ISSN 0258-7122 (Print), 2408-8293 (Online)
Bangladesh J. Agril. Res. 50(3): 247-262, September 2025

EFFECT OF LIMING ON GROWTH, YIELD AND PROFITABILITY OF NAGA CHILI (*CAPSICUM CHINENSE JACQ*) IN ACIDIC SOIL

F. AHMED[1*], J. C. SARKER[2], M. M. RAHMAN[3], S. M. L. RAHMAN[4]
AND M. H. M. B. BHUYAN[5*]

Abstract

Acidic soil conditions often limit the nutrient availability and plant development, thereby reducing agricultural productivity. Hence, a field investigation was conducted during 2020 and 2021 cropping seasons at the Spices Research Sub-Station, Jaintapur, Bangladesh Agricultural Research Institute, Sylhet to evaluate the effect of liming on acidic soils to optimize the vegetative growth, yield, and profitability of Naga chili (*Capsicum chinense* Jacq.). In this study, dolomite was used as a liming material. A randomized complete block design was employed with three replications. The experiment consisted of six treatments as liming doses which were- 0 (control), 0.5, 1.0, 1.5, 2.0, and 2.5 t ha^{-1}. Results revealed that lime application in acidic soil significantly boosted plant growth, fruit yield attributes, fruit yield, and economic profitability. The highest fruit yields of Naga chili were recorded 9.89 t ha^{-1} in 2020 and 7.51 t ha^{-1} in 2021 with 2.5 t ha^{-1} lime application. This was followed by 2.0 t ha^{-1} lime, which produced fruit yield, 9.20 t ha^{-1} in 2020 and 6.64 t ha^{-1} in 2021. The control treatment yielded the lowest, with 3.89 t ha^{-1} in 2020 and 3.61 t ha^{-1} in 2021. In 2020, the maximum marginal rate of return (MRR) was 1,515% with 1.5 t ha^{-1} of lime, while in 2021, it reached 970% with 1.0 t ha^{-1}. The highest average MRR (1,115%) was recorded at a liming rate of 1.0 t ha^{-1}. Consequently, applying either 1.0 t ha^{-1} or 1.5 t ha^{-1} of lime proved to be the most economically viable treatment for Naga chili cultivation in the acidic soils of Bangladesh.

Keywords: Naga chili, liming, dolomite, soil acidity, yield and MRR.

Introduction

Crops are facing a wide range of environmental stressors in the field condition, a direct consequence of global climate change (Chaki *et al*., 2020). Among these, soil acidity, characterized by a low soil pH, is a major hindrance to agricultural productivity, second only to drought. It not only reduces crop yields but also negatively impacts the structural and functional diversity of microbial communities in the soil (Hao *et al.,* 2020). Soil acidity results from various factors, including the removal of basic elements through leaching and crop uptake, the decomposition of organic matter, acid rain, the nitrification of ammonium-based nitrogen

[1,2&5]Citrus Research Station, Bangladesh Agricultural Research Institute (BARI), Jaintapur, Sylhet, [3]Fruit Division, Horticulture Research Center, BARI, Gazipur, and [4]Farm Division, BARI, Gazipur, Bangladesh.

fertilizers, and natural soil-forming processes. Globally, acidic soils are found across 30–40% of the world's arable land, being particularly common in humid tropical, subtropical, and temperate climates (Bhuyan *et al.*, 2019). Bangladesh has approximately, 8.59 million hectares of cropland, with a substantial portion suffering from acidity. About 2.78 million hectares are extremely acidic (pH below 4.5), and another 3.64 million hectares are very strongly acidic (pH 4.5 to 5.5) (SRDI, 2020). Furthermore, acid soils often contain excessive levels of aluminum (Al), iron (Fe), and manganese (Mn). These can create toxic conditions for crops, leading to stunted crop growth and significantly reduced yields (Bhuyan *et al.,* 2019). As a result, farmers frequently struggle to achieve expected harvests from their fields. To attain optimal crop yields, it becomes essential to adopt an appropriate measure for managing the high levels of soil acidity. Various soil amendments, liming stands out as a well-established and effective method for reducing soil acidity in agricultural settings (Kätterer *et al.,* 2019). Liming increases soil pH by neutralizing excess hydrogen ions (H^+) in the soil solution, which in turn boosts crop production. Chemically, liming displaces the acidic cations like H^+, Fe^{2+}, Al^{3+}, Mn^{4+}, and Cu^{2+}, from the plant root zone. This process also increases the availability of essential plant nutrients like calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the soil. Some common materials are used for liming, including: calcium carbonate (lime), calcium/magnesium carbonate (dolomitic lime or agricultural lime), calcium oxide and calcium hydroxide. Beyond pH adjustment, lime application promotes the growth of beneficial soil microorganisms and supports earthworm activity in soil. Both of these contribute positively to overall soil structure and health (Mahmud and Chong, 2022).

Soil acidity in the northeastern hilly region of Bangladesh, caused by high rainfall, leaching of basic cations, and organic matter decomposition, results in a low soil pH. This acidic environment hampers Naga chili (*Capsicum chinense* Jacq.) cultivation, leading to stunted growth, nutrient deficiencies and poor fruit development, preventing the plants from reaching their full genetic potential (Zahid *et al.*, 2020). Naga chili, locally known as 'Naga Morich,' or Dorset Naga, is economically and culturally significant in Bangladesh, especially in the northeastern hilly region, due to its intense pungency and unique flavor. It is a crucial cash crop and a staple in traditional cuisine, supporting local farmers' livelihoods (Bhuyan *et al*., 2015; Kumar *et al.,* 2022). While chili peppers (*Capsicum annuum* L.) are known to respond well to lime application in acidic soils, with several studies highlighting its positive impact on chili cultivation. But specific and detailed information on liming for Naga chili is lacking. Therefore, determining the appropriate lime application rate for Naga chili cultivation is essential. Keeping the above facts in view, a study was conducted to find out the efficacy of liming in acidic soils on the growth, yield and profitability of Naga chili (*Capsicum chinense* Jacq.) cultivation in the northeastern hilly region of Bangladesh.

Materials and Methods

Study location

The experiment was carried out at Spices Research Sub-Station, Citrus Research Station, Bangladesh Agricultural Research Institute (BARI) during 2020 to 2021. The study area is situated at 25.13562° N latitude and 92.13217° E longitude, with an average elevation of 34 meters. The experimental site is located on the northern and eastern piedmont plains (AEZ-22). The soil of the study area is sandy loam in texture with gravels and exhibits a reaction from extremely acidic to very strongly acidic (4.2 to 4.5). The soil analysis stated that the present status of nitrogen 0.14%, potassium 0.26 meq 100 g^{-1} soil, calcium 1.09 meq 100 g^{-1} soil, magnesium 0.57 meq 100 g^{-1} soil, sulfur 20.62 µg g^{-1} soil, zinc 3,07 µg g^{-1} soil and boron 1.56 µg g^{-1} soil. The organic matter content in these soils is low to medium.

Climatic condition of the study location

The experimental site is experienced with a unimodal rainfall pattern, with the highest rainfall occurring in June and July. The area is characterized by hot and humid summers and relatively cool and dry winter Average annual temperatures range from a low of 9.48°C in January to a peak of 35.5°C in May. Mean monthly rainfall is highest in June (762 mm) and lowest in January (2 mm) (Islam *et al.,* 2019).

Seed source, seedling rising and land preparation

For the first-year experiment, healthy Naga chili seeds were sourced from a local farmer in Jaintapur Upazila, Sylhet district. Subsequently, the seeds for the second-year study were obtained from the Naga chili plants cultivated during that initial experiment. Seeds were manually sown in seed beds during the first week of October in both experimental years. Watering occurred immediately after seed sowing. After one week, the emerging seedlings were transplanted into 3x5-inch poly tubs to promote optimal growth. These transplanted seedlings received irrigation twice weekly. Seedlings were secured from diseases and insects by application of Autostin®50WG fungicide and Sevin® insecticide. During the seedling growth period, the main research plots underwent methodical preparation, involving cross-ploughing and laddering. Subsequent to this, all weeds and debris were manually cleared.

Experimental design, treatments and fertilizer application

A randomized complete block design was employed with six treatments (liming rates): T_1: control (No lime), T_2: 0.5 t ha^{-1}, T_3: 1.0 t ha^{-1}, T_4: 1.5 t ha^{-1}, T_5: 2.0 t ha^{-1}, T_6: 2.5 t ha^{-1} lime. Each treatment was replicated three times. Dolomite lime [$CaMg(CO_3)_2$] was applied as the liming material. Fertilizers were applied @ 100-

50-120-20-2-1.5 kg ha^{-1} N-P-K-S-Zn-B along with 10 t ha^{-1} decomposed cow dung (Sarker *et al.,* 2018). The experimental unit plot size was 2.4 m × 1.5 m, with plants spaced at 100 cm × 60 cm. The adjacent plots were separated by a 0.75 m space, and each replication was separated by a 1 m space. Dolomitic lime was incorporated into each plot according to the specific treatment. The plots were then left for two weeks to ensure the lime was thoroughly mixed with the soil. The sources of N, P, K, S, Zn and B were urea, triple super phosphate (TSP), muriate of potash (KCL), gypsum, zinc sulphate heptahydrate and boric acid, respectively. During the final plot preparation, 50% of the cowdung and TSP, along with the entire quantities of gypsum, zinc sulfate, and boric acid, were applied to the plots. The remaining cowdung and TSP were incorporated into the seedling transplanting pits. Urea and MoP were applied as a top dressing in five equal splits at different growth stages which are- a) at 15 days after transplanting, b) at flowering, c) at fruit setting, d) at first harvest, and e) at 2nd harvest of chilies.

Transplanting of seedlings and intercultural operation

In both experimental years, fifty-day-old Naga chili seedlings were transplanted to the main plots during the third week of November, with a spacing of 100 cm between rows and 60 cm between plants. The planted seedlings were immediately watered by a hose pipe. The irrigations were done as per requirement to enable the proper establishment of plants. The research field was monitored regularly to ensure healthy crops during establishment. Any injured, dead, or weak seedlings were replaced with vigorous new ones in the same planting pit. The entire experimental area was covered with a blue net to control insect pests and prevent outcrossing. To maintain weed-free plots, three manual weeding were conducted at 15, 45, and 75 days after transplanting. Irrigation was scheduled based on soil moisture requirements to ensure optimal plant growth. During the experiment, minor infestations of aphids and mites occurred, which were managed using appropriate insecticides and acaricides. Additionally, fruit rot was observed during harvest, and this issue was controlled through timely fungicide applications. Green chilies were ready for harvest 105 days after transplanting, while ripening began at 120 days post-transplanting. Harvesting was conducted on a bright, sunny day, with great care taken to avoid any injury to the plants. Both green and ripe chilies were then transported to the laboratory for analysis of fruit quality parameters.

Data collection

For data collection, three plants were randomly selected from each treatment plot. Before harvest, the following parameters were measured from the standing plants. Plant height was measured from the soil surface to the topmost point of the plant and expressed in meters (m). Canopy volume was determined by first measuring plant spread in both east–west and north–south directions at the widest points in centimeters. Afterwards, the canopy volume was calculated using the appropriate geometric formula and expressed in cubic meters (m^3). Stem diameter was measured at 15 cm above the ground using a caliper and recorded in centimeters (cm). Five fruits from each treatment were randomly selected to measure fruit size (length and breadth) and single fruit weight. However, fruit length was measured from the apex to the base of the chili fruit and expressed in centimeters (cm). Fruit breadth was measured at the widest point using two perpendicular directions, and the average of the two values was taken and recorded in centimeters (cm). Single fruit weight was measured individually using a precision balance and expressed in grams (g). The number of primary branches was counted at the point of first branching, representing the actual number of main branches. The number of fruits per plant was determined by counting fruits from randomly selected three plants. Fruit yield was calculated after the final harvest from each treatment, averaged, and converted to a per-hectare basis.

Economic analysis

To assess the economic viability of the treatments, partial budget, dominance and marginal analyses were done. This post-experimental MRR estimation was performed to provide valuable insights to the farmers. For determining the most economically acceptable liming doses, dominance and marginal analyses were used (Elias and Karim, 1984). Marginal rate of return is calculated by the following equation:

MRR= (AdB/AdC) × 100, where, MRR=marginal rate of return, AdB=Additional benefits between each pair of cost Undominated treatments, AdC=Additional costs between each pair of cost Undominated treatments.

Data analysis and interpretation of the results

The collected data underwent compilation, rectification, and validation prior to statistical analysis, which was performed using R statistical software (version 4.2.0). For interpreting the results, treatment means were separated using the Least Significant Difference (LSD) test at 5% probability level.

Result and Discussion

Influence of liming on the growth parameters of Naga chili

The application of different liming doses significantly influenced the growth parameters of Naga chili. The growth parameters showed an increasing trend with the increasing rates of lime application, and marked variations were observed across the growing seasons of the two consecutive study years 2020 and 2021 (Table 1). The results clearly demonstrated that liming significantly influenced the vegetative growth parameters of Naga chili. The observed improvements in plant height, canopy volume, stem diameter, and number of primary branches in response to lime application can be attributed to the amelioration of soil acidity and the consequent enhancement of nutrient availability and uptake.

Plant height

This character exhibited slight but consistent significant improvements with liming (Table 1). In 2020, the tallest plants (1.00 m) were recorded at 2.5 t ha^{-1} while the shortest plant (0.95 m) was observed at 0.5 t ha^{-1}. Notably, plant height showed a more pronounced response to liming and was significantly higher in 2021 than in 2020 across all the treatments. In 2021, plant height ranged from 1.37 m to 1.63 m. The tallest plant (1.63 m) was found at 2.5 t ha^{-1} while the shortest plant (1.37 m) was found from the control treatment. Plant height reflects overall vigor and shoots elongation of the plants which increased modestly in the first year but more markedly in the second year of the present study. The maximum plant height at 2.5 t ha^{-1} suggested that, the alleviation of sub-optimal pH conditions likely enhanced uptake of essential nutrients such as nitrogen and calcium—both of which play pivotal roles in cell division and elongation (Marschner, 2012). The observation of the present study also corroborated the findings of other researchers. Liming can boost plant height by raising the pH of acidic soil, which encourages root growth and improves nutrient availability (Shaheb *et al.*, 2014). The result also aligns with the findings of other researchers, who noted that by increasing soil pH, liming enhances phosphorus availability and subsequently improve vegetative growth of the crops. Taufiq *et al.* (2011) also found that applying dolomite lime enhanced plant height compared to not using it. The greater difference in plant height in 2021 may also indicate a delayed but more substantial benefit as the lime continued to interact with the soil profile.

Canopy volume

This parameter responded notably to liming and increased steadily with liming dose, particularly in 2021 (Table 1). The control plots recorded the smallest canopy volumes (0.33 m^3 in 2020 and 0.92 m^3 in 2021 respectively), while the maximum canopy spread was observed at 2.5 t ha^{-1} (0.45 m^3 in 2020 and 1.27 m^3 in 2021 respectively). The increase of the canopy volume from the control to the highest liming level was statistically significant in both the study years suggesting enhanced vegetative growth under improved soil conditions. Canopy expansion depends on both vertical and lateral growths, which are highly sensitive to nutrient availability and hormonal regulation within the plant. The significant increase in canopy volume at higher lime rates, especially in the second year, underscores the role of liming in promoting balanced vegetative growth. Acidic soils often limit root expansion, which in turn restricts canopy development due to poor water and nutrient acquisition. By neutralizing hydrogen ions toxicity, lime can improve soil structure and root proliferation, thereby enhancing shoot architecture and ultimately larger canopy of the plants (Barros *et al.*, 2020). The improvement in canopy volume is further supported by the findings and interpretation of other researchers, who stated that liming raised soil pH, enhanced nutrient availability in the soil resulting in improved root growth, which positively increased the growth and biomass (Shaheb *et al.*, 2014).

Stem diameter

Stem diameter progressively increased with higher rate of lime application (Table 1). In 2020, the diameter ranged from 1.53 cm in the control to 1.77 cm at 2.0 t ha^{-1}. In 2021, a more notable response was observed with stem thickness reaching 1.30 cm in the control to1.87 cm in 1.5 t ha^{-1} having statistically significant differences among treatments. The increase in stem diameter with higher lime rates improved structural development of the plants. A thicker stem is often correlated with stronger vascular tissues, which facilitate better translocation of water and nutrients. Enhanced stem diameter observed in liming treatments is probably the result of improved calcium nutrition, as calcium is a key component of cell walls and plays a crucial role in maintaining structural integrity (Marschner, 2012). Gopalakrishnan *et al.* (2015) reported a significant increase in stem diameter in chili plants grown in limed acid soils compared to non-limed control, which was attributed to better nutrient uptake and reduced H^+ and Al^{3+} toxicity. Similarly, Singh *et al.* (2019) found that, liming increased stem girth in *Capsicum annuum*, supporting that lime application can effectively ameliorate the constraints under acid soil conditions.

Table 1: Effect of liming rates on the growth parameters of Naga chili

Liming dose (t ha^{-1})	Plant height (m)		Canopy volume (m^3)		Stem diameter (cm)	
	2020	2021	2020	2021	2020	2021
Control (No lime)	0.96	1.37	0.33	0.92	1.53	1.30
0.5	0.95	1.58	0.36	1.18	1.60	1.43
1 .0	0.98	1.43	0.40	0.96	1.68	1.63
1.5	0.96	1.42	0.40	0.97	1.70	1.87
2.0	0.98	1.60	0.45	1.03	1.77	1.43
2.5	1.00	1.63	0.45	1.27	1.73	1.70
LSD (0.05)	2.44	17.97	0.03	0.41	0.11	0.19
CV (%)	1.38	6.57	3.74	21.37	3.56	6.58

Lime material: Dolomite

Influence of liming on the fruit characters of Naga chili

The application of varying liming doses significantly influenced the fruit quality parameters of Naga chili during the study years (2020 and 2021) (Table 2). The key parameters studied were fruit length**,** fruit breadth, and single fruit weigh which exhibited a positive response to liming, although the degree of improvement varied between years and treatments.

Fruit length

Fruit length increased progressively with liming peaking (6.43 cm) at 0.5 t ha^{-1} in 2020 (Table 2). However, in 2021, maximum fruit length (6.10 cm) was observed at both 2.0 t ha^{-1} and 2.5 t ha^{-1} of lime, indicating a stronger positive response to higher liming rates in that specific year (2021). This suggests that while moderate liming was effective in the first year, higher doses may be needed to buffer inter-annual soil variability or differences in environmental conditions. The LSD values (0.35 in 2020 and 1.11 in 2021) confirm that these differences were statistically significant. Liming improves soil pH, enhances nutrient availability, particularly Ca, Mg, K and B and reduces H^+ and Al^{3+} toxicity in acidic soils, all of which are critical for cell elongation and division as well as fruit expansion and development during fruit development (Mengel and Kirkby, 2001). Similar trends were reported by Singh *et al.* (2017) in *Capsicum annum*, who found liming significantly increased fruit length. The broader fruits at higher lime rates could also be indicative of improved water and turgor regulation, both of which are often disrupted in acidic soils due to poor root function.

Fruit breadth

Fruit breadth was also positively influenced by liming (Table 2). The highest fruit breadth was recorded at 2.5 t ha^{-1} in both years (2.43 cm and 2.27 cm in 2020 and 2021, respectively), clearly exceeding the control (1.97 cm and 1.60 cm in 2020 and 202,1 respectively). Notably, the differences were significant, with relatively low coefficients of variation (CV) in both years (5.15% and 3.20%), indicating consistency in response. Increased calcium is known to strengthen cell walls and support better fruit girth and integrity (Marschner, 2012), which was probably attributed to liming. Moreover, enhanced availability of micronutrients such as boron and zinc due to improved soil pH may also play a role in cell wall formation and expansion, thereby improving fruit breadth (Mengel and Kirkby, 2001). Interestingly, the broader fruit dimensions under limed conditions could also signal better cell division and elongation during fruit formation.

Single fruit weight

Single fruit weight showed noticeable response to liming (Table 2). In both the experimental years, liming 2.5 t ha^{-1} treatment produced the heaviest fruits (5.37 g in 2020 and 5.36 g in 2021) representing a substantial increase over the control (3.63 g and 4.20 g in 2020 and 2021, respectively). Improved fruit weight can be attributed to enhance nutrient uptake, particularly N, P, and Ca, essential for biomass accumulation and fruit filling. Acidic soils often inhibit root function and nutrient mobility; liming reverses these effects leading to better plant growth and fruiting. Besides, Calcium is essential for cell wall formation and firmness and its uptake is severely limited in acidic soils (Marschner, 2012). Therefore, the significant increase in single fruit weight with liming could be attributed to improved calcium nutrition from liming. Despite some environmental variability, the consistent improvement in fruit weight across the years, underlines the stabilizing effect of lime on nutrient availability and plant metabolism. The findings align with Mishra *et al.* (2014) who reported significant increases in fruit weight of chili with lime application in acidic soils of northeast Indian region.

Table 2: Effect of liming rates on fruit quality parameters of Naga chili

Liming dose (t ha^{-1})	Fruit length (cm)		Fruit breadth (cm)		Single fruit weight (g)	
	2020	2021	2020	2021	2020	2021
Control (No lime)	5.8	5.17	1.97	1.60	3.63	4.20
0.5	6.43	5.07	2.10	1.97	4.47	4.78
1 .0	6.17	5.37	2.17	2.03	4.70	5.11
1.5	6.37	5.50	2.23	1.90	4.57	4.94
2.0	6.07	6.10	2.37	2.07	4.83	4.98
2.5	6.40	6.10	2.43	2.27	5.37	5.36
LSD (0.05)	0.35	1.11	0.21	0.11	0.32	0.26
CV (%)	3.08	11.01	5.15	3.20	3.85	2.97

Lime material: Dolomite

Influence of lime on yield attributes and yield

The yield-contributing parameters and fruit yield of Naga chili were significantly influenced by the application of lime. which regulates soil pH and maximizes crop productivity in acidic soils. Acidic soils often suffer nutrient deficiencies, particularly Ca, Mg, and P, and may exhibit H^+ and Al^{3+} toxicity, all of which severely affect the yield contributing parameters and yield Naga chili. In our study the data demonstrated a consistent positive trend in number of primary branches, and number of fruits per plant, which lead to increase fruit yield per hectare, particularly at higher liming rates during the experimental years 2020 and 2021.

Number of primary branches per plant

Number of primary branches per plant increased in response to liming (Table 3). All the treatments showed a modest increase over the control. In 2020, the lowest number of primary branches 2.00 was found from both control and 2.0 t ha^{-1} treatments, while the maximum number of primary branches was from 2.5 t ha^{-1} (2.67). The effect was more distinct in 2021, where plants received 0.5 and 2.5 t ha^{-1} lime produced the highest number of primary branches (3.00), compared to the control (2.00). The differences were statistically significant, highlighting the role of lime in promoting lateral growth. Branching is closely regulated by plant growth regulators (PGRs) especially auxins and cytokinins. The balance between these two PGRs can be disturbed by nutrient stress induced by soil acidity. In this study, the number of primary branches significantly influenced by liming, particularly in the second year and plants grown under 2.5 t ha^{-1} lime producing more branches, suggesting better lateral growth and potentially higher flowering and fruiting sites. By mitigating soil acidity and its associated nutrient imbalances, lime likely created a more conducive environment for hormonal regulation and meristem activity thereby promoting branching. This observation also corroborates with the findings of Singh *et al.* (2019), who reported that liming increased the number of primary branches per plant in *Capsicum annuum* grown in acidic soils. This was attributed to improved calcium availability and overall nutrient uptake. In a study by Gopalakrishnan *et al.* (2015), chili plants grown in limed plots had significantly more primary branches compared to non-limed controls. Similar outcomes have been observed in other horticultural crops, such as tomato and eggplant, where lime application promoted branching and flowering due to improved nutrient status.

Number of fruits per plant

This parameter increased progressively with the increased application of lime, which rose from control (119 in 2020) and 76 in 2021) to 2.5 t ha^{-1} lime (204 in 2020 and 155 in 2021) (Table 3). These results suggest that liming improved the reproductive capacity of the plants by alleviating stress caused by acidic conditions and increasing the availability of key nutrients (Roy *et al.*, 2014). This substantial increase also underlines the profound effect of lime on reproductive growth, likely due to improved root activity and better hormonal balance, photosynthate translocation and nutrient partitioning and all of which are essential for flowering and fruit set (Marschner, 2012). The greater number of fruits also aligns with the observed improvements in vegetative traits (Table 1) such as branching and canopy development which directly influence fruit-bearing potential. However, the decline in fruit number at the highest lime rate in 2020 may indicate that excessive liming could lead to micronutrient imbalances or other soil-chemical interactions that marginally affect reproductive efficiency.

Fruit yield per hectare

Fruit yield per hectare followed a similar trend and showed a marked and statistically significant response to lime application (Table 3). The result illustrated that the control treatment yielded the lowest-3.89 t ha^{-1} in 2020 and 3.61 t ha^{-1} in 2021, whereas the maximum yield was recorded at 2.5 t ha^{-1} lime (9.89 t ha^{-1} in 2020 and 7.51 t ha^{-1} in 2021) which were significantly higher than all other treatments. The results also showed that, the yield increment from non-limed control to liming at 2.5 t ha^{-1} representing yield increment of over 150% compared to the control. Such a dramatic improvement reinforces the role of lime in unlocking the productive capacity of acidic soils. This result is consistent with previous findings that, liming not only improves soil chemical properties but also boosts biological activity and root efficiency resulting in greater yield potential (Barros *et al.*, 2020). By raising soil pH and reducing exchangeable aluminum, liming improves soil chemical environment leading to enhance plant growth and fruiting efficiency. Moreover, even moderate lime applications (1.0–1.5 t ha^{-1}) significantly improve yields, the highest response was observed at 2.5 t ha^{-1} suggesting this as a possible optimum dose under the given conditions. Moreover, calcium plays a crucial role in developing a more extensive root network facilitates, absorbing greater quantities of other essential mineral nutrients and consequently enabling higher fruit yields. The highest fruit yield ha^{-1} resulted from the combined application of lime, organic, and inorganic fertilizers (Chuong, 2019). This observation also corroborated the findings of other researchers. Taufiq *et al.* (2011) found that applying dolomitic lime improved overall yield compared to not using it. This is likely because liming optimizes the soil's chemical environment, improving plant nutrient uptake and translocation from roots to fruits. Consequently, plots treated with lime consistently produce significantly more marketable fruits than non-limed plots. However, this should be evaluated further through cost-benefit analyses to ensure economic viability for farmers.

Table 3. Effect of liming rates on the yield contributing characters and yield of Naga chili

Liming dose (t ha^{-1})	Primary branches (No.)		Fruits $plant^{-1}$ (No.)		Fruit yield (t ha^{-1})	
	2020	2021	2020	2021	2020	2021
Control (No lime)	2.00	2.00	119	76	3.89	3.61
0.5	2.33	3.00	133	96	5.33	4.49
1 .0	2.33	2.33	158	121	6.69	5.56
1.5	2.33	2.67	201	135	8.30	6.03
2.0	2.00	2.33	211	148 b	9.20	6.64
2.5	2.67	3.00	204	155	9.89	7.51
LSD (0.05)	NS	NS	15.51	5.26	0.90	0.34
CV (%)	19.08	22.21	4.99	2.37	6.82	3.30

Lime material: Dolomite

Economics

Partial budget analysis

A partial budget was developed as a part of economic analysis to calculate the total costs that vary (lime cost) and the gross margin for each treatment of the liming experiment. The highest gross return (Tk 19,78,000 ha^{-1} in 2020 and Tk 15,02,000 ha^{-1} in 2021) and gross margin (Tk 18,78,000 ha^{-1} in 2020 and Tk 14,02,000 ha^{-1} in 2021) was obtained from 2.5 t ha^{-1} liming dose followed by 2.0 t ha^{-1} lime and so on upto 1.0 t ha^{-1} lime (Table 5). The lowest gross margin (Tk 7,78,000 ha^{-1} in 2020 and Tk 722000 ha^{-1} in 2021) was obtained from control treatment (Table 4).

Table 4. Partial budget analysis of Naga chili production as influenced by different lime doses during 2020 and 2021 cropping seasons

Lime dose (t ha^{-1})	Lime cost (Tk ha^{-1}) (2020 & 2021)	Gross return (Tk ha^{-1})		Gross margin (Tk ha^{-1})	
	2020	2020	2021	2020	2021
0.0 (control)	0.0	7,78,000	7,22,000	7,78,000	7,22,000
0.5	20,000	10,66,000	8,98,000	10,46,000	8,78,000
1.0	40,000	15,02,000	11,12,000	12,98,000	10,72,000
1.5	60,000	16,60,000	12,06,000	16,00,000	11,46,000
2.0	80,000	18,40,000	13,28,000	17,60,000	12,48,000
2.5	100,000	19,78,000	15,02,000	18,78,000	14,02,000

Lime (dolomite) price: Tk 40 kg^{-1}, produce (fresh fruit) sale price: 200 kg^{-1}

Dominance analysis

For dominance analysis, the treatments were listed in order of increasing total costs that vary (lime cost). The gross margin also increased with the increasing rate of lime (Table 5). Table 5 showed that there was no cost dominated treatments because no treatment had higher lime cost but lower in gross margin. The treatment which possesses higher lime cost but lower in gross margin is called a cost dominated treatment. It is seen that all liming treatments including control (no lime) are cost undominated.

Table 5. Dominance analysis of Naga chili production as influenced by different doses of lime during 2020 and 2021 cropping seasons

Lime dose (t ha-1)	Lime cost (Tk ha^{-1})	Gross margin (Tk ha^{-1})		Remarks	
	(2020 & 2021	2020	2021	2020	2021
2.5	100,000	1,87,8000	14,02,000	CUD	CUD
2.0	80,000	1,76,0000	12,48,000	CUD	CUD
1.5	60,000	1,60,0000	11,46,000	CUD	CUD
1.0	40,000	1,29,8000	10,72,000	CUD	CUD
0.5	20,000	10,46,000	8,78,000	CUD	CUD
Control (no lime)	0.0	7,78,000	7,22,000	CUD	CUD

CUD = Cost Undominated

Table 6. Marginal analysis of Cost- undominated treatments applied in Naga chili at TCRC, Bogura

Lime dose (t ha^{-1})	Lime cost (Tk ha^{-1}) (2020 & 2021	Gross margin (Tk ha^{-1})		Marginal increase in lime cost (Tk ha^{-1})	Marginal increase in gross margin (Tk ha^{-1})		MRR (%)		
	2020	2020	2021	2020 & 2021	2020	2021	2020	2021	Mean
2.5	100,000	18,78,000	14,02,000	20,000	1,18,000	1,54,000	590	770	680
2.0	80,000	17,60,000	12,48,000	20,000	1,60,000	1,02,000	800	510	655
1.5	60,000	16,00,000	1,146,000	20,000	3,02,000	74,000	1510	370	940
1.0	40,000	12,98,000	10,72,000	20,000	2,52,000	1,94,000	1260	970	1115
0.5	20,000	10,46,000	8,78000	20,000	2,68,000	1,56,000	1340	780	1060
Control (no lime)	0.000	77,8000	7,22,000	-	-	-		-	-

Marginal rate of return (MRR)

The highest marginal rate of return for changing from 1.0 t ha^{-1} lime to 1.5 t t ha^{-1} lime was 1510% in 2020 and from 0.5 t ha^{-1} lime to 1.0 t ha^{-1} lime was 970% (Table 6). In this way, in 2020, the other higher marginal rate of returns found from 0.5 t ha^{-1} lime to 1.0 t ha^{-1} lime treatment, and 1.0 t ha^{-1} lime to 1.50 t ha^{-1} treatment was 1340 and 1260%, respectively. In 2021, the other higher marginal rate of returns observed from 0.5 t ha^{-1} lime to 1.0 t ha^{-1} lime treatment and 0.0 t ha^{-1} lime to 1.0 t ha^{-1} lime were 970% and 780%, respectively. In average MRR over two years, the maximum MRR recorded from changing 0.5 t ha^{-1} to 1.0 t ha^{-1} lime was 1115% which revealed that for every Tk 100 of additional investment, Tk 1115 was returned; this also means, if a farmer invests Tk 40,000, he could recover Tk 40,000, plus an additional amount of Tk 223,000. Application of 1.0 t ha^{-1} or 1.5 t ha^{-1} lime appeared as the best treatments for cultivation of Naga chili from economic point of view when considering MRR.

Conclusion

Based on the above results, it revealed that liming with dolomite significantly improved Naga chili growth and yield in acidic soils. Application of lime @ 2.5 t ha^{-1} consistently produced the best results across all measured growth, yield attributes and yield. While the control treatment consistently exhibited the lowest performance, even intermediate lime doses (0.5–1.5 t ha^{-1}) led to considerable improvements. However, the superior and consistent performance of 2.5 t ha^{-1} dose of lime over two years indicates that higher application of lime may be necessary to fully neutralize soil acidity and maximize Naga chili yield potential. Application of 1.0 t ha^{-1} or 1.5 t ha^{-1} lime was found the best treatments for cultivation of Naga chili from economic point of view when considering MRR. These results suggest that lime is a critical input for sustainable Naga chili production in acidic regions, offering both significant agronomic benefits and high economic returns. Future studies should be investigated regarding the impact of liming on the physicochemical properties of the soil and chili quality parameters, including the Scoville Heat Unit (SHU). This can provide a more integrated understanding of how liming affects chili production in acidic soil environments.

References

Barros, N. F., R. F. Novais and V. H. Alvarez. 2020. Soil acidity and liming: Theory and practice for tropical conditions. *Rev. Bras. Ciênc. Solo.* **44**: e0200024.

Bhuyan, M.H.M.B., M. Hasanuzzaman, K. Nahar, J.A. Mahmud, K. Parvin, T.F. Bhuiyan and M. Fujita. 2019. Plants behavior under soil acidity stress: Insight into morphophysiological, biochemical, and molecular responses. *In: Plant abiotic stress tolerance* (Ed. Hasanuzzaman, M., Hakeem, K., Nahar, K., Alharby, H.). Springer, Cham. pp.35-82.

Bhuyan, MHMB., SML. Rahman, R. Ara and JC. Sarker. 2015. Evaluation of Naga Chilli (*Capsicum chinense* Jacq.) genotypes under North eastern region of Bangladesh. *Sci. Agric.* **12**:40-45.

Chaki, M., J.C. Begara-Morales and J.B. Barroso. 2020. Oxidative stress in plants. *Antioxidants.* **9**: 481.

Chuong, N. V. 2019. Effect of lime, organic and inorganic fertilizers on soil chemical properties and yield of chilli (*Capsicum frutescens* L.). *AGU Int. J. Sci.* **7:**84 –90.

Elias, S. and M. Karim. 1984. Application of partial budget technique on cropping system research at Chittagong. AEER No 10 April. Report of Agri-cultural Economics Division, BARI, Joydebpur, Gazipur. pp. 75–71.

FAO. 2005. Fertilizer Use by Crop. Food and Agriculture Organization of the United Nations.

Gopalakrishnan, S., V. Srinivas, G. Alekhya and J. Prakash. 2015. Influence of liming on soil acidity and nutrient uptake in chili (*Capsicum annuum* L.). *Int. J. Plant Soil Sci.* **7:**102–110.

Hao, X., Zhu, Y.G., Nybroe, O. and Nicolaisen, M.H., 2020. The composition and phosphorus cycling potential of bacterial communities associated with hyphae of Penicillium in soil are strongly affected by soil origin. *Front. microbial.* **10**, p.2951.

Harter, R. D. 2007. Acid Soils: Causes, Management and Effects. *In: Encyclopedia of Soil Science*-2nd ed. (Ed. Lal, R.). CRC Press, Boca Raton, Florida, USA.

Islam, M., T.I. Imon and A.G. Polash. 2019. Analysis of rainfall variability in Sylhet region of Bangladesh. *J. Water Resour. Eng. Manage*. **6:**1-10.

Kätterer, T., D. Roobroeck, O. Andrén, G. Kimutai, E. Karltun, H. Kirchmann, G. Nyberg, B. Vanlauwe and K.R. de Nowina. 2019. Biochar addition persistently increased soil fertility and yields in maize-soybean rotations over 10 years in sub-humid regions of Kenya. *Field Crops Res*. **235**:18-26.

Kumar, R., A. Malik, and S. Kumar. 2022. Chilli (Capsicum chinense Jacq.) production and post-harvest management: An overview. *Pharma Inno. J.* **11:**752-756.

Lal, R. 2015. Restoring soil quality to mitigate soil degradation. *Sustainability*.**7:**5875-5895.

Mahmud, M.S. and K.P Chong. 2022. Effects of liming on soil properties and its roles in increasing the productivity and profitability of the oil palm industry in Malaysia. *Agriculture*. **12:**322.

Marschner, H. 2012. Marschner's mineral nutrition of higher plants. Academic press.

Mengel, K., and E. A. Kirkby. 2001. Principles of Plant Nutrition (5th ed.). Springer.

Mishra, A.C., V.K. Pandey and V.P. Rai. 2014. Effectiveness of fertilizer doses, liming and Rhizobium inoculation in vegetable pea under acidic soil of Jharkhand. *Asian J. Hort.* **9**: 140-142.

Roy, B., M.A. Satter and P.K. Saha. 2014. Liming to improve productivity of crops in acidic soils of Bangladesh. *Bangladesh J. Agric. Res.* **39:** 683–695.

Sarker, J.C., M.H.M.B. Bhuyan, S.M.L. Rahman, K. Chandra and M.M. Haque. 2018. Effect of NPKS on Growth and Yield of Naga Chili (*Capsicum chinense* Jacq.). *J. Hort. Sci. Forest.* **1**:1–7

Shaheb, M.R., M.I. Nazrul and M.A. Rahman. 2014. Production potential and economics of wheat as influenced by liming in north eastern region of Bangladesh. *Asian J. Agric. Biol*. **2**:152-160.

Singh, B., M.M. Dolk, Q. Shen and M. Camps-Arbestain. 2017. Biochar pH, electrical conductivity and liming potential. *In: Biochar: A guide to analytical methods* (Ed. Singh, B. Camps-Arbestain, M. and Lehmann, J.) Csiro Publishing. p.23.

Singh, R., P. Sharma and A. Verma. 2019. Effect of liming and nutrient management on growth and yield of chili under acidic soil conditions. *J. Pharma. Phytochem.* **8:**1776–1780.

SRDI (Soil Resource Development Institute). 2020. Land and Soil Resource Utilization Guide: Sylhet District. Ministry of Agriculture, Government of the People's Republic of Bangladesh.

Taufiq, A., A. Wijanarko and Suyamto. 2011. Effect of NPKS fertilizer, dolomite and manure on soybean yield in tidal land (in Indonesian). *J. Penelitian. Pertanian*. **30:** 52-57.

Zahid, A.M., N.A. Kohinoor, M.A. Hossain and J.U. Shoaib. 2020. Land degradation in Bangladesh: baseline study of land degradation processes 1985–2000. FAO supported Research Report, SRDI, Dhaka.