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Lime and Organic Manure Amendment: A Potential Approach for Sustaining Crop Productivity of the T. Aman-Maize-Fallow Cropping Pattern in Acidic Piedmont Soils

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Citation: Islam, M.R.; Akter, A.; Hoque, M.A.; Farzana, S.; Uddin, S.; Talukder, M.M.H.; Alsanie, W.F.; Gaber, A.; Hossain, M.A. Lime and Organic Manure Amendment: A Potential Approach for Sustaining Crop Productivity of the T. Aman-Maize-Fallow Cropping Pattern in Acidic Piedmont Soils. *Sustainability* **2021**, *13*, 9808. https://doi.org/10.3390/su13179808

Academic Editors: Danutė Karčauskienė and Ieva Mockeviciene

Received: 14 July 2021
Accepted: 26 August 2021
Published: 1 September 2021

Abstract: Acid soil is a hindrance to agricultural productivity and a threat to food and environmental security. Research was carried out to assess the impact of lime and organic manure (OM) amendments on yield and nutrient uptake by using the T. Aman-Maize-Fallow cropping pattern in acid soils. The experiment was set up in an RCBD design and used nine treatments and three replications. The treatments, comprising of various doses of lime, OM (cow dung and poultry manure), and a lime-OM combination, were applied to the first crop, T. Aman (Binadhan 7), and in the next crop, maize (BARI Hybrid Maize-9), the residual impacts of the treatments were assessed. Results demonstrate that the highest grain yield, 4.84 t ha^{-1} (13.61% increase over control) was recorded for T. Aman and 8.38 t ha^{-1} (58.71% increase over control) for maize, was achieved when dololime was applied in combination with poultry manure. The total rice equivalent yield increase over the control ranged from 20.5% to 66.1%. The application of lime with cow dung or poultry manure considerably enhanced N, P, K, and S content and uptake in both crops, compared to the control. Thus, it may be inferred that using dololime in association with poultry manure can increase crop productivity in acid soils.

Keywords: lime; organic manure; crop productivity; acidic soil; nutrient content and uptake; soil properties

1. Introduction

Rice (*Oryza sativa*) is the world's second most frequently cultivated cereal grain, feeding 164 million Bangladeshis and 60 per cent of the world's population [1–3]. Bangladesh's population is anticipated to reach 186 million by 2030, indicating that the world's population is growing at a promising rate. For ensuring food security and food safety, food demand for the increasing population must be met up. Maize (*Zea mays*) is another cereal crop that is grown in a range of agroecological environments all over the world. By 2020, maize production is expected to outnumber wheat and rice in developing countries [4]. In Bangladesh, maize production has increased at a substantial rate over the last ten years, and increased by 14.63% in 2020 compared to 2019 [5].

Acid soils occupy 30% of the arable land of Bangladesh [6], as well as 57% of the world's land surface [7]. However, the intrinsic qualities of acid soils are thought to impair agricultural productivity by 30 to 40% [8]. The most fundamental causes of soil acidification include leaching due to excessive rainfall, acidic parent material, organic matter breakdown and the release of organic acids, the harvest of high-yielding crops, and the presence of alumina-silicate minerals [9,10]. In tropical and subtropical areas, acid soils are common and possess the key characteristics of low pH, highly soluble excessive Al^{3+}, Mn^{2+} concentrations, and reduced cation exchange capacity (CEC) that restrict plant development in acidic soils [11]. Mineralization, nitrification, nodulation, and mycorrhizal infection are all reduced when soil acidity is high [12,13], and P, Ca, Mg, and Mo deficiency in acid soils may result in decreased nutrient absorption and nutritional imbalances in plants [14]. In acid soils, P adsorption is usually attributed to hydrous iron and aluminum oxides. Natural aluminum or iron phosphates (such as variscite and strengite) are likely to present in these soils, rendering P the most restricting nutrient for crop yield [15–18]. In acid soils, according to Mengel and Kirkby [19], the performance of applied N, P, and K fertilizers is very poor.

The most frequent and effective way of lowering soil acidity is liming [20]. Liming, either alone or in conjunction with mineral and organic fertilizer, is widely suggested for growing field crops on acid soils [21]. Liming enhances the soil reaction, calcium concentration, cation exchange capacity (CEC), and base saturation of acidic soils while lowering Al and increasing P availability [22]. As long as they remain within a safe range, all of these chemical changes enhance root development, resulting in better uptake of water and nutrients, resulting in grain yields and agricultural sustainability [23,24]. Soil physical properties are also improved because the application of lime in acidic soil results in better soil structure [25]. Microbial activity is favored due to the proper environment offered by lime application in acid soil, which leads to decomposition of soil organic matter resulting in increased mineral N and P levels, as well as losses of soil organic carbon due to CO_2 emissions from microbial respiration [26].

In acidic soil areas, a combination of lime and organic manure treatment may be a better option for increasing soil fertility. Because it regulates biological processes that impact nutrient availability, organic manure amendment increases soil organic matter status, which is a critical component in sustaining long-term soil fertility. The addition of manures like cow dung (CD) and poultry manure (PM) help to retain soil fertility by providing an alternative source of plant nutrients to chemical fertilizers, which is especially important in rice cultivation [27]. The physico-chemical and biological characteristics of the soil are improved by CD and PM, which increase nutrient availability [28,29]. In the Old Himalayan Piedmont Plain (AEZ-1) and Northern and Eastern Piedmont Plains (AEZ-22), Sultana et al. [30] reported that soil amendment with dololime at the rate of 1 t ha^{-1} combined with poultry manure at 3 t ha^{-1} or farm yard manure at 5 t ha^{-1} could be an efficient practice for achieving higher crop yield due to an increase in soil pH and nutrient absorption by the crops (AEZ-22). According to Venkatesh et al. [31], the application of FYM and lime resulted in a 7.22–15.85 and 29.67% increase in yield and P use efficiency, respectively, along with an average 5.64 t ha^{-1} P uptake in maize.

T. Aman-Maize-Fallow is one of the most widely used cropping patterns in Bangladesh. Previous studies regarding the effects of lime and organic manure were conducted using a different cropping pattern and other regions of the country [30,32,33]. However, there is no available data of management impacts on crop productivity of T. Aman-Maize-Fallow cropping pattern and soil quality of acidic piedmont soils of Northern and Eastern Piedmont Plains. Consequently, the aim of this study was to assess how lime and organic manure amendments affect the crop productivity of the T. Aman-Maize-Fallow cropping pattern, as well as to elucidate an effective management strategy for profitable crop production in the acidic Piedmont soil of Nalitabari Upazila in the Northern and Eastern Piedmont Plains. This research will aid farmers in increasing crop yields in acid-prone locations through better management of soils.

2. Materials and Methods

2.1. Experimental Site and Soil Properties

The research was conducted at the farmer's field of Ramchandrakura Union, Nalitabari Upazila, Sherpur (25°11′ N, 90°15′ E), from July 2017 to May 2018. The study site was located in the agro-ecological zone, of the Northern and Eastern Piedmont Plains (AEZ-22). The location is classified as Grey Terrace Soil under the General Soil Type classification system [34]. Topographically, the experimental site was considered to be medium-high. Twenty initial composite soil samples (0–15 cm depth) were taken from the experimental plots and evaluated using conventional procedures before the experiment began. The soil had a sandy loam texture and was extremely acidic, with a soil reaction of 4.12, organic C of 5.02 g kg^{-1}, total N of 0.56 g kg^{-1}, available P of 0.01 g kg^{-1}, exchangeable K of 0.02 g kg^{-1}, and available S of 0.02 g kg^{-1}.

2.2. Plant Materials and Treatments

Two crops, T. Aman rice and maize, were grown in the T. Aman-Mazie-Fallow cropping pattern under field conditions. The crop varieties were Binadhan7 for T. Aman rice and BARI Hybrid Maize-9 for maize. T. Aman rice was grown during July to October (mid monsoon to late monsoon), followed by maize from early December to late April (winter to early summer). For the rest of the cropping year, the land was kept as bared fallow. Treatments were comprised of two levels of lime (dololime at the rate of 1 and 2 t ha^{-1}) and two types of organic amendment (cow dung and poultry manure). The following treatments were used in the experiment: T_1: control (no lime and organic amendment), T_2: Lime-1 (dololime 1 t ha^{-1}), T_3: Lime-2 (dololime 2 t ha^{-1}), T_4: OM-1 (cow dung 5 t ha^{-1}), T_5: OM-2 (poultry manure 3 t ha^{-1}), T_6: Lime-1 OM-1 (dololime 1 t ha^{-1}, cow dung 5 t ha^{-1}), T_7: Lime-1 OM-2 (dololime 1 t ha^{-1}, poultry manure 3 t ha^{-1}), T_8: Lime-2 OM-1 (dololime 2 t ha^{-1}, cow dung 5 t ha^{-1}), and T_9: Lime-2 OM-2 (dololime 2 t ha^{-1}, poultry manure 3 t ha^{-1}). The chemical compositions of the organic manures used in this study are presented in Table 1. Carbon (C) content in both CD and PM was similar whereas N content was more than double in PM than that in CD (Table 1). The total P content was 0.50% and 2.33% in CD and PM, respectively. Total S content in PM was double that of CD. C:N, C:P and C:S ratios were higher in CD than those in PM, while the pH of PM was higher than that of CD (Table 1).

Table 1. Salient properties of organic manures (cow dung and poultry manure) used in this study.

Manure	C (%)	N (%)	P (%)	S (%)	C:N	C:P	C:S	pH
Cow dung (CD)	33.14	1.27	0.50	0.28	26.2	66.8	118.4	7.7
Poultry manure (PM)	33.54	3.08	2.33	0.56	10.9	14.4	59.9	8.2

2.3. Preparation of Experimental Plots and Growing Crops

The average temperature and rainfall were 29.8 °C and 142.6 mm, and 27.6 °C and 38.8 mm during the growing season of T. Aman rice and maize, respectively. The field was prepared by ploughing and cross ploughing using a power tiller. The tilt was then laddered using conventional techniques. All grasses and beard stubbles were removed from the field prior to the final land preparation and laying out. The experiment was set up in a Randomized Complete Block Design (RCBD), with the experimental area divided into three blocks representing the replications, in order to reduce the heterogenic effects of soil. The treatments were randomly allocated to the unit plots in each block after each block was split into nine plots. Thus, the total number of unit plots was 27. Each plot was 4 m × 2.5 m in size and was separated from the others by ails (30 cm). A one-meter drain ran between the blocks, separating them from one another. The fertilizers were applied as per the Bangladesh Agricultural Research Council (BARC) Fertilizer Recommendation Guide [6]. The recommended dose (RD) of chemical fertilizers were 90 kg N, 10 kg P, 35 kg K, 8 kg S, and 1 kg B per ha for T. Aman rice; and 140 kg N, 15 kg P, 60 kg K, 15 kg S, 2 kg Zn, and

1 kg B per ha for maize. Urea, triple superphosphate, muriate of potash, gypsum, zinc sulphate, and boric acid were the sources of N, P, K, S, Zn, and B, respectively. All of the treatments, including the control, received full doses of the chemical fertilizers. Except for urea, all of the chemical fertilizers were applied during the final land preparation. For T. Aman rice and maize, urea was administered in three equal portions. Dololime, cow dung, and poultry manure were combined with soil and applied two weeks before planting crops. Lime, cow dung, and poultry manure were applied to the first crop, and their effects were assessed in the second crop. In the case of T. Aman rice, seedlings were grown in the nursery bed, and 25–30-day old seedlings were carefully removed and transplanted into the plots with a spacing of 20 cm × 20 cm. In each hill, three seedlings were replanted. After the final field preparation, maize seeds were spread in lines with a planting spacing of 50 cm × 25 cm. Depending on the soil type and crop requirement, four to five flood irrigations (about 190 mm) were applied to supply sufficient moisture for successful crop production. Intercultural activities, such as weeding and pest control, were carried out as needed to ensure and maintain a favorable environment for the crop's regular growth and development.

2.4. Harvesting and Data Recording

At the physiological maturity stage, the crops were cut. Each plot's produce was collected across a 1 m^2 area, and the harvested crop was bundled separately. The bundles were then taken to the threshing floor, where they were threshed. Grain yields were calculated using a 14% moisture basis, whereas straw yields were calculated using a sun dry basis (avoiding scorching sunlight to avoid N loss from grain and straw). The total nitrogen concentration in the grain and straw samples was determined using the semi-micro Kjeldahl method [35], phosphorus by Olsen method [36], potassium by the atomic absorption spectrometry, and sulfur by using the spectrophotometer method. The uptake of N, P, K and S by grain and straw was determined from the grain and straw yield data. The nutrient uptake was determined by the formula [37,38]:

$$Nutrient\ uptake\ (\mathrm{kg/ha}) = \frac{Nutrient\ content\ (\%) \times Dry\ mass\ production\ (\mathrm{kg/ha})}{100}$$

A total nutrient uptake value of <170 kg ha^{-1}, 150–200 kg ha^{-1} and >200 kg ha^{-1} would be considered as low, optimum and high for rice, respectively, while <300 kg ha^{-1}, 300–400 kg ha^{-1} and >400 kg ha^{-1} total nutrient uptake would be considered as low, optimum and high for maize, respectively. The total rice equivalent yield of the cropping pattern was calculated by the summation of the rice equivalent yield of each crop. The rice equivalent yield (REY) was calculated in order to compare system performance by converting the yield of non-rice crops into equivalent rice yields on a price basis, using the formula: REY = Yx (Px/Pr), where Yx is the yield of non-rice crops (kg ha^{-1}), Px is the price of non-rice crops (TK kg^{-1}), and Pr is the price of rice (TK kg^{-1}).

2.5. Analysis of Soil Samples

The initial and after harvest soil samples were analyzed in order to determine the properties of soil, including soil organic matter (SOM) content, soil total nitrogen (STN), available P, pH, electrical conductivity (EC), and CEC. SOM content was determined by multiplying organic carbon (OC) by 1.73 as suggested by Ghosh et al. [39] and OC was determined titrimetrically following the Walkley and Black method [40]. STN was measured by the semi-micro Kjeldahl method [35], and available P was determined following the method of Bray and Kurtz [41]. The pH of the soil samples was determined using a soil:water ratio of 1:2.5 with a glass electrode pH meter [42]. The EC of collected soil samples was measured electrometrically (1:5: soil:water ratio) by a conductivity meter using 0.01 M KCL solution to calibrate the meter, following the procedure described by Ghosh et al. [39]. The CEC was determined following the ammonium acetate extraction method as suggested by Chapman [43].

2.6. Statistical Analysis

According to Gomez and Gomez, the data were statistically evaluated using the F-test, and the mean differences were determined using the Duncan New Multiple Range Test (DMRT) [44].

3. Results

3.1. Effect of Lime and Manure Amendment on Yield, Nutrient Content and Nutrient Uptake of T. Aman Rice (Binadhan 7)

3.1.1. Grain and Straw Yield

Although there was a small variation in grain production across the treatments ($p < 0.05$), the grain yield of the first crop (Binadhan 7) responded strongly to the application of dololime, cow dung, and poultry manure (Figure 1). Grain yields varied from 4.26 to 4.84 tons per hectare. The maximum grain yield (4.84 t ha^{-1}) was reported in T_7, while the lowest value (4.26 t ha^{-1}) was found in T_1. Based on the grain yield, the treatments may be ranked in order of $T_7 > T_8 > T_5 > T_9 > T_4 = T_3 = T_2 > T_6 = T_1$. The increase in grain production over the control varied from 0.23 to 13.61 per cent, with T_7 (13.61%) having the largest increase while T_6 showed the smallest (0.23%) increase.

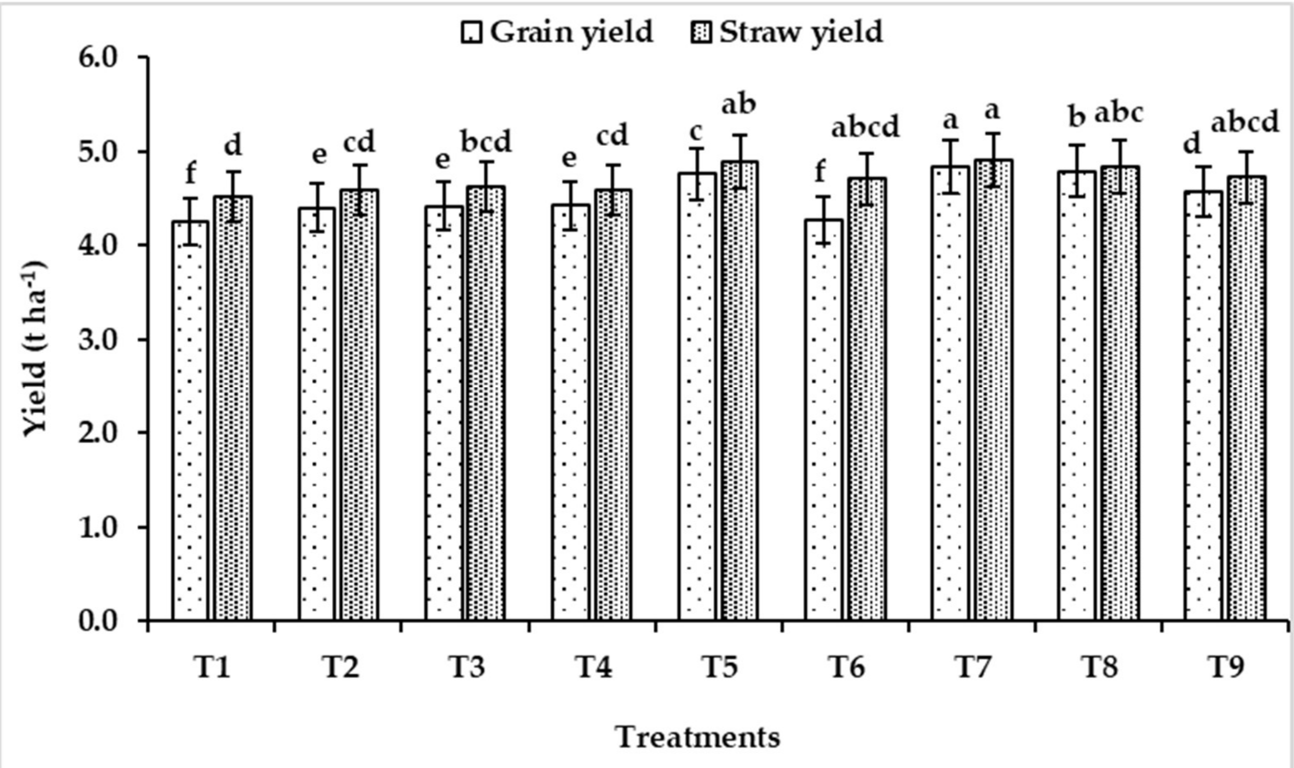

Figure 1. Effect of lime and manure amendment on yield of T. Aman rice (Binadhan 7). Comparison is made across treatments for grain and straw separately. The small letters (i.e., a, b, c, d, e, and f) in the figure indicate that treatments are statistically different at 5% level of significance.

The different treatments studied had a substantial impact on the straw yield of Binadhan 7. Straw yields varied from 4.52 to 4.91 tons per hectare ($p < 0.05$) (Figure 1). T_8 produced the highest straw yield of 4.91 t ha^{-1}, while T_1 produced the lowest yield of 4.52 t ha^{-1}. The treatment may be ranked in the order of $T_7 > T_5 > T_8 > T_9 = T_6 > T_3 > T_4 = T_2 > T_1$, in terms of straw yield. In terms of the increase in the percentage of straw yield, T_7 had the highest increase (8.62%) while T_2 had the lowest increase (1.53%).

The grain and straw yield of T. Aman rice show that the yield performance of T_1 is inferior to other treatments, although T_1 received all chemical fertilizers in the recommended doses. This, in turn, indicates the beneficial roles of lime and/or manure application as noticed in other treatments where the same dose of chemical fertilizers was applied but it was accompanied by lime and/or manure.

3.1.2. Nutrient Content

The application of the combination of lime and organic amendment or the application of each amendment alone significantly affected the nutrient content in both grain and straw of Binadhan 7 ($p < 0.05$) (Table 2). The amount of N in the grain varied from 1.04 to 1.26%, whereas the straw had a value of 0.28 to 0.42% (Table 2). T_9 had the greatest N content, which was statistically equivalent to T_7, T_6, and T_5 in the case of grain, and T_8, T_7, T_6, T_5, and T_4 in the case of straw, with the lowest value in T_1. The levels of P in grain and straw were 0.22 to 0.26% and 0.11 to 0.19%, respectively (Table 2). T_9, was statistically equivalent to T_7, while it had the greatest P concentration in grain, whereas T_1 had the lowest. In straw, T_7 had the greatest P concentration which was equivalent to T_9 whereas T_1 had the lowest P content. K concentration in grain ranged from 0.27 to 0.38%, while straw had a K content of 1.11 to 1.25%. In both grain and straw, the highest K concentration was found in T_9 and the lowest value in T_1. Grain and straw had S levels of 0.26 to 0.36% and 0.19 to 0.27%, respectively. T_9 had the highest S concentration in both grain and straw, whereas T_1 had the lowest values (Table 2).

Table 2. Grain and straw nutrient content of T. Aman rice (Binadhan 7) are affected by lime and manure application.

Treatments	N Content (%)		P Content (%)		K Content (%)		S Content (%)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.04 ± 0.060 e	0.28 ± 0.016 d	0.22 ± 0.013 e	0.11 ± 0.006 g	0.27 ± 0.016 h	1.11 ± 0.064 e	0.26 ± 0.015 g	0.19 ± 0.011 g
T_2	1.11 ± 0.064 de	0.33 ± 0.019 cd	0.25 ± 0.014 c	0.14 ± 0.008 f	0.33 ± 0.019 f	1.17 ± 0.068 cd	0.28 ± 0.016 f	0.21 ± 0.012 f
T_3	1.13 ± 0.065 cd	0.35 ± 0.020 bc	0.25 ± 0.015 bc	0.16 ± 0.009 d	0.35 ± 0.020 d	1.19 ± 0.069 bc	0.29 ± 0.017 e	0.22 ± 0.013 e
T_4	1.13 ± 0.065 cd	0.36 ± 0.021 abc	0.23 ± 0.013 e	0.15 ± 0.009 e	0.31 ± 0.018 g	1.16 ± 0.067 cde	0.28 ± 0.016 f	0.22 ± 0.013 e
T_5	1.19 ± 0.069 abcd	0.39 ± 0.023 abc	0.24 ± 0.014 d	0.16 ± 0.009 d	0.34 ± 0.020 e	1.17 ± 0.068 cd	0.29 ± 0.017 e	0.23 ± 0.013 d
T_6	1.20 ± 0.069 abc	0.39 ± 0.023 ab	0.25 ± 0.014 c	0.17 ± 0.010 c	0.36 ± 0.021 c	1.20 ± 0.069 de	0.33 ± 0.019 d	0.23 ± 0.014 d
T_7	1.22 ± 0.070 ab	0.39 ± 0.023 abc	0.26 ± 0.015 ab	0.19 ± 0.011 a	0.37 ± 0.021 b	1.23 ± 0.071 ab	0.35 ± 0.020 b	0.25 ± 0.014 b
T_8	1.17 ± 0.068 bcd	0.40 ± 0.023 ab	0.25 ± 0.015 bc	0.18 ± 0.011 b	0.37 ± 0.021 b	1.23 ± 0.071 ab	0.34 ± 0.020 c	0.25 ± 0.014 c
T_9	1.26 ± 0.073 a	0.42 ± 0.024 a	0.26 ± 0.015 a	0.19 ± 0.011 a	0.38 ± 0.022 a	1.25 ± 0.072 a	0.36 ± 0.021 a	0.27 ± 0.015 a
CV (%)	0.04	0.03	0.003	0.002	0.001	0.00002	0.003	0.0023
SE (±)	4.14	10.36	1.48	1.82	0.79	2.48	1.19	1.18

Comparison is made across treatments for grain and straw separately. The same letter in a column represents an insignificant difference at $p < 0.05$. CV (%) = coefficient of variation; SE = standard error of means.

3.1.3. Nutrient Uptake

The overall uptake of the macronutrients N, P, K, and S was significantly influenced by the application of lime and organic amendments ($p < 0.05$). The amount of N taken up by T. Aman rice as a result of the lime and organic amendment treatment ranged from 57.41 to 78.28 kg ha^{-1}. The experimental plots following T_7 treatment took up the highest total N, which was statistically equal to T_8 and T_9, and the lowest value was observed in T_1 (Figure 2). The total P uptake ranged from 14.44 to 21.99 kg ha^{-1}. The highest total P uptake was observed in T_7 and the lowest value in T_1 (Figure 2). The value of K uptake by T. Aman ranged from 62.44 to 78.38 kg ha^{-1}. The highest K uptake was recorded in T_7 which was similar to T_8 and T_9, and the lowest value was observed in T_1 (Figure 2). S uptake ranged from 19.81 to 29.24 kg ha^{-1}, showing the highest value in T_7 and the lowest value in T_1 (Figure 2).

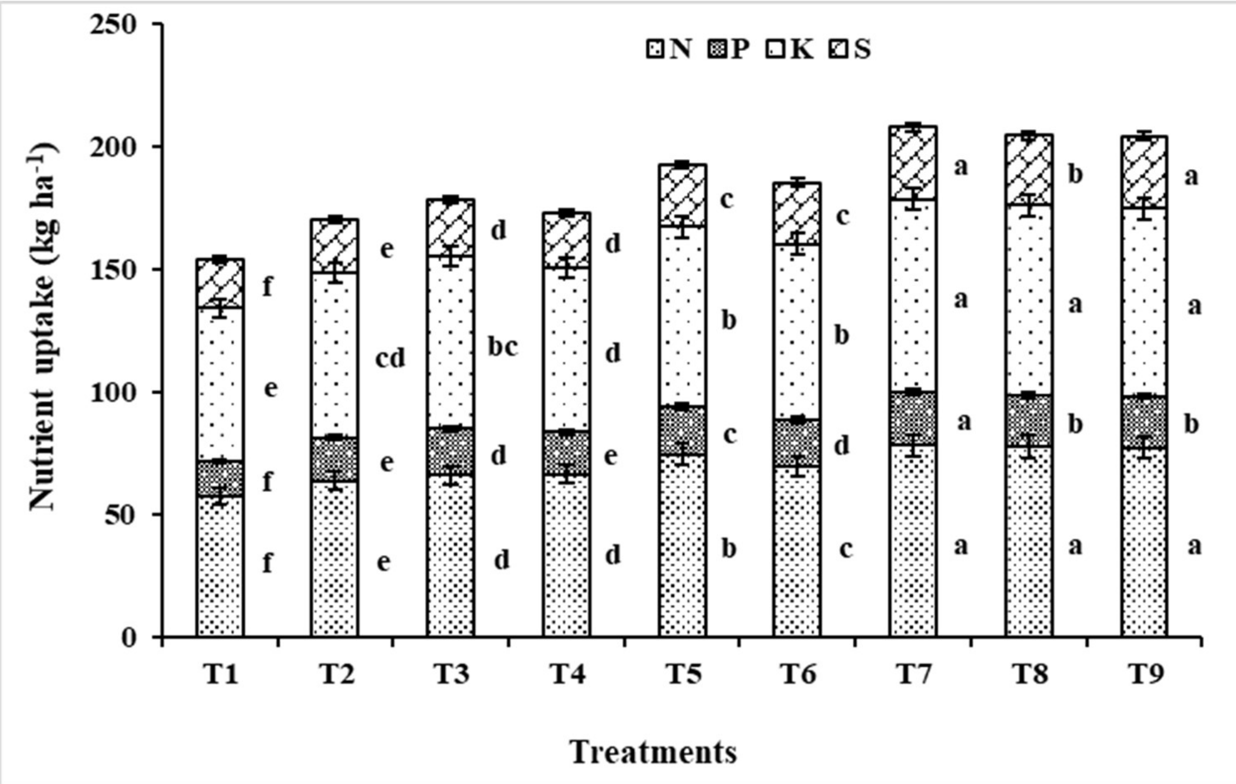

Figure 2. Nutrient uptake of T. Aman rice (Binadhan 7) as influenced by lime and manure amendment. The small letters (i.e., a, b, c, d, e, and f) in the figure indicate that treatments are statistically different at 5% level of significance.

3.2. Residual Effect of Lime and Manure Amendment on Yield, Nutrient Content, and Nutrient Uptake of Maize (BARI Hybrid Maize-9)

3.2.1. Grain and Straw Yield

The residual dololime, cow dung, and poultry manure had a substantial impact on the grain production of BARI Hybrid Maize-9 (Figure 3). Grain yields varied from 5.28 to 8.38 tons per hectare. The maximum grain production (8.38 t ha^{-1}) was found in T_9, while the lowest yield (5.28 kg ha^{-1}) was found in T_1. The increase in grain production compared to control varied from 16.47 to 58.71%, with T_9 having the largest increase and T_4 having the lowest increase. Based on the grain yield values, the treatments may be ranked in order of $T_9 > T_8 = T_7 > T_6 = T_3 > T_2 > T_5 = T_4 > T_1$.

The straw yields of BARI Hybrid Maize-9 also responded significantly to the different treatments under study. The yield of straw ranged from 8.13 to 11.61 t ha^{-1} (Figure 3). The highest straw yield of 11.61 t ha^{-1} was obtained in T_9 and the lowest value of 3.11 t ha^{-1} was noted in T_1. The treatments may be ranked in the order of $T_9 > T_8 > T_7 > T_6 > T_3 > T_2 > T_5 > T_4 > T_1$ in terms of straw yield. Regarding the percentage of increase of straw yield, a maximum increase (42.68%) was noted in T_9 and the minimum one (10.33%) was found in T_4.

The yield data of maize demonstrates that the T_1 with the sole application of chemical fertilizers in the recommended dose produced the lowest grain and straw yield. However, the other treatments with the same dose of fertilizers, but with lime and/or manure added, produced the higher grain and straw yield of maize. This indicates that soil acidity restricts the crop productivity in T_1, which is recovered to some extent in other treatments by the amendment of lime and/or manure.

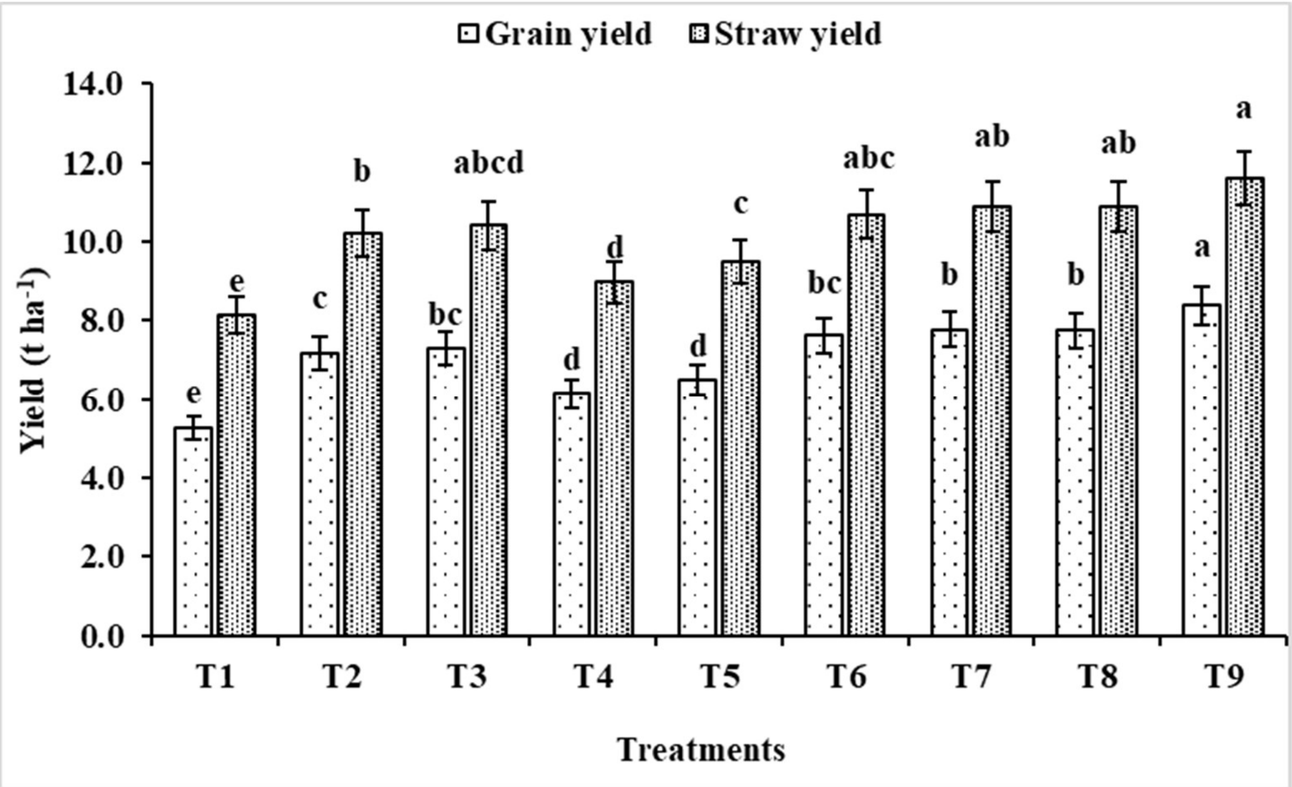

Figure 3. Residual effect of lime and manure amendment on yield of maize (BARI Hybrid Maize-9). Comparison is made across treatments for grain and straw separately. The small letters (i.e., a, b, c, d, and e) in the figure indicate that treatments are statistically different at 5% level of significance.

3.2.2. Nutrient Content

The residual effect of the combination or unilateral application of lime and organic amendment significantly altered the nutrient content in different parts of BARI Hybrid Maize-9 ($p < 0.05$) (Table 3). The amount of nitrogen in grain ranged from 1.35% to 1.65%, whereas straw had a value of 0.35% to 0.47% (Table 3). T_9 had the greatest P content in grain, which was statistically similar to T_8 in grain and T_8, T_7, T_6, T_5 and T_3 in straw whereas T_1 had the lowest value. The levels of P in grain and straw were 0.17% and 0.24%, and 0.13% and 0.21%, respectively (Table 3). T_9 had the greatest P content in grain, which was statistically similar to T_8 in grain and T_8, T_7, T_6, and T_5, respectively, in straw and T_1 had the lowest value in both the cases. K content ranged from 0.28% to 0.40% in grain and 1.11% to 1.30% in straw. The highest K content was observed in T_9 and the lowest value was noted in T_1 in both grain and straw. The levels of S in grain and straw were 0.28% to 0.32% and 0.14% to 0.18%, respectively. In both grain and straw, the maximum S content was found in T_9 and the lowest in T_1 (Table 3).

Table 3. Residual effect of lime and organic manure amendment on grain and straw nutrient content of maize (BARI Hybrid Maize-9).

Treatments	N Content (%)		P Content (%)		K Content (%)		S Content (%)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.35 ± 0.078 d	0.35 ± 0.020 d	0.17 ± 0.010 e	0.13 ± 0.008 d	0.28 ± 0.016 c	1.11 ± 0.064 d	0.28 ± 0.016 d	0.14 ± 0.008 d
T_2	1.43 ± 0.083 c	0.38 ± 0.022 cd	0.21 ± 0.012 d	0.15 ± 0.009 bcd	0.33 ± 0.019 bc	1.20 ± 0.069 c	0.29 ± 0.017 c	0.16 ± 0.01 c
T_3	1.46 ± 0.084 c	0.40 ± 0.023 bcd	0.21 ± 0.012 c	0.17 ± 0.010 abcd	0.33 ± 0.019 bc	1.24 ± 0.072 bc	0.30 ± 0.017 b	0.16 ± 0.009 c
T_4	1.43 ± 0.083 c	0.37 ± 0.021 cd	0.21 ± 0.012 d	0.14 ± 0.008 cd	0.33 ± 0.019 bc	1.20 ± 0.069 c	0.29 ± 0.017 cd	0.15 ± 0.009 c
T_5	1.47 ± 0.085 c	0.39 ± 0.023 cd	0.22 ± 0.013 c	0.16 ± 0.009 abcd	0.35 ± 0.020 ab	1.22 ± 0.070 bc	0.29 ± 0.017 cd	0.16 ± 0.009 c
T_6	1.57 ± 0.091 b	0.42 ± 0.024 abc	0.22 ± 0.013 c	0.18 ± 0.010 abcd	0.37 ± 0.021 ab	1.24 ± 0.072 bc	0.30 ± 0.017 b	0.17 ± 0.009 b
T_7	1.63 ± 0.094 ab	0.45 ± 0.026 ab	0.23 ± 0.013 b	0.20 ± 0.012 ab	0.38 ± 0.022 ab	1.26 ± 0.073 ab	0.30 ± 0.017 b	0.17 ± 0.010 b
T_8	1.63 ± 0.094 ab	0.45 ± 0.026 ab	0.23 ± 0.013 ab	0.19 ± 0.011 abc	0.38 ± 0.022 ab	1.27 ± 0.073 ab	0.32 ± 0.018 a	0.17 ± 0.010 ab
T_9	1.65 ± 0.095 a	0.47 ± 0.027 a	0.24 ± 0.014 a	0.21 ± 0.012 a	0.40 ± 0.023 a	1.30 ± 0.075 a	0.32 ± 0.018 a	0.18 ± 0.010 a
CV (%)	0.03	0.03	0.003	0.00003	0.03	0.02	0.003	0.002
SE (±)	2.75	8.15	1.75	19.61	10.50	2.39	1.35	1.82

Comparison is made across treatments for grain and straw separately. Same letter in a column represents insignificant difference at $p < 0.05$. CV (%) = coefficient of variation; SE = standard error of means.

3.2.3. Nutrient Uptake

The residual impact of the lime and manure treatment on total nutrient acquisition was more evident in the second crop of the cropping pattern. The residual effect of lime and manure had a significant impact on the total N, P, K, and S uptake ($p < 0.05$). The total N uptake by maize ranged from 99.88 to 192.75 kg ha^{-1}. The T_9 had the highest total N uptake and T_1 had the lowest value (Figure 4). Similarly, T_9 had the highest P, K, and S uptake, while T_1 had the lowest uptake (Figure 4). The total uptake of P, K, and S ranged from 19.51 to 43.44 kg ha^{-1}, 104.86 to 184.15 kg ha^{-1}, and 26.44 to 47.10 kg ha^{-1}, respectively (Figure 4).

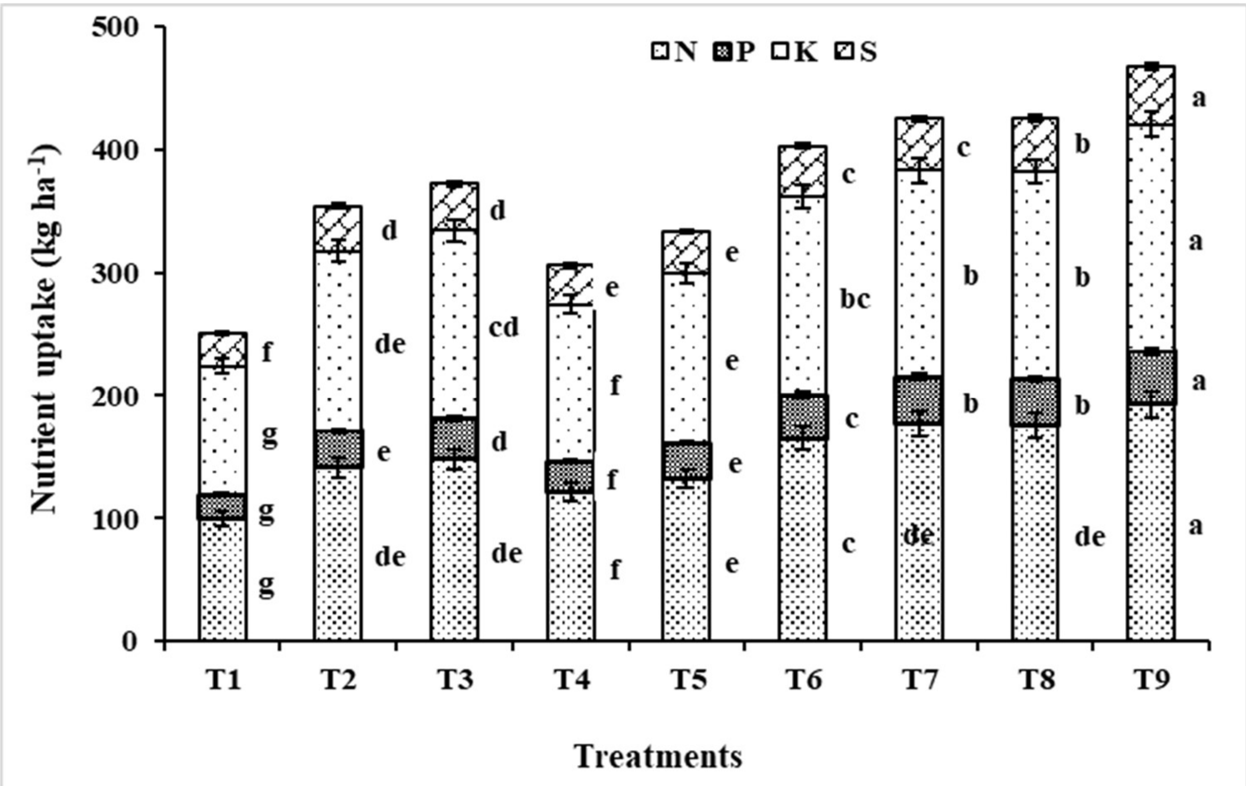

Figure 4. Residual effect of lime and manure amendment on nutrient uptake of maize (BARI Hybrid Maize-9). The small letters (i.e., a, b, c, d, e, f, and g) in the figure indicate that treatments are statistically different at 5% level of significance.

3.3. Total Rice Equivalent Yield of the T. Aman-Maize-Fallow Cropping Pattern

The total rice equivalent yield of the T. Aman-Maize-Fallow cropping pattern was significantly influenced due to the application of dololime, cow dung, and poultry manure, although there was a little difference in grain yield among the treatments ($p < 0.001$) (Figure 5). The total rice equivalent yield ranged from 8.48 to 11.27 t ha^{-1}. The highest total rice equivalent yield (11.27 t ha^{-1}) was observed in T_9, which was statistically similar to T_7 (11.06 t ha^{-1}), and the lowest value (8.48 t ha^{-1}) was recorded in T_1. Based on the total rice equivalent yield, the treatments may be ranked in order of $T_9 = T_7 = T_8 > T_6 = T_3 > T_2 > T_5 > T_4 > T_1$. The increase in the total rice equivalent yield over the control ranged from 20.5 to 66.1%, where the highest increase was obtained in T_9 (66.1%) and the lowest one was obtained in T_4 (20.5%).

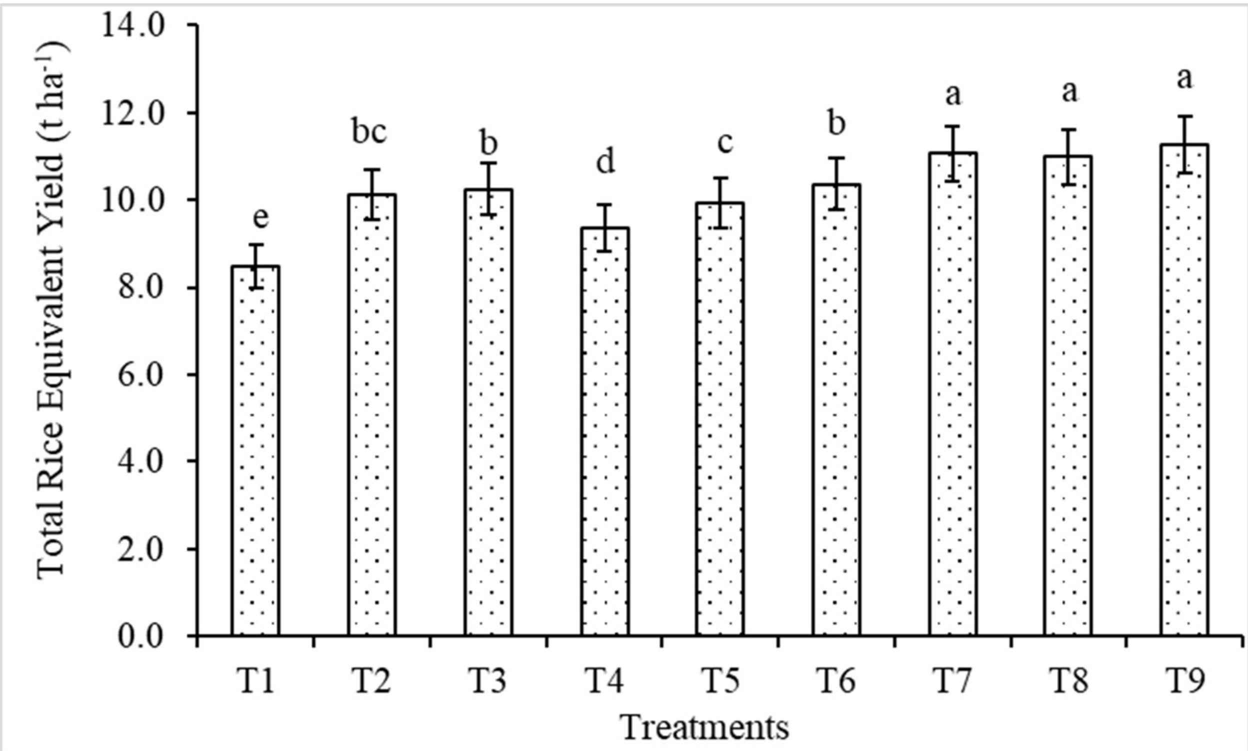

Figure 5. Total rice equivalent yield of T. Aman- Maize-Fallow cropping pattern as influenced by lime and manure amendment. The small letters (i.e., a, b, c, d, and e) in the figure indicate that treatments are statistically different at 5% level of significance. Error bar in each histogram indicates standard error of mean in each treatment.

3.4. Effect of Lime and Organic Manure on Soil Properties

The sole application of chemical fertilizer (T_1) decreased the availability of P by 3.0% and 4.0% after T. Aman and maize harvest, respectively. In contrast, the application of lime and organic manure alone or in combination increased the availability of P by 6.4% to 21.3%, and 15.0% to 45.0% in post-harvest soils of T. Aman and maize, respectively. The highest increase was observed in T_9, whereas the lowest increase was observed in T_4 (Table 4). Soil pH decreased by 8.0% and 14.2% in T_1 after T. Aman and maize harvest, respectively. In contrast, the application of lime and organic manure alone or in combination increased the soil pH by 2.6% to 10.0%, and 7.3% to 22.3% in post-harvest soils of T. Aman and maize, respectively. The highest increase was observed in T_9, whereas the lowest increase was observed in T_4 (Table 4). The sole application of chemical fertilizer (T_1) decreased the CEC of the post-harvest soils of T. Aman and maize by 3.6% and 5.2%, respectively. In contrast, the application of lime and organic manure alone or in combination increased soil CEC by 2.1% to 8.9%, and 6.3% to 20.0% in post-harvest soils of T. Aman and maize, respectively.

The highest increase was observed in T_9, whereas the lowest increase was observed in T_4 (Table 4).

Table 4. Effect of lime and manure amendment on changes of soil properties under T. Aman-Maize-Fallow cropping pattern.

Treatments	Soil pH			STN (%)			Available P (ppm)		
	Before	After T. Aman Rice Harvest	After Maize Harvest	Before	After T. Aman Rice Harvest	After Maize Harvest	Before	After T. Aman Rice Harvest	After Maize Harvest
T_1	4.1 ± 0.01 g	3.8 ± 0.01 g	3.6 ± 0.01 g	6.1 ± 0.03 h	5.9 ± 0.03 h	5.9 ± 0.03 i	30.3 ± 0.02 b	29.3 ± 0.61 d	28.8 ± 1.24 d
T_2	4.6 ± 0.01 d	4.7 ± 0.01 e	4.9 ± 0.01 e	6.3 ± 0.02 g	7.1 ± 0.02 f	7.9 ± 0.02 g	30.6 ± 0.01 b	31.8 ± 0.02 bc	33.6 ± 0.01 bc
T_3	4.7 ± 0.01 ab	4.9 ± 0.01 cd	5.3 ± 0.01 cd	6.5 ± 0.02 de	7.5 ± 0.02 d	8.8 ± 0.02 d	30.7 ± 0.01 b	32.4 ± 0.01 bc	34.7 ± 0.01 bc
T_4	4.3 ± 0.02 f	4.4 ± 0.02 f	4.6 ± 0.02 f	6.4 ± 0.01 ef	6.8 ± 0.01 g	7.4 ± 0.01 h	30.7 ± 0.28 b	31.4 ± 0.48 c	32.7 ± 0.73 c
T_5	4.4 ± 0.01 e	4.6 ± 0.01 e	5.0 ± 0.01 e	6.5 ± 0.02 cd	7.3 ± 0.02 e	8.2 ± 0.02 f	30.5 ± 0.01 b	31.7 ± 0.51 bc	33.4 ± 1.03 bc
T_6	4.6 ± 0.01 cd	4.8 ± 0.01 d	5.2 ± 0.01 d	6.6 ± 0.01 bc	7.5 ± 0.02 d	8.6 ± 0.02 e	30.7 ± 0.01 b	32.5 ± 0.01 bc	35.0 ± 0.02 bc
T_7	4.7 ± 0.02 bc	5.0 ± 0.02 bc	5.4 ± 0.02 bc	6.7 ± 0.02 b	7.8 ± 0.02 c	9.0 ± 0.02 c	30.7 ± 0.02 b	32.6 ± 0.02 bc	35.0 ± 0.02 bc
T_8	4.7 ± 0.01 abc	5.1 ± 0.01 b	5.5 ± 0.02 b	6.8 ± 0.02 a	8.1 ± 0.02 b	9.5 ± 0.02 b	30.8 ± 0.01 b	33.1 ± 0.01 b	36.1 ± 0.01 b
T_9	4.8 ± 0.02 a	5.2 ± 0.03 a	5.8 ± 0.07 a	6.9 ± 0.01 a	8.2 ± 0.02 a	10.0±0.02 a	33.2 ± 0.26 a	36.1 ± 0.29 a	39.8 ± 0.32 a
CV (%)	0.58	0.61	0.96	0.46	0.45	0.43	0.69	1.59	2.85
Level of significance	***	***	***	***	***	***	***	***	***

*** indicates significant at 0.1% level of significance, Same letter in a column represents insignificant difference at $p < 0.05$. CV (%) = coefficient of variation; SE = standard error of means.

3.5. Relationship between Soil Properties and Yields of T. Aman Rice and Maize

Table 5 demonstrates the Pearson's correlation matrix for the yields of T. Aman and Maize, and the physicochemical properties of the soil. The yield of T. Aman rice was moderately correlated with the post-harvest soil properties (Table 5). In contrast, the soil properties had a moderate to very high positive correlation among themselves (Table 5). Maize yield was moderate to strongly correlated with the soil properties (Table 5). Like T. Aman, the soil properties had also a moderate to very high positive correlation among themselves (Table 5).

Table 5. Correlation between soil properties and yields of T. Aman rice and Maize.

T. Aman Rice							
	Yield (t ha^{-1})	SOM (%)	STN (%)	Available P (ppm)	pH	EC (dS m^{-1})	CEC (cmol$_c$/kg)
Yield (t ha^{-1})	1						
SOM (%)	0.62 ***	1					
STN (%)	0.58 **	0.94 ***	1				
Available P (ppm)	0.61 ***	0.81 ***	0.75 ***	1			
pH	0.58 **	0.76 ***	0.66 ***	0.98 ***	1		
EC (dS m$^{-1)}$	0.63 ***	0.87 ***	0.87 ***	0.94 ***	0.88 ***	1	
CEC (cmol$_c$/kg)	0.41 *	0.71 ***	0.66 ***	0.89 ***	0.86 ***	0.87 ***	1
Maize							
	Yield (t ha^{-1})	SOM (%)	TN (%)	Available P (ppm)	pH	EC (dS m^{-1})	CEC (cmol$_c$/kg)
Yield(t ha^{-1})	1						
SOM (%)	0.61 ***	1					
TN (%)	0.54 **	0.93 ***	1				
Available P (ppm)	0.81 ***	0.80 ***	0.70 ***	1			
pH	0.80 ***	0.82 ***	0.69 ***	0.98 ***	1		
EC (dS m$^{-1)}$	0.74 ***	0.86 ***	0.84 ***	0.93 ***	0.89 ***	1	
CEC (cmol$_c$/kg)	0.69 ***	0.75 ***	0.86 ***	0.92 ***	0.91 ***	0.88 ***	1

r value: 0.0 to 0.2—very weak correlation, 0.2 to 0.4—weak correlation, 0.4 to 0.7—moderate correlation, 0.7 to 0.9—strong correlation, 0.9 to 1.0—very strong correlation, * indicates significant at 5% level of significance, ** indicates significant at 1% level of significance, and *** indicates significant at 0.1% level of significance.

4. Discussion

Liming is one of the most important and effective soil acidity control methods [45]. The quality of the liming materials, such as particle size and material types [46], as well as the fundamental original chemical and physical characteristics, such as pH buffering capability and soil organic content, have a significant impact on soil pH [47]. According to Fageria and Baligar [12], adding lime at the proper amount induces a number of chemical and biological changes in the soil, many of which are favorable to crop development and yields in acid soils.

Lime and organic manure amendment had variable effects on the crops of this experiment. In case of rice, T. Aman (Binadhan 7), the effects of lime and organic manure were less prominent. However, a significant effect of lime or organic manure alone or in combination was observed in maize (BARI Hybrid Maize-9). The increase in grain output over the control ranged from 0.23% to 13.61% in the case of Binadhan 7. Liming has also been linked to an increase in rice yields [48,49]. Crop yields of straw likewise followed a similar pattern. Liming elevates the pH and decreases the acidity of the soil, resulting in better straw yields [50–52]. Pritam and Prasad [53] tested dolomite limestone on an acid soil in order to examine how it influenced rice production, and found that it substantially improved the soil pH and rice yield contributing characteristics. According to Asrat et al. [54], using 5 tons of manure and 2.2 tons of lime per acre increased grain output by 279%. According to Whalen et al. [55], lime treatment in acid soil had a substantial influence on straw yield. Sukristiyonubowo et al. [56] discovered that mixing organic manure (straw compost), lime, and mineral fertilizer increased rice grain yield by 42.8% to 79.7%. Liming can also be employed to boost rice output and P uptake in the double rice cropping system, according to Liao et al. [57]. Rahman et al. [31] and Halim et al. [32], demonstrated that applying lime in combination with full dose of chemical fertilizer or organic fertilizer to acid soils in Bangladesh's Rangpur and Dinajpur areas increased agricultural yields. Maize yields also increased 16.47% to 58.71% over the control due to the application of lime and organic manure. The system productivity of crops over the control varied from 20.5% to 66.1% due to the influence of different treatments. Bordoloi [58] reported that the percentage increase in an average yield of maize over local practice was 180.28%, and the application of 1.5 t ha^{-1} of lime resulted in the maximum stover production. According to Andric et al. [59], the use of lime boosted maize grain production by up to 34%. This might be attributed to an increase in the plant availability of soil nutrients due to improvements in the soil pH and other physicochemical characteristics. Sanjay-Swami and Singh [18] reported comparable findings. According to Kumar et al. [60], liming at 300 kg ha^{-1} (furrow application) increased the yield by 32.4% above the control, whereas applying FYM at 5 t ha^{-1} combined with NPK + lime increased the yield by 291%. Our findings are consistent with those of Sharma et al. [61], who reported a 14–50% increase in crop yield in response to a lime application at 2–4 q ha^{-1}, and a 49–390% higher yield following combined use of NPK and lime compared to the control (i.e., farmer's practice), based on 141 experiments in farmers' fields across Assam and Meghalaya.

Our results demonstrated that the application of lime and organic manure significantly improved soil properties and nutrient availability which was consistent with Islam et al. [38]. The STN and available P content in the soil rose as a result of the higher soil pH in the lime and manure treatment [62]. According to Yagi et al. [63] and Kisi et al. [64], higher soil pH caused by the addition of lime and manure also enhanced the soil EC and CEC, which is in line with our results. The yields of both T. Aman and maize had a strong positive correlation with soil properties, which was also similar to the results of the previous study [38]. Soil enzyme activity is an important indicator of soil biological quality. According to Samuel et al. [65], the application of lime to soil increased dehydrogenase and catalase activity significantly, resulting in decomposition of the organic manure and higher nutrient availability. Similarly, the application of chemical fertilizer along with organic fertilizer (green manure and farmyard manure) remarkably increased dehydrogenase, catalase, acid and alkaline phosphatase activities, which resulted in nutrient availability and plant biomass production [66]. Organic amendments (manure and pea vine) stimulated activity, but increasing the rates of inorganic N decreased the activity of these enzymes [67,68]. The sole application of mineral fertilizer decreased the soil pH as well as the nutrient availability resulting from the less catalytic activity [69].

Plants' transformation and absorption of nutrients can both be influenced by liming [70,71] and, additionally, nutrient use efficiency [72]. The use of lime and organic manure amendment considerably increased the content and absorption of macronutrients in both rice and maize, according to our findings. These benefits are only seen when soil chemical characteristics, such as CEC and pH, improve to the point where the negative implications of plant-available Al and P shortages are no longer a concern [73,74]. Besides, the addition of lime has both active and passive positive influence on soil pH, plant nutrient mobilization, soil aggregates and structure, and soil biological activity, resulting in improved nutrient availability [47,75]. Liming enhances soil N availability and rice N absorption, which is consistent with prior research [57,76]. In contrast, a field experiment undertaken by Kovacevic and Rastija [77] found no significant influence of liming on K availability and content, but the addition of 10 and 15 tons of dolomite per hectare significantly increased the P level. Liming promoted root growth by lowering the micronutrient toxicity and, hence, improved P and K uptake [78], resulting in an improved rice output. The combined application of lime and manure greatly boosted the total production, nutrient uptake and REY of each crop in the T. Aman-Maize-Fallow cropping pattern, according to our findings. Sultana et al. [30] found that applying one-ton of dololime, coupled with three tons of poultry manure or five tons of FYM per hectare, boosted crop output and nutrient uptake in the Old Himalayan Piedmont Plains Potato-Mungbean-Rice cropping pattern.

5. Conclusions

The results of the present study revealed that the application of lime and organic manure alone or in combination to acidic piedmont soils (grey terrace soil) significantly boosted the system productivity, nutrient content and uptake of the T. Aman-Maize-Fallow cropping pattern. Lime and organic manure alone or in conjugation improved the soil quality, especially in terms of soil pH, which improved the nutrient availability compared to the sole chemical fertilizer application. Based on the results obtained, it can be recommended that lime (dololime) at 1 t ha^{-1} in combination with organic manure (poultry manure at 3 t ha^{-1}) can be used to improve the productivity of the T. Aman-Maize-Fallow cropping pattern, as well as the quality of the acidic piedmont soils (grey terrace soil). This improved technology will contribute to ensuring the food security of the country. However, similar studies in other acid-prone areas of Bangladesh might be worthwhile to explore for broader recommendations.

Author Contributions: Conceptualization, M.R.I., A.A. and M.A.H. (Mohammad Anamul Hoque); methodology, M.R.I., A.A. and M.A.H. (Mohammad Anamul Hoque); software, A.A., S.F. and S.U.; validation, M.R.I., A.A. and M.A.H. (Mohammad Anamul Hoque); formal analysis, A.A., S.F., M.M.H.T. and S.U.; investigation, M.R.I., A.A. and M.A.H. (Mohammad Anamul Hoque); resources, M.R.I. and M.A.H. (Mohammad Anamul Hoque); data curation, M.R.I., A.A., M.A.H. (Mohammad Anamul Hoque), M.M.H.T. and S.U.; writing—original draft preparation, M.R.I., A.A., M.A.H. (Mohammad Anamul Hoque) and S.U.; writing—review and editing, M.R.I., A.A., M.A.H. (Mohammad Anamul Hoque), S.F., S.U., M.M.H.T., M.A.H. (Mohammad Anwar Hossain), W.F.A. and A.G.; visualization, M.R.I., S.U., M.A.H. (Mohammad Anwar Hossain), W.F.A. and A.G.; supervision, M.R.I. and M.A.H. (Mohammad Anamul Hoque); project administration, M.R.I., A.A. and M.A.H. (Mohammad Anamul Hoque); funding acquisition, M.R.I., M.A.H. (Mohammad Anamul Hoque), W.F.A. and A.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by Taif University Researchers Supporting Project (TURSP-2020/53), Taif University, Taif, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study will be available from the corresponding authors upon request.

Acknowledgments: The authors are grateful to National Agricultural Technology Program Phase-II implemented by Bangladesh Agricultural Research Council for its partial support to conduct this research. Also, the authors appreciate Taif University Researchers Supporting Project (TURSP-2020/53), Taif University, Taif, Saudi Arabia.

Conflicts of Interest: The authors declare that they have no conflict of interest to publish this manuscript.

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