Optimizing Soil pH and Nutrient Availability for Wheat Productivity in Acidic Tista Floodplain Soils of Bangladesh: Assessing the Impact of Liming in Soil

Abstract

Lime is crucial for improving soil pH, enhancing nutrient availability, and promoting healthier plant growth in acidic soils. The objectives of the study were to identify the effects of liming on wheat on nutrients status of soil before and after harvest. Over three years, six experiments were conducted in various locations across Bangladesh, including Kishoreganj, Gangachara, Kurigram, and Rangpur districts, to assess the effects of liming on wheat productivity. Each year featured two experimental setups to evaluate soil and crop responses in different regions. A randomized complete block design (RCBD) experiment was conducted during the rabi season in the Tista Floodplain (AEZ-3). The application of various lime doses had a significantly positive impact on plant height, total number of tillers per hill, branches per plant, spike length, number of filled grains per spike, 1000-grain weight, and overall grain yield of wheat. Notably, a lime application of 1.0 tha^{-1} resulted in the highest grain yield. The contents and uptake of calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), and sulfur (S) were also significantly affected by the different treatments. Liming effectively helps reclaim acidic soils in the Tista Floodplain. Therefore, for acidic soils, the use of lime is recommended to enhance yield, yield-contributing traits, and nutrient availability.

Keywords: Liming; Acidic Soil; Nutrient Availability; Wheat Productivity; Grain Yield; Soil Reclamation.

1. Introduction

Soil acidification is the gradual decline in soil pH, causing the soil to become acidic (Adane, 2014; Smith & Hardie, 2022). This phenomenon occurs when hydrogen ions (H^+) are released into the soil due to reactions involving carbon (C), nitrogen (N), sulfur (S), and fertilizers. As a result, base cations are displaced and leached away, while the solubility of toxic elements like aluminum (Al^{3+}) and manganese (Mn^{2+}) increases (Bolan et al., 2003; Lesturgez et al., 2006). As soil pH decreases, the concentrations of aluminum (Al^{3+}) and hydrogen (H^+) cations rise, while essential base cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+) are washed out (von Uexküll and Mutert, 1995; Agegnehu et al., 2021). Base cations in the soil play a vital role in regulating acidification processes. However, their depletion poses a significant challenge, as they are essential for neutralizing soil acidity and supporting plant growth (Tian & Niu, 2015; Fenn et al., 2006). Acidic soils adversely affect agricultural productivity and account for over 30-40% of the global agricultural area (von Uexküll & Mutert, 1995; Bian et al., 2013; Alemu et al., 2022).

Soil acidification is primarily generated by many processes, such as acidic precipitation, acidifying gases deposition and environmental pollution (Yadav *et al*., 2020). The primary factors contributing to soil acidification in agricultural areas are the utilization of fertilizers including ammonium and urea, the usage of elemental sulfur fertilizers, and the cultivation of leguminous plants (Ashitha *et al.,* 2021). Acidification leads to the depletion of cations which leads to decrease in agricultural productivity. In extreme cases, acidification can result in irreversible dissolution of clay minerals and a decrease in the ability to exchange cations, leading to structural degradation (Dong *et al.,* 2022). The application of lime or other acid-neutralizing minerals helps to improve soil acidity.

A total number of 9.15 million people's live in this flood plain areas in five districts of Rangpur Division (Gaibandha, Kurigram, Lalmonirhat, Nilphamari, and Rangpur) (Parvin et al, 2024). Climate change is already affecting soil conditions of the area (Khatun et al., 2015; Huda et al., 2019; Karim et al., 2017; Sultana et al., 2018)

Various crops exhibit varying degrees of susceptibility to low soil pH (Hijbeek et al., 2021). Typically, in the presence of acidic soil, the Al3+ ions penetrate the cells of root tips and hinder the elongation of roots, resulting in stunted root growth. This, in turn, reduces the ability of the roots to absorb water and nutrients. Al3+ tolerant plants possess the capacity to eliminate Al3+ from their roots through the secretion of organic acids like citrate and malate, which form complexes with Al3+ (Sanjib Kumar Panda and Matsumoto, 2009). The ideal soil pH for most crops falls within the range of 6.0 to 7.0, as this allows all necessary nutrients to be present in accessible forms (Rosen & Bierman, 2005). Soil pH can be elevated by incorporating soil amendments with a neutralising impact, such as lime (Hijbeek et al., 2021). Liming has been identified in multiple studies as an effective method for raising soil pH. It is also considered one of the most cost-effective approaches for managing soil acidity (Orton et al., 2018). The primary constituents of liming materials are predominantly calcium and magnesium hydroxides, oxides, carbonates, and silicates (Anderson et al., 2013). The Romans utilized lime 2000 years ago to counteract acidity in agricultural soil, a practice that followed for millennia (Connor *et al.*, 2011). The fundamental aspects of soil acidity and the process of liming remain constant. A thorough and informative explanation of these concepts can be found in the works of Adams (1984), Kennedy (1992), and Rengel (2003).

Liming enhances the levels of Ca^{2+} and enhances the strength of ions in the soil solution, leading to the aggregation of clay particles and thus improving soil quality (Haynes & Naidu, 1998). Its additionally enhances microporosity and earthworm activity (Bolan *et* *al.,* 2003). Extensive studies have been conducted on the application of lime and other substances that neutralize acidity to enhance the quality of deteriorated soils. This research has been motivated by the positive impact of lime on soil structure. For instance, Kirkham *et al.* (2007) have extensively explored this topic. In a study conducted by Bennett *et al.* (2014), it was discovered that the application of lime at a rate of 5 metric tons per hectare continued to enhance many soil properties likes particles stability, electrical conductivity, plant cover, total carbon and nitrogen content even 12 years after the lime was applied.

This nation's agricultural productivity in terms of wheat production is below average (Zhang *et al.,* 2022). The disparity in yield can be attributed to various variables, encompassing both living and non-living components. The diminished production of wheat in tropical and subtropical regions can be ascribed to a multitude of variables. These factors encompass the absence of high yielding varieties, prevention of diseases and pests, and abiotic stresses and nutritional insufficiency. Among all these features, the most impactful factor that greatly impedes agricultural productivity is problematic soil, such as acidic soil and saline soil.

Bangladesh encompasses various categories of problematic soils. These soils impede plant growth and hinder crop production, occasionally rendering it unfeasible (Islam, 2021). Specific management techniques must be implemented in order to achieve profitable crop production in these types of soils. Acidic soil in Bangladesh is considered to be one of the challenging soil types. The productivity of acid soil for agricultural cultivation is constrained by the low accessibility of phosphorus and the harmful effects of aluminum.

According to pH value soil is classed as alkaline, neutral, or acidic based on its pH, which falls within the range of 6.6 to 7.4. The reference is from Hausenbuiller's work published in 1972. The majority of plant nutrients exhibit high availability in soil with a neutral pH range of 6.6 to 7.4. Soil acidity is a significant constraint on plant growth in various regions worldwide (Adams, 1980).

Aluminum toxicity is the cause of low crop productivity in acidic soils (Lierop, 1984). The acid soil poses infertility which causes significant constraints on crop yield. There are various methods to reclaim acid soils, such as liming. Liming increases the availability of nutrients like P, Ca, Mg and Mo. It also makes iron and manganese insoluble and harmless, improves the efficiency of fertilizers, and reduces plant diseases (Sahai, 1990).

From the above discussion, it is clear that liming has great impact for increasing the production of crop. So, it becomes essential to explore the response of crops to different doses (treatments) of lime.

To achieve its objectives, this study aimed to:

- Evaluate the effects of liming on crop yield and yield attributes across various lime application doses.
- Assess the impact of liming on the nutrient status of the soil following crop harvest under different lime treatment regimes.

2. Materials and Methods

First Year Experiment: In first year, two experiments were conducted. The 1st experiment was set up at Chadkhana union of Kishoreganj upazila under Nilphamari district and the 2nd experiment was set up at Betgari union of Gangachara upazila under Rangpur district of Bangladesh .

Second Year Experiment: In second year, another two experiments were conducted. The 1st experiment was set up at Chadkhana union of Kishoreganj upazila under Nilphamari district and the 2nd experiment was set up at Razarhat union of Gangachara upazila under Kurigram district.

Third Year Experiment: In third year, another two experiments were conducted. The 1st experiment was set up at Balapara , Sadar Upazila under Rangpur District and the 2nd experiment was set up at Sarai union of Kaunia Upazila under Rangpur District.

Experimental design

The experiment was conducted using a randomized complete block design (RCBD) with three replications. The experimental areas were divided into 15 plots (5 × 3 units) based on treatments and replications, with 1-meter drains separating the unit blocks. Each plot measured 5 m × 4 m during the fiscal year 2018-19. For the following years (2019-20 and 2020-21), the experimental areas were expanded to 18 plots (6 × 3 units) using the same plot size and drainage setup. Lime requirements (LR) were calculated to achieve a targeted pH of 6.5 using the formula:

$$LR(6.5)=1.6\times(6.5-\text{Soil pH})\times(\%OM)$$

Wheat was used as the test crop for these experiments. Statistical analysis was performed using an F-test, with the least significant difference (LSD) test applied to identify significantly different treatments. The MSTAT-C software package was utilized for variance analysis (ANOVA) of various parameters.

The experimental areas were divided into 18 (6×3) units of plots as per treatments and replications. 1m drains separated unit blocks from one another. Each plot measuring 5m×4m. Lime requirements (LR) were calculated using the formula for targeted pH raised at 6.5 using the following formula:

LR (6.5)=1.6 (6.5-Soil pH) × (%OM). (Fiscal year 2019-20 & 2020-21).

Wheat crop was used as test crop for these experiments. A statistical analysis was conducted using an F-test. LSD test was used for significantly different treatments. The MSTAT-C software package was utilized to analyze variance (ANOVA) for various parameters.

3. Results

Findings from the Experiments of First Year (2018-19)

The application of lime had a notable impact on the height of the plants. For wheat the treatment 1.0 tha^{-1} lime produced tallest plant than other treatments for four experiments. The treatment 0.75 tha^{-1} lime produced tallest plant than other treatments for one experiment. The tallest plants were observed with the application of lime at a rate of 1.0 ton per hectare, while the shortest plants were found in the control group (T_1). Total number of tillers hill^{-1}, spike length, filled grains spike^{-1}, thousand grains weight were also maximum at 1.0 tha^{-1} lime (Table 1). Application of lime also significantly increased the grains yields. The treatment 1.0 tha^{-1} produced significantly highest grain yield than other treatments. The lowest grain yield was obtained at treatment T_1 (control) in each year of experiment (Table 1 and Table 2). Highest number of tillers $hill^{-1}$, filled grains $spike^{-1}$ and total yield was obtained by the treatment 1.0 tha^{-1} lime (Table 1). It might due to the effect of liming on nutrient uptake capacity of wheat plant.

Table 1: Effects of liming on growth and yield components of wheat :(Experiment-1, Year: 2018-2019)

Treatments	Plant Height at Maturity (cm)	Tillers Hill^{-1} (no.)	Spike Length (cm)	Grains Spike^{-1}	1000-grains weight (g)	Grain yield (t ha^{-1})
T_1: Control	84.59 c	3.00 b	7.91 b	34.58 c	44.40 b	4.57 b
T_2: 0.5 t ha^{-1}	85.16 bc	3.33 b	8.68 a	43.99 b	46.80 ab	5.29 a
T_3 :0.75 t ha^{-1}	87.14 bc	3.93 a	8.84 a	47.35 a	47.90 ab	5.37 a

T_4:1.0 t ha^{-1}	91.12 a	4.27 a	8.97 a	49.43 a	50.10 a	5.56 a
T_5 :1.25 t ha^{-1}	89.56ab	4.00 a	8.93 a	48.17 a	49.40 a	5.49 a
F-test	*	**	**	**	*	**
$LSD_{0.05}$	4.52	0.442	0.347	2.70	3.59	0.337
CV (%)	2.75	6.35	2.14	3.21	3.99	3.42

**= Sig at 1% level, *= Sig at 5% level

Table 2: Effects of liming on growth and yield components of wheat: (Experiment-2, Year: 2018-2019)

Treatments	Plant Height at Maturity (cm)	Tillers $Plant^{-1}$ (no.)	Spike Length (cm)	Grains $Spike^{-1}$	1000-grains weight (g)	Grain yield (t ha^{-1})
T_1: Control	87.14 c	3.53 d	6.90 b	28.17 c	47.60 b	4.52 c
T_2: 0.5 t ha^{-1}	95.11 ab	4.93 b	8.58 a	47.39 ab	48.70 b	5.22 b
T_3 :0.75 t ha^{-1}	96.49 a	5.53 a	8.86 a	48.77 a	50.90 a	5.63 a
T_4:1.0 t ha^{-1}	96.47 a	5.27 a	8.84 a	48.75 a	49.00 b	5.52 ab
T_5 :1.25 t ha^{-1}	92.28 b	4.13 c	8.45 a	45.41 b	48.40 b	4.65 c
F-test	**	**	**	**	**	**
$LSD_{0.05}$	3.72	0.337	0.526	2.71	1.67	0.342
CV (%)	2.11	3.83	3.35	3.29	1.81	3.56

**= Sig at 1% level, *= Sig at 5% level

Liming increases the availability of Phosphorus and Sulpher which enhance the flowering and fruiting of plants (Year: 2018-2019). The treatment T_4 (1.0 tha^{-1}) obtained the highest P content (110.53µg g^{-1} soil) than the other four treatments T_5 (1.25 tha^{-1}), T_3 (0.75 tha^{-1}), T_2 (0.5 tha^{-1}) and T_1 (control) respectively (Table 3). Application of lime increased phosphorus content in soil. The S content in soil was also significantly changed by the different doses of lime. The highest S content (26.17µg g^{-1} soil) was obtained at the treatment T_4 (1.0 tha^{-1}) and the lowest S content was obtained at control. The treatment T_5 (1.25 tha^{-1}) was in second position. Application of lime increased K content in soil. The highest K content (0.29meq 100 g^{-1}soil) was obtained at treatment T_4 (1.0 tha^{-1}) and T_5 (1.25 tha^{-1}). The lowest K content (0.23meq 100 g $soil^{-1}$) was found in control. Application of lime increased soil pH. The highest pH was obtained at treatment T_5 and the pH of the treatment T_4 was in second position. The lowest soil pH was in treatment T_1 (control) (Table-3). Results obtained from soil sample analysis after the harvesting of wheat showed that the highest P and S content was obtained at the treatment T_3 (75.0 tha-1) (Table 4). which might result in highest flowering and fruiting. For these reason, we obtained the highest yield at the treatment T_3 ($0.75tha^{-1}$).

Table 3: Effects of liming on soil properties after harvest :(Experiment-1, Year: 2018-2019)

Treatments	pH	Organic Matter (%)	N (%)	K (μgg^{-1})	Mg (μgg^{-1})	P (μgg^{-1})	S (μgg^{-1})	Zn (μgg^{-1})
Analytical Values before 1st Year Experiment	5.20	1.78	0.09	0.17	0.36	95.42	16.65	0.65
Analytical Values after 1st Year Experiment								
T_1: Control	5.20c	1.79 b	0.09	0.23 b	0.80 d	105.87c	14.96 b	1.10 b
T_2: 0.5 t ha^{-1}	5.41 b	1.86 b	0.09	0.25 b	1.26 b	106.36 bc	16.76 b	1.25 b
T_3 :0.75 t ha^{-1}	5.57a	2.00 a	0.10	0.28a	1.21 b	106.88 bc	23.34 a	1.28 b
T_4:1.0 t ha^{-1}	5.65a	1.83 b	0.09	0.29 a	1.09 c	110.53 a	26.17 a	1.86 a
T_5 :1.25 t ha^{-1}	5.69 a	1.97 a	0.10	0.29 a	1.56 a	108.43ab	24.38 a	1.86 a
F-test	**	**	NS	**	**	**	**	**
$LSD_{0.05}$	0.146	0.103	0.017	0.029	0.084	2.27	3.99	0.238
CV (%)	1.44	2.76	9.21	5.72	3.59	1.12	10.04	8.52

Table 4: Effects of liming on soil properties after harvest (Experiment-2, Year: 2018-2019)

Treatments	pH	Organic Matter (%)	N (%)	K (μgg^{-1})	Mg (μgg^{-1})	P (μgg^{-1})	S (μgg^{-1})	Zn (μgg^{-1})
Analytical Values before 1st Year Experiment	5.75	2.13	0.11	0.10	0.40	24.44	14.43	0.61
Analytical Values after 1st Year Experiment								
T_1: Control	5.72 c	1.67 b	0.08	0.17	0.55 d	24.50 d	19.18 d	4.38 b
T_2: 0.5 t ha^{-1}	5.81 bc	1.65 b	0.08	0.19	0.89 c	25.85 bc	32.94 c	5.45 a
T_3 :0.75 t ha^{-1}	5.86 abc	1.90 a	0.09	0.20	1.05 bc	27.28 a	84.56 a	2.10 d
T_4:1.0 t ha^{-1}	5.92 ab	1.74 b	0.09	0.19	1.14 b	26.77 ab	56.08 b	3.26 c
T_5 :1.25 t ha^{-1}	5.98 a	1.94 a	0.09	0.18	1.38 a	24.88 cd	14.56 d	1.61 d

F-test	*	**	NS	NS	**	**	**	**
$LSD_{0.05}$	0.146	0.158	0.016	0.030	0.188	1.24	5.30	0.636
CV (%)	1.30	4.64	10.07	8.42	9.77	2.55	6.78	10.03

Findings from the Experiments in Second Year (2019-2020)

The application of lime had a notable impact on the height of the plants. For wheat the treatment 1.0 tha^{-1} lime produced tallest plant than other treatments for four experiments (Table 5). The tallest plants were observed with the application of lime at a rate of 1.0 ton per hectare, while the shortest plants were found in the control group (T_1). Total number of tillers $hill^{-1}$, spike length, filled grains spike^{-1}, thousand grains weight were also maximum at 1.0 tha^{-1} lime (Table 5).

Table 5: Effects of liming on growth and yield components of wheat: (Experiment-1, Year 2019-2020)

Treatments	Plant height at maturity (cm)	Tillers plant^{-1} (no.)	Spike length (cm)	Grains spike^{-1}	1000-grains weight (g)	Grain yield(g)/20 m^2)
T_1: Control	93.54 b	3.15 d	7.85 c	35.98 d	45.19 d	4.23 c
T_2: 1.0 t lime ha^{-1}	101.00 a	5.33 a	9.30 a	49.86 a	50.47 a	5.51 a
T_3: 2.0 t lime ha^{-1} (8kg/dec)	99.53 a	4.77 b	8.88 ab	48.93 a	49.77 ab	4.90 b
T_4: 3.0 t lime ha^{-1} (12kg/dec)	92.86 b	4.60 bc	8.74 b	45.20 b	49.14 b	4.71 b
T_5: 4.0 t lime ha^{-1} (16kg/dec)	94.13 b	4.36 c	8.55 b	43.83 b	47.73 c	4.39 c
T_6: 5.0 t lime ha^{-1} (20kg/dec)	82.42 c	4.41 c	8.44 b	41.73 c	47.20 c	4.39 c
F-test	**	**	**	**	**	**
$LSD_{0.05}$	1.90	0.299	0.434	1.57	0.793	0.223
CV (%)	1.11	3.73	2.76	1.95	0.90	2.63

The treatment T_4 (3.0 tha^{-1}) obtained the highest P content (62.51µg g^{-1} soil), treatment T_2 (1.0 tha^{-1}) was in second position. The S content in soil was also significantly influenced by the different doses of lime. The highest S content (25.79 µg g^{-1} soil) was obtained at the treatment T_2 (1.0 tha^{-1}). The pH of soil, Ca and Mg content also significant (Table-6). The treatment T_4 (3.0 tha^{-1}) obtained the highest S content (10.70 µg g^{-1} soil) than the other five treatments T_3 (2.0 tha^{-1}), T_2 (1.0 tha^{-1}), T_5 (4.0 tha^{-1}), T_6 (5.0 tha^{-1}) and T_1 (control) respectively. Application of lime increased S content in soil. The highest Mg content (1.50µg g^{-1} soil) was obtained at the treatment T_4 (3.0 tha^{-1}). The treatment T_5 (4.0 tha^{-1}) was in second position. Application of lime significantly increased K content in soil. The highest K content (0.147meq 100 g^{-1} soil) was obtained at treatment T_3 (2.0 tha^{-1}) and The treatment T_4 (3.0 tha^{-1}) was in second position. The pH of soil also significantly influenced by the application of lime. Application of lime increased soil pH . The highest pH was obtained at treatment T_6 and the lowest soil pH was in treatment T_1 (control) (Table-7).

Table 6: Effects of liming on soil properties after harvest: (Experiment-1, Year 2019-2020)

Treatments	pH	Organic matter (%)	N (%)	P (µgg^{-1})	K (µgg^{-1})	S (µgg^{-1})	Zn (µgg^{-1})	Ca (µgg^{-1})	Mg (µgg^{-1})
Initial	**5.40**	**1.65**	**0.08**	**68.36**	**0.12**	**3.44**	**0.45**	**1.69**	**0.30**
T_1: Control	5.15 d	3.64 ab	0.183	61.00 ab	0.313	23.57 a	1.25 a	2.23 b	0.900 b
T_2: 1.0 t lime ha^{-1}	5.54 c	3.62 ab	0.183	61.41 ab	0.273	25.79 a	0.743 c	2.34 ab	1.31 a
T_3: 2.0 t lime ha^{-1} (8kg/dec)	5.60 bc	3.41 b	0.163	59.88 bc	0.296	16.07 b	0.690 c	2.40 ab	1.35 a
T_4: 3.0 t lime ha^{-1} (12kg/dec)	5.85 a	2.85 c	0.143	62.51 a	0.330	25.41 a	0.696 c	2.45 ab	1.39 a
T_5: 4.0 t lime ha^{-1} (16kg/dec)	5.48 c	2.68 c	0.140	60.44 ab	0.243	18.69 b	1.32 a	1.79 c	0.856 b
T_6: 5.0 t lime ha^{-1} (20kg/dec)	5.81a b	3.73 a	0.180	57.89 c	0.276	24.01 a	1.10 b	2.56 a	1.39 a
F-test	**	**	NS	**	NS	**	**	**	**
LSD$_{0.05}$	0.225	0.281	0.056	2.19	0.097	2.96	0.138	0.239	0.195
CV (%)	2.24	4.71	19.15	2.03	18.02	7.46	7.99	5.76	9.22

Table 7: Effects of liming on soil properties after harvest (Experiment-2, Year 2019-2020)

Treatments	pH	Organic matter (%)	N (%)	P (µgg^{-1})	K (µgg^{-1})	S (µgg^{-1})	Zn (µgg^{-1})	Mg (µgg^{-1})
Inital	**5.20**	**1.44**	**0.07**	**42.96**	**0.11**	**2.16**	**2.19**	**0.55**
T_1: Control	5.21 c	1.81 c	0.093	53.44 b	0.110	2.62 d	0.84 a	0.586 c
T_2: 1.0 t lime ha^{-1}	6.05 b	1.94 b	0.093	54.43 b	0.123	7.54 b	0.39 c	0.626 c
T_3: 2.0 t lime ha^{-1} (8kg/dec)	6.26 ab	2.04 a	0.100	55.52 b	0.147	9.41 a	0.13 d	1.30 b
T_4: 3.0 t lime ha^{-1} (12kg/dec)	6.38 a	2.02 a	0.100	55.94 b	0.127	10.70 a	0.087 d	1.50 a
T_5: 4.0 t lime ha^{-1} (16kg/dec)	6.43 a	1.99 ab	0.100	67.19 a	0.107	4.92 c	0.380 c	1.41 ab
T_6: 5.0 t lime ha^{-1} (20kg/dec)	6.53 a	1.92 b	0.097	67.39 a	0.117	4.65 c	0.563 b	1.36 ab
F-test	**	**	NS	**	NS	**	**	**
LSD$_{0.05}$	0.276	0.080	0.015	4.87	0.037	1.86	0.126	0.178
CV (%)	2.50	2.34	8.40	4.64	17.33	15.70	17.82	8.64

Findings from the Experiments in Third Year (2020-21)

For wheat the treatment 3.0 tha^{-1} lime produced tallest plant than other treatments. The treatment resulting in the tallest plants was the application of lime at a rate of 3.0 tons per hectare, while the shortest plants were observed in the control group (T_1) (Table 8 and Table 9).

Application of lime significantly increased the phosphorus content in soil. The treatment T_5 (1.25 tha^{-1}) obtained the highest P content (38.49µg g^{-1} soil), treatment T_4 (1.0 tha^{-1}) was in second position. Application of lime increased phosphorus content in soil. The highest S content (17.98µg g^{-1} soil) was obtained at the treatment T_4 (1.0 tha^{-1}) and the lowest S content was obtained at control. The treatment T_5 (1.25 tha^{-1}) was in second position. Application of lime increased soil pH. The highest pH was obtained at treatment T_4. The lowest soil pH was in treatment T_1 (control) (Table 10).

The treatment T6 (3.0 tha^{-1}) obtained the highest phosphorus content (62.27 µg g^{-1} soil) the treatment T_2 (1.0 tha^{-1}) was in second position (61.85 µg g^{-1} soil). Application of lime increased phosphorus content in soil. Application of lime increased K and Z content in soil. The treatment T_2 (1.0 tha^{-1}) obtained the highest Ca and Mg content. Application of lime increased soil pH. The highest pH was obtained at treatment T_6 and the lowest soil pH was in treatment T_1 (control) (Table 11).

Table 8: Effects of liming on growth and yield components of wheat: (Experiment-1, Year: 2020-2021)

Treatments	Plant height at maturity (cm)	Tillers $plant^{-1}$ (no.)	Spike length (cm)	Grains $spike^{-1}$	1000-grains weight (g)	Grain yield(g)/20 m^2)
T_1: Control	98.52 e	3.98 d	8.20 d	44.33 e	43.00 e	4.023 c
T_2: 0.5 t lime ha^{-1}	99.94 d	4.12 cd	8.97 c	48.66 d	45.00 d	4.517 b
T_3: 0.75 t lime ha^{-1}	101.50 c	4.53 bc	9.52 b	50.33 c	48.00 c	4.827 ab
T_4: 1.0 t lime ha^{-1}	106.30 a	5.33 a	10.30 a	54.01 a	53.01 a	5.187 a
T_5: 1.25 t lime ha^{-1}	103.90 b	4.66 b	9.98 a	52.66 b	50.02 b	4.967 a
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.425	0.487	0.453	0.491	0.386	0.362
CV (%)	0.22	5.71	2.56	0.52	0.43	4.08

Table 9: Effects of liming on growth and yield components of wheat: (Experiment-2, Year: 2020-2021)

Treatments	Plant height at maturity (cm)	Tillers $plant^{-1}$ (no.)	Spike length (cm)	Grains $spike^{-1}$	1000-grains weight (g)	Grain yield(g)/20 m^2)
T_1: Control	98.68 d	3.98 c	4.037 e	45.03 e	46.20 c	4.53 d
T_2: 1.0 t lime ha^{-1}	107.20 a	5.00 a	5.33 a	54.33 a	54.53 a	5.20 a
T_3: 1.5 t lime ha^{-1}	105.00 b	4.65 b	5.03 b	50.66 b	52.13 b	4.98 ab
T_4: 2.0 t lime ha^{-1}	104.30 c	4.03 c	4.98 b	48.33 c	51.74 b	4.83 bc
T_5: 2.5 t lime ha^{-1}	104.70 bc	4.33 bc	4.66 c	48.03 cd	51.58 b	4.79 bcd
T_6: 3.0 t lime ha^{-1}	104.30 c	4.23 c	4.33 d	47.83 d	51.34 b	4.68 cd
F-test	**	**	**	**	**	**
$LSD_{0.05}$	0.467	0.340	0.237	0.474	1.38	0.264
CV (%)	0.25	4.27	2.74	0.53	1.48	3.02

**= Significant at 1% level of probability

Table 10: Effects of liming on soil properties after harvest (Experiment-1, Year: 2020-2021)

Treatments	pH	Organic matter (%)	N (%)	P ($\mu g g^{-1}$)	K ($\mu g g^{-1}$)	S ($\mu g g^{-1}$)	Zn ($\mu g g^{-1}$)	Br ($\mu g g^{-1}$)	Ca ($\mu g g^{-1}$)	Mg ($\mu g g^{-1}$)
Initial	**5.25**	**1.10**	**0.10**	**17.96**	**0.21**	**15.28**	**1.24**	**0.13**	**1.72**	**0.52**
T_1: Control	4.97 c	2.36ab	0.118	16.72 c	0.177ab	12.45 c	0.943 b	0.620 c	1.63 c	0.856 b
T_2: 0.5 t lime ha^{-1}	5.11 c	2.29 b	0.123	19.02bc	0.150 b	18.89 a	1.587 a	0.767 b	3.65b	0.993 b
T_3: 0.75 t lime ha^{-1}	5.19 bc	2.30 b	0.130	23.62 b	0.153 b	15.18 b	1.027 b	0.723 b	4.03 b	1.077ab
T_4: 1.0 t lime ha^{-1}	5.51 a	2.51 a	0.145	34.43 a	0.163 b	17.98 a	1.14 b	0.943 a	5.19 a	1.277a
T_5: 1.25 t	5.47	1.98 c	0.101	38.49 a	0.203	17.40	1.447	0.873	4.92a	1.247

lime ha^{-1}	ab				a	a	a	a		a
F-test	**	**	NS	**	*	**	**	**	**	**
$LSD_{0.05}$	0.281	0.152	0.032	4.78	0.031	2.21	0.207	0.099	0.757	0.223
CV (%)	2.95	3.74	14.21	9.93	10.00	7.43	9.27	7.52	10.69	11.38

Table 11: Effects of liming on soil properties after harvest (Experiment-2, Year: 2020-2021)

Treatments	pH	Organic matter (%)	N (%)	P (µgg^{-1})	K (µgg^{-1})	S (µgg^{-1})	Zn (µgg^{-1})	Br (µgg^{-1})	Ca (µgg^{-1})	Mg (µgg^{-1})
Initial	**5.20**	**1.03**	**0.10**	**35.02**	**0.12**	**19.05**	**2.03**	**0.12**	**3.46**	**0.88**
T_1: Control	4.94 b	1.44 bc	0.163	60.36ab	0.196	5.53 c	2.37 d	0.817 c	3.77 c	1.047bc
T_2: 1.0 t lime ha^{-1}	5.40 ab	1.34 c	0.113	61.85 a	0.200	10.35 b	2.57 cd	1.04b	4.847 a	1.223 a
T_3: 1.5 t lime ha^{-1}	5.61 a	1.56 ab	0.133	58.17 c	0.190	6.20 c	2.15 d	1.05 b	4.32 b	1.20 ab
T_4: 2.0 t lime ha^{-1}	5.52 a	1.57 a	0.133	60.43ab	0.203	14.37 a	2.87bc	1.237 a	4.46 b	1.07abc
T_5: 2.5 t lime ha^{-1}	5.53 a	1.38 c	0.120	59.30bc	0.163	12.95 a	3.03ab	1.367 a	3.89 c	1.217ab
T_6: 3.0 t lime ha^{-1}	5.87 a	1.33 c	0.113	62.27a	0.206	13.73 a	3.36 a	1.227 a	4.27b	1.017 c
F-test	*	**	ns	**	ns	**	**	**	**	*
$LSD_{0.05}$	0.509	0.126	0.056	1.94	0.056	1.91	0.417	0.159	0.276	0.159
CV (%)	5.23	5.00	24.97	1.81	14.22	10.20	8.64	7.93	3.65	7.98

4. Discussion

In consecutive experiments, it was observed that the application of lime significantly impacted the height of wheat plants. The tallest plants were observed in the groups where lime was applied, while the shortest plants were found in the control group. Furthermore, the application of lime led to a notable increase in grain yields. This effect is likely attributed to the enhancement of nutrient uptake capacity in wheat plants facilitated by liming. Specifically, liming increased the availability of phosphorus and sulfur in the soil, thereby promoting flowering and fruiting.

Additionally, the application of lime resulted in an increase in phosphorus content in the soil. There were also significant alterations in the sulfur (S) content in the soil across different lime doses. Moreover, lime application led to an increase in potassium (K) content in the soil. The pH level of the soil was notably influenced by the application of lime, with an increase in soil pH observed following lime treatment. Again, this is likely due to the enhanced nutrient uptake capacity facilitated by liming, leading to improved flowering and fruiting. Lime application also increased phosphorus, potassium, and zinc content in the soil

5. Conclusion

The experiment provides compelling evidence of the significant response of wheat plants to varying amounts of lime. Applying 1.0 ton of lime per hectare is sufficient to achieve optimal wheat yields, particularly when the initial soil pH ranges between 5.20 and 5.75. Importantly, lime addition positively influences several factors that contribute to crop yield. It acts as a catalyst, significantly enhancing key aspects of wheat cultivation, including plant height, tiller count, spike length, grain count per spike, and overall grain yield. This finding underscores the critical importance of lime application for improving agricultural productivity and highlights its potential as an essential practice for sustainable crop cultivation.

References

Adams, F. 1984. Soil acidity and liming, 2nd edn, Agronomy 12. American Society of Agronomy. Crop Science Society of America/Soil Science Society of America, Madison, Wisconsin.

Adams, P. B. 1980. Life history patterns in marine fishes and their consequences for fisheries management. Fishery bulletin, 78(1), 1-12.

Adane B. 2014. Effects of liming acidic soils on improving soil properties and yield of haricot bean. J. Environ. Analytical Toxicol. 05 (01), 248. doi: 10.4172/2161-0525.1000248

Agegnehu G., Amede T., Erkossa T., Yirga C., Henry C., Tyler R., et al. 2021. Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. In Acta Agriculturae Scandinavica Section B: Soil Plant Sci. Vol. 71, Issue 9, 852–869). doi: 10.1080/09064710.2021.1954239

Alemu E., Selassie Y. G., Yitaferu B. 2022. Effect of lime on selected soil chemical properties, maize (Zea mays) yield and determination of rate and method of its application in northwestern Ethiopia. Heliyon 8 (1), 2405–8440. doi: 10.1016/j.heliyon.2021.e08657

Anderson N. P., Hart J. M., Sullivan D. M., Horneck D. A., Pirelli G. J. 2013. Applying lime to raise soil pH for crop production (Western Oregon) (Corvallis (OR: Oregon State University Extension), EM 9057.

Ashitha, A., Rakhimol, K. R., & Mathew, J. 2021. Fate of the conventional fertilizers in environment. In Controlled release fertilizers for sustainable agriculture (pp. 25-39). Academic Press.

Bennett, J.McL, Greene, R.S.B., Murphy, B.W., Hocking, P. & Tongway, D. 2014. Influence of lime and gypsum on long-term rehabilitation of a Red Sodosol, in a semi-arid environment of New South Wales. Soil Research, 52, 120–128.

Bian M., Zhou M., Sun D., Li C. 2013. Molecular approaches unravel the mechanism of acid soil tolerance in plants. In Crop J. Vol. 1, Issue 2, 91–104). doi: 10.1016/j.cj.2013.08.002

Bolan N., Curtin D., Adriano D. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bio-availability (Advances in agronomy. Academic Press) 78, 215–272. doi: 10.1016/S0065-2113(02)78006-1

Bolan, N.S., Adriano, D.C. & Curtin, D. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in Agronomy, 78, 215–272.

Connor, D.J., Loomis, R.J. & Cassman, K.G. 2011. Crop Ecology: productivity and Management in Agricultural Systems, 2nd edn. Cambridge University Press, Cambridge.

Dong, Y., Yang, J. L., Zhao, X. R., Yang, S. H., Mulder, J., Dörsch, P., ... & Zhang, G. L. 2022. Soil acidification and loss of base cations in a subtropical agricultural watershed. Science of The Total Environment, 827, 154338.

Fenn M. E., Huntington T. G., McLaughlin S. B., Eagar C., Gomez A., Cook R. B. 2006. Status of soil acidification in north America. J. For. Sci. 52, 3–13. doi: 10.17221/10152-JFS

Haynes, R.J. & Naidu, R. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient Cycling in Agroecosystems, 51, 123–137.

Hijbeek R., van Loon M. P., Ouaret W., Boekelo B., van Ittersum M. K. 2021. Liming agricultural soils in Western Kenya: can long-term economic and environmental benefits pay off short term investments? Agric. Syst. 190. doi: 10.1016/j.agsy.2021.103095

Huda S, Kabir MR, Tabassum S, Sonet M RAF, Muhammad N. Information Needs of the Female Farmers in Agricultural Activities. Asian Journal of Agricultural Extension, Economics & Sociology. 2019; 30(2):1-11

Islam, T. 2021. Performance of ecological revetment in Haor areas of Bangladesh. MSc. Engg Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Karim MR, Ampony D, Muhammad N, Noman MRF, Rahman MS. Factors affecting adopting of local adaptation options to climate change vulnerability. Journal of Science and Technology. 2017;15:1-8.

Kennedy, I.R. 1992. Acid soil and acid rain, 2nd edn. John Wiley and Sons, New York.

Khatun A, Khatun R, Muhammad N, Uddin, MY, Talukder MAI. effect of flooding on human life and environment in Sirajganj district of bangladesh. Journal of Science and Technology. 2015;93:97.

Kirkham, J.M., Rowe, B.A. & Doyle, R.B. 2007. Persistent improvements in the structure and hydraulic conductivity of a Ferrosol due to liming. Australian Journal of Soil Research, 45, 218–223.

Lesturgez G., Poss R., Noble A., Grünberger O., Chintachao W., Tessier D. 2006. Soil acidification without pH drop under intensive cropping systems in northeast Thailand. Agriculture Ecosyst. Environ. 114 (2–4), 239–248. doi: 10.1016/j.agee.2005.10.020

Lierop, J. G. 1984. The densification of monolithic gels. Journal of Non-Crystalline Solids, 63(1-2), 131-144.Rengel (ed.) 2003. Handbook of soil acidity. Marcel Dekker, New York.

Orton T. G., Mallawaarachchi T., Pringle M. J., Menzies N. W., Dalal R. C., Kopittke P. M., et al. 2018. Quantifying the economic impact of soil constraints on Australian agriculture: a case-study of wheat. Land Degradation Dev. 29 (11), 3866–3875. doi: 10.1002/ldr.3130

Parvin, R., Bari, M. S., & Muhammad, N. (2024). Impacts of Climate Change on Teesta River Basin Char Lands: A Study of Livelihood and Ecosystem Dynamics in Bangladesh. *International Journal of Environment and Climate Change*, *14*(2), 407-422.

Rosen C. J., Bierman P. M. 2005. Nutrient management for fruit & vegetable crop production: maintaining soil fertility in an organic system (University of Minnesota Extension Service. Retrieved from the University of Minnesota Digital Conservancy). Available at: Https://Hdl.Handle.Net/11299/197961.

Sahai, S. 1990. Academic library system. Allied Publishers.

Sanjib Kumar Panda F. B., Matsumoto H. 2009. Aluminum stress signaling in plants. Plant Signaling Behav. 4 (7), 592–597. doi: 10.4161/psb.4.7.8903

Smith J. F. N., Hardie A. G. 2022. Long-term effects of micro-fine and class a calcitic lime application rates on soil acidity and rooibos tea yields under clanwilliam field conditions. South Afr. J. Plant Soil 39 (4), 270–277. doi: 10.1080/02571862.2022.2107244

Sultana R, Muhammad N, Zakaria AKM. Role of indigenous knowledge in sustainable development. International Journal of Development Research. 2018; 8(2):18902-18906.

Tian D., Niu S. 2015. A global analysis of soil acidification caused by nitrogen addition. Environ. Res. Lett. 10 (2). doi: 10.1088/1748-9326/10/2/024019

von Uexküll H. R., Mutert E. 1995. "Global extent, development and economic impact of acid soils," in Plant and soil (KluwerAcademic Publishers) 171, 1-15. doi: 10.1007/BF00009558

Yadav, D. S., Jaiswal, B., Gautam, M., & Agrawal, M. 2020. Soil acidification and its impact on plants. Plant responses to soil pollution, 1-26.

Zhang, G., Zhao, D., Liu, S., Liao, Y., & Han, J. 2022. Can controlled-release urea replace the split application of normal urea in China? A meta-analysis based on crop grain yield and nitrogen use efficiency. Field Crops Research, 275, 108343.