was done using Levene's test, and it revealed that data followed normal distribution.

3. Result and Discussion

3.1 Soil Properties

3.1.1 Soil pH

Soil pH was significantly variable across treatments at all stages of crop growth (Table 1). At the stage of active tillering and panicle initiation, treatments T2 to T9 had significantly higher pH compared to T1 (control), where the liming effect is evident. The highest value of pH was consistently observed for T7 (Dolomite applied 125 %

based on Ca equivalent) across all growth stages. At the harvest stage, there was a general decline in pH across all treatments. However, it is evident that the liming treatments T2 to T9 had significantly higher pH compared to the control. It might be due to the acid-neutralizing ability of dolomite because dolomite contains calcium and magnesium, which have the ability to neutralize acidity. Dolomite $CaMg(CO_3)_2$ releases carbonate ions which neutralize the hydrogen ions present in acidic soils, thus increasing the soil pH. Magnesium also increases the cation exchange capacity of soil and the soil buffering capacity. Similar findings were reported by Rastija *et al.* (2010) that dolomite showed a significant increase in soil pH. Kasno *et al.* (2023) assessed the effect of dolomite on acidic Oxisols and found a significant improvement in soil chemical properties and maize yield (Chairiyah *et al.,* 2021).

3.1.2 Electrical Conductivity

From the given Table 1 it is observed that the soil electrical conductivity was significantly different for all the crop growth stages. The increase in electrical conductivity was observed for all the treatments from active tillering to harvest. At active tillering, panicle initiation and harvest, T7 (Dolomite applied 125 % based on Ca equivalent) registered the highest electrical conductivity, while T1 (control) had the lowest. The elevated electrical conductivity found in limed treatments, especially those treated with dolomite, can be explained by the dissolution of dolomite, which results in the release of calcium (Ca^{2+}), magnesium (Mg^{2+}), and carbonate ions into the soil solution. The increase in the number of soluble salts and exchangeable bases contributed to increased electrical conductivity. According to Pimolrat et al. (2020), the mixing of natural dolomite with acidic soils (5-30% w/w) resulted in improved soil chemical characteristics such as electrical conductivity due to enhanced exchangeable calcium and magnesium ions (Slattery & Morrison, 1995). The recent meta-analyses have also shown that the addition of liming material such as dolomite improves exchangeable Ca^{2+} and Mg^{2+} ions and base saturation in soil (Enesi *et al.,* 2023).

Table 1. Effect of soil ameliorants on soil pH and Electrical conductivity

Treatments	pH			Electrical conductivity (dS/m)		
	Active tillering	Panicle initiation	At harvest	Active tillering	Panicle initiation	At harvest
T1	5.17^{b}	5.02^{d}	4.79^{d}	0.01^{e}	0.04^{de}	0.09^{f}
T2	5.34^{b}	5.48^{bc}	4.82^{cd}	0.02^{d}	0.08^{b}	0.15^{e}
T3	5.71^{a}	5.75^{a}	5.24^{ab}	0.06^{b}	0.13^{a}	0.26^{b}
T4	5.69^{a}	5.63^{ab}	5.04^{bc}	0.02^{d}	0.05^{d}	0.18^{d}
T5	5.67^{a}	5.74^{a}	5.23^{ab}	0.06^{b}	0.04^{e}	0.26^{b}
T6	5.71^{a}	5.74^{a}	5.10^{b}	0.03^{c}	0.05^{d}	0.19^{cd}
T7	5.79^{a}	5.86^{a}	5.47^{a}	0.08^{a}	0.14^{a}	0.30^{a}
T8	5.65^{a}	5.71^{ab}	5.17^{b}	0.06^{b}	0.07^{c}	0.26^{c}
T9	5.67^{a}	5.37^{c}	5.09^{b}	0.04^{c}	0.07^{c}	0.19^{b}
SE (m)	0.077	0.082	0.082	0.003	0.003	0.004
CD (0.05)	0.231	0.246	0.246	0.009	0.01	0.011

Values are mean of 3 replications. ANOVA for RBD was done. Values with same superscript alphabet indicate that the treatments are not significantly different; whereas, different alphabets indicate significant difference at 5% level of significance

3.1.3 Available Nitrogen

Available nitrogen content was found to exhibit significant variation among treatments at all stages of crop growth, shown in Table 2. The data recorded at all the three stages showed maximum available N content in T7 (Dolomite applied 125 % based on Ca equivalent), followed by T3 (Dolomite applied 100 % based on Ca equivalent), whereas, the minimum available N content was recorded in the control (T1). The available N content was found to increase in the active tillering to panicle initiation stage and decrease in the harvest stage.

The increased availability of nitrogen due to dolomitic soil could be explained through the improvement of soil pH, thereby improving microbial activity and nitrogen mineralization. Dolomite neutralizes the acidity of the soil, as well as aluminum toxicity, thus increasing the decomposition of organic matter and mineralization of organic nitrogen into available forms. The presence of calcium and magnesium in dolomite helped enhance root development. The use of dolomite on acidic rice soils led to an increase in soil pH and improved the process of nitrogen mineralization and transformation due to the stimulation of ammonia oxidizers (Shaaban *et al.,* 2024;

Fageria *et al.,* 2010). Liming decreased aluminum toxicity and promoted microbial activities (Haynes & Naidu, 1991).

3.1.4 Available Phosphorous

Soil available phosphorus was significantly different among the treatments during the entire crop growing period (Table 2). During the active tillering stage, panicle initiation and at harvest, the highest soil available phosphorus was recorded by treatment T7 (Dolomite applied 125 % based on Ca equivalent), closely followed by T3 (Dolomite applied 100 % based on Ca equivalent), while T1 (control) recorded the lowest soil available phosphorus. During the harvest stage, soil available phosphorus was highest in treatment T7, while treatments T3, T4, and T9 were on a similar statistical level.

The high availability of phosphorus in limed soils, especially those that have been limed with dolomite, could be attributed to high soil pH and low phosphorus fixation by iron and aluminum ions. Dolomite liming neutralized soil acidity and reduced aluminum ion activities, thus enhancing phosphorus availability. The calcium ions introduced into the soils through dolomite also improved root development and nutrient uptake. High phosphorus levels in T7 show the residual effect of dolomite on phosphorus availability. According to Fan et al. (2021), dolomite increased Olsen-P concentration by 66% compared to the control after 120 days of incubation. Magnesium is one of the elements contained in dolomite, and it makes it more effective than $CaCO_3$ since it inhibits the formation of Ca-P compounds, hence maintaining phosphorus in its available form. In acid soils with pH less than 5.0, phosphorus fixation by aluminum compounds is very high, but liming raises soil pH and decreases Al^{3+} ions, resulting in high phosphorus availability (Wang et al., 2006). Liming also aids in the microbial mineralization of organic phosphorus (Haynes, 1982; Chen & Arai, 2024).

3.1.5 Available Potassium

Soil available potassium content was also significantly affected by the treatment at both active tillering and panicle initiation stages as depicted in Table 2. At active tillering, panicle initiation and at harvest significantly higher available potassium content in the soil was recorded in treatment T7 (Dolomite applied 125 % based on Ca equivalent). and T3 (Dolomite applied 100 % based on Ca equivalent) and the lowest in T1 (control).

The increase in availability of potassium when dolomite is applied could be attributed to the improvement in soil pH, reduction of aluminium toxicity, and increase in cation exchange capacity that prevented potassium fixation and loss through leaching in acidic coastal sandy soils. The supply of calcium and magnesium by dolomite assisted in retention of potassium in available form. Kasno *et al.* (2023) found that the application of dolomite increased soil pH, exchangeable Ca, Mg, and K (Cahyono, 2019), and exchangeable Al and aluminum saturation. The application of dolomite not only reduced the uptake of toxic Fe^{2+} in the rice plants but also increased the uptake of phosphorus and potassium (Suriyagoda *et al.,* 2017; Oladele *et al*., 2019).

Table 2. Effect of soil ameliorants on availability of primary nutrients in the soil

Treatments	Available Nitrogen (Kgha^{-1})			Available Phosphorous (Kgha^{-1})			Available Potassium (Kgha^{-1})		
	Active tillering	Panicle initiation	At harvest	Active tillering	Panicle initiation	At harvest	Active tillering	Panicle initiation	At harvest
T1	109.76^{h}	235.20^{f}	78.40^{h}	14.45^{f}	2.31^{g}	18.37^{f}	50.73^{f}	60.36^{h}	70.56^{g}
T2	188.16^{d}	360.64^{de}	78.40^{h}	17.29^{e}	3.01^{g}	22.96^{c}	60.48^{e}	65.18^{g}	93.63^{e}
T3	313.60^{b}	454.72^{b}	344.96^{b}	23.88^{b}	20.97^{b}	23.89^{b}	119.50^{a}	105.16^{b}	120.93^{b}
T4	125.44^{g}	344.96^{e}	172.48^{e}	15.33^{f}	18.87^{cd}	23.23^{bc}	86.91^{c}	93.85^{c}	98.89^{d}
T5	203.84^{c}	423.36^{c}	219.52^{c}	20.41^{c}	15.76^{f}	18.96^{ef}	105.95^{b}	83.66^{e}	117.35^{b}
T6	156.80^{f}	376.32^{d}	94.08^{g}	19.22^{d}	16.72^{e}	22.08^{d}	65.74^{d}	45.92^{i}	108.36^{c}
T7	329.28^{a}	486.08^{a}	454.72^{a}	26.12^{a}	22.27^{a}	27.73^{a}	122.75^{a}	117.44^{a}	128.81^{a}
T8	172.48^{e}	407.68^{c}	188.16^{d}	16.58^{e}	18.09^{d}	19.65^{e}	60.59^{e}	73.58^{f}	101.48^{d}
T9	172.48^{e}	407.68^{c}	156.80^{f}	17.51^{e}	19.10^{c}	23.53^{bc}	68.54^{d}	88.48^{d}	87.79^{f}
SE (m)	2.421	6.099	3.368	0.361	0.286	0.249	1.339	1.02	1.736
CD (0.05)	7.259	18.285	10.097	1.082	0.859	0.747	4.015	3.057	5.204

Values are mean of 3 replications. ANOVA for RBD was done. Values with same superscript alphabet indicate that the treatments are not significantly different; whereas, different alphabets indicate significant difference at 5% level of significance

3.2 Plant Nutrient Content

3.2.1 Total Nitrogen

Soil ameliorant treatments significantly increased plant nitrogen content in all growth stages compared to the control (T1) shown in Table 3. Nitrogen concentration increased in the tillering to panicle initiation stages but decreased in the harvest stage. However, all treatments showed increased values compared to the control. At the tillering stage, highest plant nitrogen content was recorded in T7 (Dolomite applied 125 % based on Ca equivalent), followed by treatments T5 (Calcium silicate applied at 100 % based on Ca equivalent) and T3 (Dolomite applied at 100 % based on Ca equivalent). At the panicle initiation stage, the highest nitrogen content was recorded in T7 (Dolomite applied 125 % based on Ca equivalent), followed by treatments T4 (Gypsum applied 100 % based on Ca equivalent) and T3 (Dolomite applied 100 % based on Ca equivalent), as well as treatment T9 (Calcium silicate applied 125 % based on Ca equivalent). At the harvest stage, there was a decrease in nitrogen content in all treatments but was still significantly high nitrogen was observed in treatment T7 (Dolomite applied 125 % based on Ca equivalent), recording 1.05%, which accounted an increase of 114% compared to the control that recorded 0.49%. All treatments showed an improvement in plant growth due to soil ameliorant application. Dolomite applied at 125 % based on Ca equivalent (T7) recorded the highest nitrogen content in all growth stages.

Application of dolomite significantly increased shoot nitrogen content and total N uptake in maize grown on reclaimed acid sulfate soils compared to unlimed soils (Lestari *et al.* 2016), which could be attributed to increased pH and improved root development for better nitrogen absorption. Zhang *et al.* (2021) found that dolomite amendment to acidic paddy soils increased nitrate-N (NO_3^--N) contents through improved nitrification, thereby improving nitrogen uptake and increasing N concentration in rice plants (Fageria *et al.,* 2011). Amendment application with Mg increased plant nitrogen (Varghese and Money, 1965), similarly recent research has shown that liming increase nitrogen uptake by improving soil pH and nitrification (Zhang *et al.,* 2023).

3.2.2 Total Phosphorous

From the data (Table 3), it is observed that during the tillering stage, the highest phosphorus content of 0.472% was recorded in treatment T7 (Dolomite applied 125 % based on Ca equivalent), followed by treatment T3 (Dolomite applied 100 % based on Ca equivalent) with 0.449% and treatment T6 (Lime applied 125 % of POP of KAU 2016) with 0.406%. The lowest phosphorus of 0.248% was recorded in control. During the panicle initiation stage, the phosphorus content in plant increased in all the treatments. Significantly higher phosphorus content of 0.452% was observed in treatment T7 (Dolomite applied 125 % based on Ca equivalent), followed by treatment T3 (Dolomite applied 100 % based on Ca equivalent) with 0.393% and treatment T5 (Calcium silicate applied 100 % based on Ca equivalent) with 0.380% and lowest P of 0.286% was recorded in T1(control).

During the harvest stage, the phosphorus content slightly declined in all the treatments but remained higher in the amended soils, with treatment T7 (Dolomite applied 125 % based on Ca equivalent), maintaining the highest value of 0.468%, almost double the value of the control treatment with 0.24%, followed by treatment T3 (Dolomite applied 100 % based on Ca equivalent) with 0.445% and treatment T5 (Calcium silicate applied 100 % based on Ca equivalent) with 0.405%. Soil amelioration significantly improved the plant phosphorus content during the entire growth period, with treatment T7 (Dolomite applied 125 % based on Ca equivalent), maintaining the highest value in all the stages.

The high phosphorus level after application of dolomite might be attributed to the high soil pH and low fixation of phosphorus by iron and aluminium compounds in acidic soil conditions. Moreover, dolomite was found to improve root development and increase phosphorus uptake by the plant. Magnesium-enriched liming products like dolomites promote phosphorus absorption through the development of healthy roots and nutrient balance (Mengel et al., 2012). In addition, Hartatik *et al.* (2023) found that dolomite application to acid sulfate soils not only boosted phosphorus availability but also decreased iron toxicity and enhanced nitrogen, phosphorus, and potassium absorption in rice because of the increased pH and nutrients in the soil.

3.2.3 Total Potassium

Soil ameliorants substantially increased plant potassium content at all crop growth stages compared to the control (T1). The potassium concentration showed an increase from tillering to panicle initiation and was sustained and further increased in most treatments during the harvest stage (Table 3). At the tillering, panicle initiation stage, the highest potassium content of 0.372% and 0.346% respectively, was recorded in T7 (Dolomite applied 125 % based on Ca equivalent) and was statistically on par with T3 (0.367%) at tillering (0.323%) at panicle initiation stage, but significantly higher than other treatments. At the harvest stage, the potassium content showed further increase and T7 (Dolomite applied 125 % based on Ca equivalent) showed superiority (366%) over other treatments and was followed by T3 (0.332%) and T8 (0.328%). Soil amelioration significantly improved the potassium content in all crop growth stages.

The high potassium content in relation to dolomite treatment could be due to improved soil pH levels, increased cation exchange capacity, and decreased potassium leaching from acidic coastal sandy soils. Root development and nutrient uptake were positively influenced by dolomite application, which contributed to high potassium content in plants. The addition of dolomite resulted in an increase in phosphorus and potassium levels, plant growth, and grain yield with a decrease in iron toxicity in rice (Suriyagoda *et al.,* 2017). Increased potassium absorption in acidic soils by magnesium-containing liming materials was also noted by Fageria and Baligar (2008). Likewise, Bhindhu *et al.* (2018) recorded an increase in potassium availability and plant potassium content after liming acidic tropical soils of Kerala.

Table 3. Effect of soil ameliorants on the primary nutrient concentration in the plant

Treatments	**Total Nitogen (%)**			**Total Phosphorous (%)**			**Total Potassium (%)**		
	Active tillering	**Panicle initiation**	**At harvest**	**Active tillering**	**Panicle initiation**	**At harvest**	**Active tillering**	**Panicle initiation**	**At harvest**
T1	1.26^{f}	0.7^{f}	0.49^{g}	0.248^{g}	0.286^{e}	0.24^{g}	0.166^{g}	0.24^{f}	0.257^{f}
T2	1.33^{ef}	0.98^{d}	0.56^{f}	0.356^{d}	0.287^{e}	0.268^{f}	0.32^{c}	0.266^{e}	0.259^{f}
T3	1.89^{b}	1.05^{c}	0.98^{b}	0.449^{b}	0.393^{b}	0.445^{b}	0.367^{a}	0.323^{b}	0.332^{b}
T4	$1.4d^{e}$	1.12^{b}	0.84^{c}	0.388^{c}	0.36^{c}	0.379^{d}	0.304^{d}	0.301^{c}	0.301^{c}
T5	1.96^{ab}	0.98^{d}	0.7^{e}	0.332^{ef}	0.38^{b}	0.405^{c}	0.307^{d}	0.289^{d}	0.286^{d}
T6	1.75^{c}	0.77^{e}	0.84^{c}	0.406^{c}	0.327^{d}	0.294^{e}	0.245^{f}	0.292^{cd}	0.295^{cd}
T7	2.03^{a}	1.19^{a}	1.05^{a}	0.472^{a}	0.452^{a}	0.468^{a}	0.372^{a}	0.346^{a}	0.366^{a}
T8	1.47^{d}	0.77^{e}	0.98^{b}	0.354^{de}	0.31^{d}	0.383^{d}	0.262^{e}	0.245^{f}	0.328^{b}
T9	1.47^{d}	1.05^{c}	0.77^{d}	0.318^{f}	0.329^{d}	0.292^{e}	0.346^{b}	0.266^{e}	0.274^{e}
SE (m)	0.034	0.014	0.01	0.007	0.006	0.006	0.004	0.004	0.003
CD (0.05)	0.101	0.042	0.03	0.022	0.019	0.017	0.011	0.012	0.01

Values are mean of 3 replications. ANOVA for RBD was done. Values with same superscript alphabet indicate that the treatments are not significantly different; whereas, different alphabets indicate significant difference at 5% level of significance

3.3 Yield Attributes

The number of productive tillers, grain yield, and straw yield differed significantly among treatments (Table 4). Productive tillers ranged from 3 in T1, T4, T6, and T9 to 7 in T7, with T7 (Dolomite applied 125 % based on Ca equivalent) recording a significantly higher number than all other treatments, followed by T2 (Lime applied as per POP of KAU 2016) and T8 (Gypsum applied 125 % based on Ca equivalent) ie, 5 tillers. Treatments T3 (Dolomite applied 100 % based on Ca equivalent) and T5 (Calcium silicate applied 100 % based on Ca equivalent) produced a moderate number of tillers (4), while the control remained among the lowest.

Significantly superior grain yield of 8800.00 kg ha^{-1} was recorded in T7 (Dolomite applied 125 % based on Ca equivalent), followed by T3 (7600.00 kg ha^{-1}) and T5 (6380.00 kg ha^{-1}), whereas the lowest yield was recorded in control. Straw yield also differed significantly with 18463.09 kg ha^{-1} in T7 (Dolomite applied 125 % based on Ca equivalent), followed by T3 (Dolomite applied 100 % based on Ca equivalent) and T5 (Calcium silicate applied 100 % based on Ca equivalent), which were statistically on par and lowest (7266.56 kg ha^{-1}) in T1. Overall, T7 (Dolomite applied 125 % based on Ca equivalent) consistently recorded the highest productive tillers, grain yield, and straw yield, demonstrating its clear superiority, while T1 showed the poorest performance.

The excellent results of T7 might be explained by better soil pH, higher availability of nutrients, and lower toxicity of aluminium and iron due to dolomite application. Calcium and magnesium provided by dolomite contributed to more intensive growth of roots, nutrient absorption, and development. Better availability of nitrogen, phosphorus, and potassium helped to increase tillering, biomass accumulation, and grain formation, thus improving productivity. Several research works have consistently proved the positive effects of the application of dolomite on rice growth and yield in acidic soils. Mansingh and Suresh (2022) and Devi *et al.* (2023) found that the application of dolomite improved plant height, tillers, and productive tillers in strongly acidic and acid sulfate soils. The application of dolomite improved rice growth and yield due to the amelioration of soil pH and the supply of calcium and magnesium, which improved rice growth and yield, as proved by Caires *et al.* (2006). Earlier research works by Varghese and Money (1965) and later research works by Biswas *et al.* (2013) and Koruth *et al.* (2013) found that the application of Ca-Mg through the application of dolomite or Mg fertilizer improved grain yield and straw yield in magnesium-deficient soils. Furthermore, Suriyagoda *et al.* (2017) found that the application of dolomite improved rice yield by mitigating iron toxicity and improving the level of P and K in the plants. In agreement with the above study, Mansingh *et al.* (2019) observed increased yield and returns in rice plants with the application of dolomite and fertilizers in acidic soils.

Table 4. Effect of soil ameliorants on the yield attributes of the plant

Treatments	No of productive tillers (nos)	Yield (kgha^{-1})	Straw (kgha^{-1})
T1	3^{d}	4066.66^{h}	7266.556^{g}
T2	5^{b}	4750.00^{g}	13444.617^{d}
T3	4^{c}	7600.00^{b}	17109.372^{b}
T4	3^{d}	5133.33^{f}	8018.667^{f}
T5	4^{c}	6380.00^{c}	16803.033^{b}
T6	3^{d}	5733.33^{d}	15517.205^{c}
T7	7^{a}	8800.00^{a}	18463.088^{a}
T8	5^{b}	4150.00^{h}	15349.733^{c}
T9	3^{d}	5366.66^{e}	11722.292^{e}
SE (m)	0.072	65.823	181.851
CD(0.05)	0.217	197.337	545.188

Values are mean of 3 replications. ANOVA for RBD was done. Values with same superscript alphabet indicate that the treatments are not significantly different; whereas, different alphabets indicate significant difference at 5% level of significance

4. Conclusion

From the results of the experiment, it can be concluded that the application of soil ameliorants such as dolomite, lime, gypsum, and calcium silicate is effective in reducing soil acidity and improving rice productivity in coastal sandy soils. The application of liming materials was found to significantly increase grain and straw yields of rice, along with major yield attributes such as plant height and number of productive tillers. In addition, liming materials increased the availability of major nutrients, leading to increased concentrations of macronutrients in the soil and plant tissues. Among the soil ameliorants tested in the experiment, dolomite at 125% based on calcium equivalent applied at two equal splits at tillering and panicle formation was found to be the most effective treatment. It increased the biometric and yield attributes of rice. It can be explained by the improvement of soil pH and increased availability of essential macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur in the soil-plant system.

Overall, the experiment has demonstrated that the use of non-conventional soil ameliorants such as dolomite is a viable and sustainable management tool for improving soil health and rice productivity in acidic coastal sandy soils.

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Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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