ISSN: 1991-0037 (print), 2710-3285 (online)
SOUTH ASIAN JOURNAL OF AGRICULTURE
https://www.banglajol.info/index.php/SAJA
Agrotechnology Discipline, Khulna University
https://ku.ac.bd/discipline/at

OPEN ACCESS

South Asian J. Agric.

Research Article Vol. 11, No. 2, Dec., 2025: 100-116

Title: Interactive Effects of Soil pH and Organic Matter on Phosphorus Solubility and Maize Yield in Calcareous-Acid Mixed Soils

Authors: Md. Masud Parvez[1,*] and Md. Harunor Rashid Khan[2]

[1]Soil, Water and Environment Discipline, Khulna University, Khulna-9208, Bangladesh
[2]Department of Soil, Water and Environment, University of Dhaka, Dhaka-1000, Bangladesh

*Corresponding Author: Md. Masud Parvez Email: masud@swe.ku.ac.bd

Article Info:

Received: *November 30, 2025*
Accepted: *December 05, 2025*
Published: *December 20, 2025*

Keywords: *Soil mixing, problem soils, pH vs phosphorus, compost, maize, P uptake.*

ABSTRACT

Phosphorus (P) is a crucial nutrient for plant growth, particularly in maize (*Zea mays* L.), a staple crop in many regions. However, its availability in soils, especially in calcareous-acid mixed soils, is often limited due to complex interactions between soil pH and organic matter (OM) content. Limited availability of phosphorus (P) is a significant constraint in acid and calcareous soils. P gets fixed in these soils, which impedes its mobility and absorption by plants. Very few studies have been conducted on soil pH and organic matter in interaction, especially when it comes to calcareous acid mixed soils. This study evaluated the combined effects of soil mixing ratios and organic amendments on soil properties (pH, OM, P dynamics), maize (*Zea mays* L.) productivity, and grain P concentration. Two mixing ratio of calcareous and acid soil (1:1, 1:2, and 1:3) and seven organic amendment treatments, namely, vermicompost, mixed compost, and Tricho-compost applied at two rates and a control was arranged in a completely randomized factorial design. The soil organic matter (SOM), pH, available P (at 40 days of treatment application and after harvest), maize yield, and grain P were measured. The 1:3 mixing ratio consistently produced the highest OM (Vermicompost 8 t/ha), available P at 40 days (Tricho-compost 8 t/ha, Vermicompost 8 t/ha), and grain P content (Vermicompost 8 t/ha, Mixed-compost 4 t/ha), which demonstrated better P mobility under less calcareous conditions. OM and pH stabilization near neutral were also enhanced through organic amendments, whose effects improved nutrient availability. Correlation analysis revealed that there were weak to moderate positive correlations of OM and available P (40 days) ($r = 0.37$, $p < 0.01$), and pH (after harvest) and available P (after harvest) ($r = 0.48$, $p < 0.01$). Grain P had a weak positive correlation with available P at 40 days. There were no significant correlations between maize yield and soil chemical properties, suggesting that other variables may have influenced the ultimate yield. Such results demonstrate the relevance of integrating soil mixing strategies with organic nutrient sources to reduce P fixation, increase P-use efficiency, and enhance the nutritional quality of crops in P-deficient agroecosystems. More long-term research is required to ensure sustainability and optimize amendment rates.

DOI: https://doi.org/10.3329/saja.v11i2.85983

To cite this article: Parvez, M. M., & Khan M. H. R. (2025). Interactive Effects of Soil pH and Organic Matter on Phosphorus Solubility and Maize Yield in Calcareous-Acid Mixed Soils. *South Asian Journal of Agriculture*, *11*(2): 100-116.

INTRODUCTION

Phosphorus (P) deficiency and low availability due to fixation are major barriers to crop productivity worldwide, including in Bangladesh. Despite substantial P reserves in soils, most P is chemically bound and unavailable to plants, especially in tropical, acidic, calcareous, and highly weathered soils common in Bangladesh and many developing regions. Globally, only 8–25% of applied P fertilizer is taken up by crops; the rest is fixed in soil or lost to the environment (Blackwell et al., 2019; Johan et al., 2021; Zhang et al., 2025a; Yu et al., 2021). Acidic hill soils and intensive agriculture lead to low available P (1.29–10.9 mg/kg), requiring careful fertilizer management and liming to improve PUE (Phosphorus Use Efficiency) (Tania et al., 2025). Accumulated P from past fertilizer use is often locked in unavailable forms, but can be mobilized with improved management (Zhu et al., 2018; Blackwell et al., 2019).

The fixation of phosphorus is highly problematic production of both acidic and calcareous soils, owing to varying chemical reactions, yet leading to the low phosphorus availability. In soils that have pH of less than 5.5, as is common in acid sulfate and piedmont lands, P is chelated by oxides of aluminum (Al) and iron (Fe) and it is insoluble. This leads to very low P solubility and high P deficiency, as seen in the Ganges Delta and hill tracts (Johan et al., 2021; Sarangi et al., 2022; Islam et al., 2010). In soils with pH above 7.5, typical of calcareous regions, P reacts with calcium (Ca) to form insoluble calcium phosphates, again reducing P solubility (Johan et al., 2021; Adnan et al., 2025). Maximum P solubility and plant availability generally occur at near-neutral pH (6.0–7.0). This is the classic “textbook” recommendation, as both Al/Fe and Ca fixation are minimized in this range (Penn and Camberato, 2019; Johan et al., 2021).

Phosphorus (P) solubility and availability in Bangladesh’s problem soils such as acid sulfate, acid piedmont, and calcareous soils, are strongly governed by soil pH. Most soils in Bangladesh are not in the range of optimum pH, which limits P availability due to chemical fixation. Long-term fertilizer use in tea gardens has acidified soils, reducing pH by up to 24% and decreasing available P by 25% over several decades (Jahan et al., 2022). In the Ganges Tidal Floodplain, P sorption capacity is negatively correlated with pH-lower pH increases P fixation, reducing availability (Hoque et al., 2018; Hoque et al., 2016). Acid sulfate soils in the Ganges Delta (pH < 3.5) show extremely high P fixation and deficiency, requiring amendments like lime or organic matter to improve P solubility (Sarangi et al., 2022). High sand content and low organic matter reduce P retention and cycling, while organic matter can help mobilize P (Singh et al., 2021; Achat et al., 2016; Tania et al., 2025).

Phosphorus solubility in Bangladesh’s problem soils is lowest at very low and very high pH due to fixation by Al/Fe or Ca, respectively. To maximize P availability and crop productivity it is important to manage the soil pH to a neutral level. To achieve good management, special approaches are needed like pH control, organic addition, and novel fertilizers to reduce fixation and enhance crop P uptake.

The scientific literature has shown that organic substances like biochar, compost, farmyard manure, and liquid organic fertilizer can enhance the soil chemical characteristics, augment the organic content, and improve the availability of phosphorus even when the soil is calcareous or acidic. As an illustration, the biochar composed of rice husk and lime was used in acidic soils, which showed that the combination significantly raised the soil pH, phosphorus, and yield of maize, and in addition to this, it decreased the amount of harmful aluminum and iron, thereby to a more conducive environment to grow maize (Mosharrof et al., 2021). On the same note, the combination of organic and inorganic fertilizers or the use of composts and organic acid with mineral phosphorus and potassium has been found to increase phosphorus absorption and the yield of maize in calcareous soils (Tabbasum et al., 2020; Ahirwar et al., 2025; Matheus et al., 2023). These amendments can not only enhance the availability of nutrients but also enhance the healthy development of beneficial microbes and soil enzymes, which further increases the phosphorus cycling and plant assimilation (Hu et al., 2023; Yang et al., 2025). Phosphorus solubility and maize yield could be further enhanced by the combination of phosphorus-solubilizing bacteria and plant development-promoting microorganisms alongside organic amendments by decreasing the rhizosphere soil pH and releasing previously inaccessible phosphorus (Hussain et al., 2020; Javeed et al., 2019). Notably, the strategies work well in a variety of soils and environment, such as the acid and calcareous soils found in Bangladesh, and are linked to better soil structure, water retention, and environmental stress resistance (Kätterer and Bolinder, 2024; Mahmood et al., 2017).

Existing literature often treats soil pH and organic matter as isolated factors, neglecting the complexity of their interactions in real-world agricultural systems. This research seeks to fill this gap by systematically examining how varying levels of soil pH from mixing calcareous and acid soil, and organic matter from organic amendments, affect phosphorus solubility and maize yield.

The study was conducted to: a) evaluate how different calcareous-acid soil mixing ratios along with organic amendments affect soil pH and phosphorus solubility, b) analyze the interaction between soil pH and organic matter content on available P and maize P uptake. c) find out the best mixing ratio and organic amendment dose combination for maximum yield of maize.

The findings will provide applicable evidence-based recommendations on optimizing phosphorus management and enhancing crop productivity in regions facing soil acidity-calcareousness constraints.

MATERIALS AND METHODS

Site of the experiment

To carry out the experiment, soils from two sites were selected, depending on low and high pH. For low pH, an acid soil was collected from Binnapara, which is a village of Chehelgazi union of Dinajpur Sadar upazila of Dinajpur district. The geographical location of the sampling site is 25°42'52.58" N and 88°39'36.07" E. This site falls under the AEZ-1 (Old Himalayan Piedmont Plain Agro Ecological Zone). Soil was collected from a field adjoining to a homestead area of the village.

Faridpur Sadar was selected as the experimental site due to its location on the calcareous soil belt. The experiment site is situated in Parchar, a village of Krishnanagar union of Faridpur Sadar upazilla in Faridpur district. The geographical location of the field experiment site is 23°35'8.34" N and 89°46'51.76" E. This site falls under the AEZ-12 (Low Ganges River Floodplain

Agro Ecological Zone). The area belongs to Medium Highland Soils. Then the acid soil was mixed with calcareous soil on site at a proportion of 1:1, 2:1, 3:1 and the experiment was carried out.

Characteristics of the selected soils

The acid soil of Binnapara of Dinajpur is a Non-calcareous Brown Floodplain soil that belongs to the Pirgacha series (SRDI, 2012). This series comprises seasonally flooded, moderately well-drained soils of silt loam texture with relatively low soil reaction, which limits crop potentials.

On the other hand, the soil of Parchar of Faridpur is a Calcareous Dark Grey Floodplain soil belonging to the Sara series (SRDI, 2012). This series comprises soils of loamy to clay loam texture, low to moderate water holding capacity, and partially flooded during the monsoon. The top soil contains lime and is moderately to highly alkaline in reaction. Different physical, physico-chemical, and chemical properties of the acid and calcareous soils are presented in the Table below.

Table 1. Initial properties of the soil used in the experiment

Properties	**Acid Soil**	**Calcareous Soil**
Series	Pirgacha	Sara
USDA Soil Taxonomy	Ultic Ustochrepts	Typic Eutrochrepts
General Soil Type	Non-Calcareous Brown Floodplain	Calcareous Dark Grey Floodplain
World Reference Base*	Orthi–Gleyic Cambisols	Fluvi–Calcaric Gleysols
Texture	Sandy Loam	Clay
pH	4.90	7.95
Organic Matter (%)	0.78	1.82
Available P (mg/kg)	1.097	12.11
Total P (%)	0.003	0.075
Elevation above Mean Sea Level	37 m	14 m
Flooding Condition	0.1-0.5 m (Flooding Season)	0.1-1 m (Flooding Season)

***Collected from Huq and Shoaib, 2013.**

Experimental design

A completely randomized factorial design was employed to examine the combined effects of soil mixing ratios and organic amendments on soil properties and maize performance. The experiment consisted of three soil mixing ratios assigned as Factor A, and seven organic amendment treatments as Factor B. Each treatment combination was replicated three times, resulting in a total of 63 experimental units.

Table 2. Factors of the experimental design

Factor A: Soil Mixing Ratio	**Factor B: Organic Amendments**
1:1 (Calcareous: Acid)	Control (No Organic Amendments)
1:2 (Calcareous: Acid)	Vermicompost (4 and 8 t/ha)
1:3 (Calcareous: Acid)	Tricho-compost (4 and 8 t/ha)
	Mixed-compost (4 and 8 t/ha)*

* Composed of leaf litter, cow dung etc. Specific composition was not supplied by the producer

The organic amendments (ready to use commercial composts) were bought and analyzed to find out their key characteristics for this experiment.

Table 3. Chemical concentration of the organic amendments used in the experiment

Properties	Vermicompost	Tricho-compost	Mixed Compost
pH	7.58	7.70	7.3
Organic Matter (%)	22.1	18.7	17.4
Phosphorus (%)	0.5272	0.9208	0.391

Cropping season, seed sowing and basal dose

The field experiment was done in the Late Rabi/Early Kharif-1 cropping season. BARI Hybrid Maize- 9 was used for the experiment. Certified seeds for the field experiment were collected from the Bangladesh Agricultural Research Institute (BARI). The seeds were sown by hand, maintaining a 30 cm distance between seeds and a 60 cm distance between rows.

Treatments of the experiment

Treatment ID	Mixing Ratio (Calcareous: Acid)	Organic Amendments
$1_C:1_A$	1:1	No Organic Dose
$1_C:1_A$ V_4	1:1	Vermicompost 4 t/ha
$1_C:1_A$ V_8	1:1	Vermicompost 8 t/ha
$1_C:1_A$ T_4	1:1	Tricho-compost 4 t/ha
$1_C:1_A$ T_8	1:1	Tricho-compost 8 t/ha
$1_C:1_A$ M_4	1:1	Mixed-compost 4 t/ha
$1_C:1_A$ M_8	1:1	Mixed-compost 8 t/ha
$1_C:2_A$	1:2	No Organic Dose
$1_C:2_A$ V_4	1:2	Vermicompost 4 t/ha
$1_C:2_A$ V_8	1:2	Vermicompost 8 t/ha
$1_C:2_A$ T_4	1:2	Tricho-compost 4 t/ha
$1_C:2_A$ T_8	1:2	Tricho-compost 8 t/ha
$1_C:2_A$ M_4	1:2	Mixed-compost 4 t/ha
$1_C:2_A$ M_8	1:2	Mixed-compost 8 t/ha
$1_C:3_A$	1:3	No Organic Dose
$1_C:3_A$ V_4	1:3	Vermicompost 4 t/ha
$1_C:3_A$ V_8	1:3	Vermicompost 8 t/ha
$1_C:3_A$ T_4	1:3	Tricho-compost 4 t/ha
$1_C:3_A$ T_8	1:3	Tricho-compost 8 t/ha
$1_C:3_A$ M_4	1:3	Mixed-compost 4 t/ha
$1_C:3_A$ M_8	1:3	Mixed-compost 8 t/ha

Basal doses of Urea, TSP, MoP, and other fertilizers were applied in the plots.

Fertilizer Dose	kg ha^{-1}
Urea	280
Triple Super Phosphate	120
Murate of Potash	200
Gypsum	220
Zinc Sulphate	12
Boric Acid	5

Soil/grain sampling and analysis

Soil samples were collected at Mid-season (40 days after applying treatment) and after harvesting of crop (around 120 days), and Grain samples at harvest.

Analysis of the parameters: Soil pH was measured using a glass electrode pH meter following the method of Jackson (1973). Organic carbon (%) was determined by the Walkley–Black wet oxidation method (Walkley and Black, 1934) and multiplied by Van Bemmelen's factor of 1.724 (Piper, 1950) to calculate the OM (%). Available P was measured by the Ascorbic acid blue color method after extraction by the Olsen method (calcareous soil) and Bray II method (neutral/ acidic soil) (Olsen et al., 1954; Bray and Kurtz, 1945). For Total P determination, the samples were first digested using HNO_3–$HClO_4$ (Nitric - Perchloric Acid) and then measured by a spectrophotometer developing the Vanadomolybdophosphoric Yellow color method (Jackson, 1973).

Data analysis

The obtained data were statistically analyzed and presented with the help of SPSS 26.0 and Microsoft Excel. The data from different parameters were subjected to Two-way ANOVA, Post Hoc Tukey Test, and Correlation. Duncan Multiple Range Test was run at a probability level of 0.05 to compare the difference between treatment means.

RESULTS AND DISCUSSION

Soil organic matter

In light of the statistical analysis, Soil Organic Matter (OM) at 40 days after treatment application significantly differed on the basis of soil mixing ratio, organic doses and in their interactive effect (Mixing ratio x Organic dose). Average OM of the 1:1 and 1:2 mixing ratio showed similar results whereas 1:3 ratio exhibits higher OM content (8.7% increase over the lowest value). A few reasons for that to happen might be the increase of short-term retention of OM by retaining organic fractions, reduced microbial activity (Tonon et al., 2010) and stabilizing OM through organo-mineral complexes in soils with acidic materials (Lehmann et al., 2020; Eusterhues et al., 2005). Average OM content of the applied treatments showed that vermicompost 8 t/ha was the best at increasing OM of the treated soils (28.7% increase from the control). The initial investigation of properties of the organic amendments showed that vermicompost had the highest OM content which was evident from the data at 40 days.

Post-harvest OM was also significant in relation to soil mixing ratio, organic doses and in their interactive effect (Mixing ratio x Organic dose). 1:1 soil mixing ratio produced the highest post-harvest OM (8.7% increase over the lowest value), while the 1:3 ratio produced closer results. From the mean OM content under the soil mixing ratio a fluctuating trend was evident. After the growing season at post-harvest, OM in some soil is reduced. Rising temperature, moisture, pH, and their subsequent effect on microbial activity and OM decomposition may be the reason behind this reduction. Ryan et al. (2009) studied the changes in OM during a cropping season and noticed a decrease in Total SOM. In some treatments, OM content increased from its previous level. The reason behind this might be the accumulation of OM from plant residues during the growing season. The accumulated plant residues transform into OM to enrich the soil (Trowbridge, 2019).

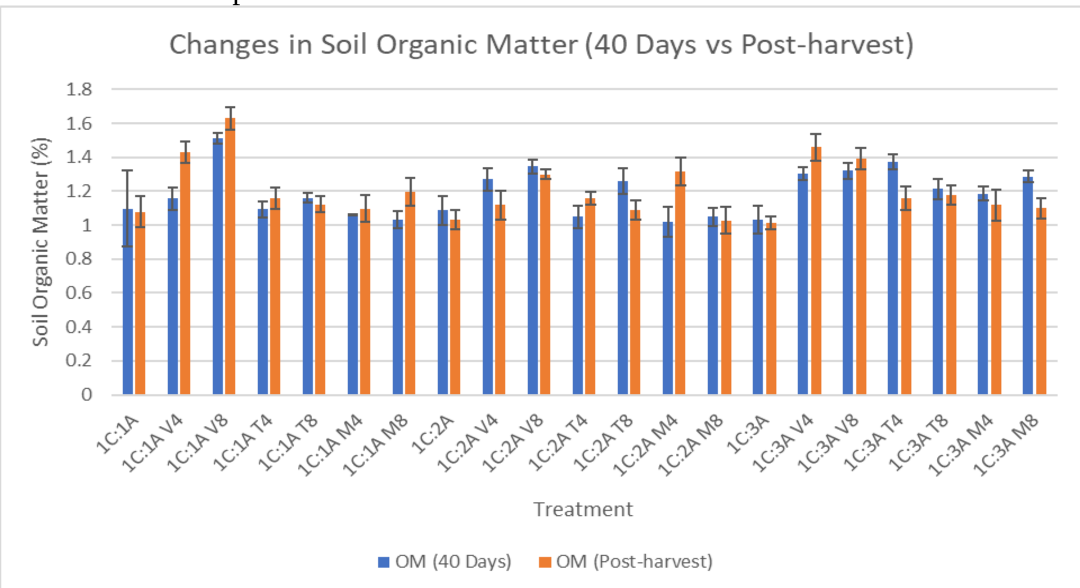

Figure 1. Changes in SOM from 40 days after treatment application to post-harvest level

Vermicompost at 8 t/ha on average again topped the list of OM content (38.5% increase from the control), similar to the 40-day value. The same organic amendment at 4 t/ha holds the second-best place for OM increase. High stability of vermicast organic fractions may influence the performance of vermicompost. Licitra et al. (2024) and Jakubus and Michalak-Oparowska (2022) studied vermicompost and concluded that vermicast generally contains higher levels of humic substances and more stable organic carbon fractions than traditional compost.

Soil pH

From the statistical analysis, pH at 40 days after treatment application was found significant on the basis of soil mixing ratio, organic doses, and in their interactive effect (Mixing ratio x Organic dose). The change (36% decrease from the initial calcareous soil pH) was evident from the pH of the initial soil (7.95) where the experiment was carried. Higher organic doses showed lower soil pH. Mixed compost at 8 t/ha showed the lowest average pH. Mixed compost had a lower pH than the rest of the organic amendments (7.3), which may be one of the reasons.

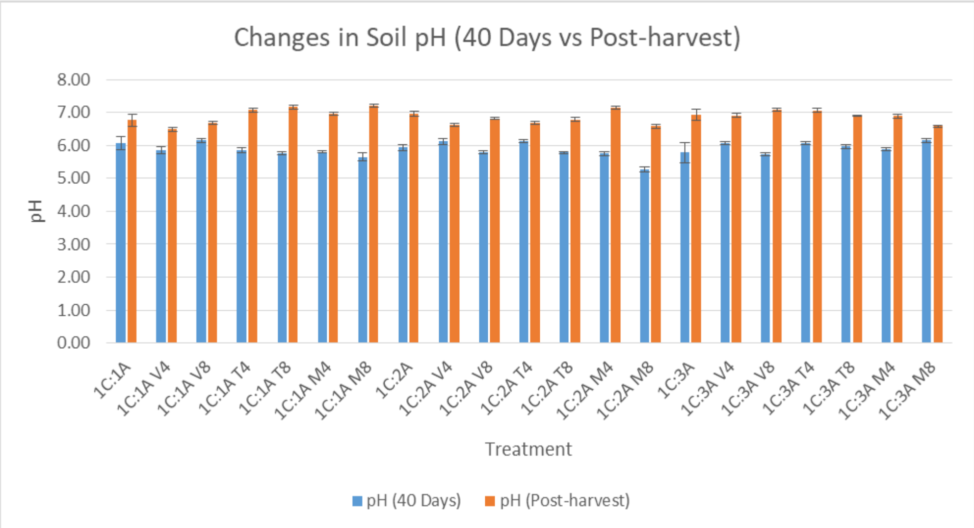

Figure 2. Changes in Soil pH from 40 days after treatment application to post-harvest level

But in general, compost does not drastically lower the pH of a soil, rather increases or stabilizes to a near neutral value (Ch'ng et al., 2014; Ho et al., 2022). So, the initial lowering of soil pH may be entirely due to mixing of high pH calcareous and low pH acidic soil (Solaiman et al., 2023).

At post-harvest time, the pH of the treated soils showed a significant difference in relation to soil mixing ratio, organic doses, and in their interactive effect (Mixing ratio x Organic dose). The pH at 40 days after applying treatments bounced back to near neutral pH (7.0). Saha et al. (2023) and Solaiman et al. (2023) found similar results in their experiments. The 1:3 and 1:1 mixing ratio maintained a slightly higher average post-harvest pH (15% decrease from the initial calcareous soil pH) than the 1:2 ratio of mixed soil. Mixed compost at 4 t/ha produced the highest pH in post-harvest soil, closely followed by Tricho-compost at 4 and 8 t/ha. This distinct pH buffering mechanism might be due to the release of base cations from exchange sites (Shi et al., 2019), $CaCO_3$ dissolution (Bolan et al., 2023), and microbial-mediated buffering (Zheng et al., 2022; Herndon et al., 2015; Wagner et al., 2017; Ye et al., 2012). So, it can be said that the soil pH response is not linear, and cannot be understood by dosing alone. The underlying calcareous-acid soil proportions determine the decomposition rate, organic acid neutralization, $CaCO_3$ dissolution, and microbial community behavior.

Available phosphorus

During the sampling at 40 days after treatment application and after harvesting, it was evident from statistical analysis that soil mixing and organic amendments are both major determinants of phosphorus availability. At 40 days the soil mixing ratio of 1:3 showed the highest mean available phosphorus content (56.3% increase over the lowest value) among the mixing ratios. As the availability of P in soil is greatly influenced by soil pH, the maximum P will be available at a near-neutral pH of 6-7 (Penn and Camberato, 2019; Lindsay, 1979). The correlation between pH and available P at 40 days produced a moderate positive relationship (r=0.37), which means that within that pH range, available P increased in most cases.

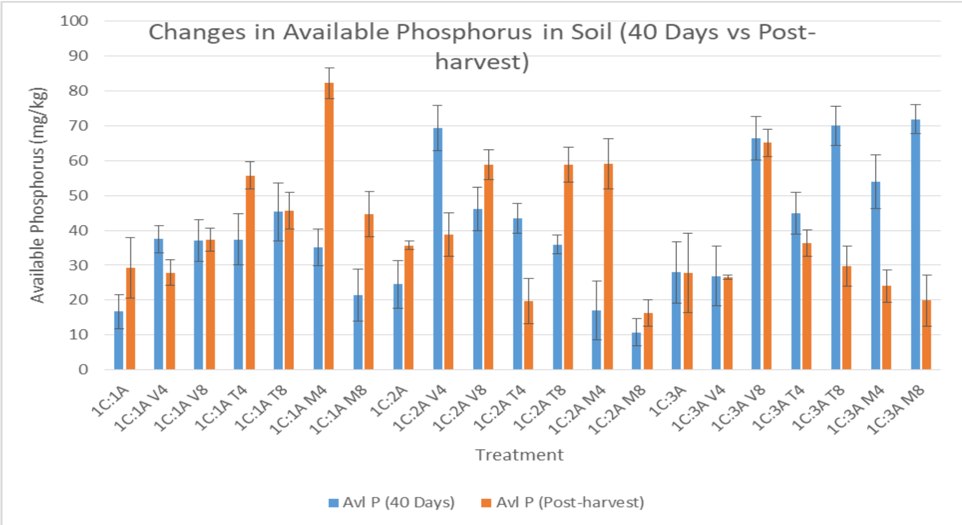

Figure 3. Changes in available P from 40 days after treatment application to post-harvest level

Tricho-compost at 8 t/ha, closely followed by Vermicompost at 8 t/ha, exhibited the highest availability of P (113% increase from the control) in the treated soils. *Trichoderma* from Tricho-compost can solubilize P in soil, which may help in the increase of P availability in the treated soil (Bononi et al., 2020). Vermicompost helps to increase available P by higher content of P (Lim et al., 2015), and earthworms can promote the activity of the P cycle by influencing microbial activity (Benaffari et al., 2022; Cruz et al., 2024).

At post-harvest measurement, the trend almost reverses with 1:1 soil mixing ratio having the highest available P content (39.6% increase over the lowest value). There might be several reasons behind this. The Ca^{2+} being present from the calcareous soil might hinder P uptake due to Ca-P interactions initially at first (Han et al., 2021). But organic amendments and root exudates slowly solubilize Ca-bound P over time (Audette et al., 2016; Randall et al., 2001). This can lead to more residual available P at the end of the crop cycle. The high available P in 1:3 ratio at 40 days may be used up by the maize plants. Mixed-compost at 4 t/ha showed the highest post-harvest available P (74.7% increase from the control), which is on par with vermicompost at 8 t/ha. The correlation between pH and available P at post-harvest produced a moderate positive relationship (r=0.48), which means that within that pH range, available P increased in most cases. The post-harvest increase in available P may be explained by a favorable pH at that treatment (Penn and Camberato, 2019; Lindsay, 1979).

Maize yield

From the Two-way ANOVA, we can see that the effect of mixing ratio was not statistically significant (p=0.177)**.** The soil mixing ratios 1:1, 1:2, and 1:3 did not produce meaningful differences in maize yield when averaged across all treatments. The yield differed slightly in the order of 1:2>1:1>1:3 (only 7% difference between them). But, the effect of organic dose was highly significant ($p < 0.001$), indicating strong differences among the seven treatments.

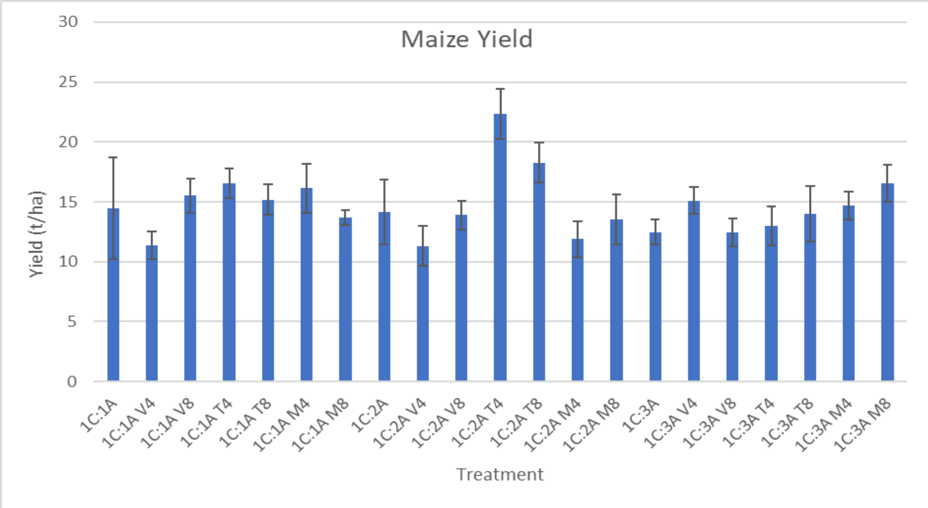

Figure 4. Yield of Maize (t/ha)

When the organic treatments were grouped and averaged, Tricho-compost treatments (especially 4 t/ha) produced the highest yield (24.7% increase from the control) closely followed by Tricho-compost at 8 t/ha. Then comes the mixed compost at 4 t/ha and 8 t/ha both. Vermicompost at both doses produced comparatively lower yields. Interaction Effect (Mixing Ratio × Organic Dose) is statistically significant and indicates very strong interaction ($p < 0.001$). From the above discussion we can see that, the treatments do not act independently; certain ratios enhance or suppress the effect of specific compost types. Maize growth in tricho-compost combined with the inorganic fertilizers produced the most positive results, which proves that tricho-compost can be used to supplement the traditional farming practices of fertilization (Hermansyah et al., 2023).

The high performance of Tricho-compost (especially 4 t/ha) implies that these amendments offer a better balance of nutrients and the stimulations of microorganisms to support the growth of maize. The use of tricho-compost has also been associated with a better nutrient status of soil (Zhang et al., 2025b), and pathogen reduction (Mañas and Heras, 2025), which leads to increased yields. In this experiment, mixed-compost may have a balanced nutrient and better related characteristics than vermicompost.

P Content in maize grain

The average phosphorus levels in maize grain are 2000-3300mg/kg (Nenova et al., 2019). Phosphorus content in maize is affected by the phosphorus fertilization (Nadeem et al., 2014; Khaleeq et al., 2023), the Grain position in the Cob (Nadeem et al., 2014), and genetic determinations and breeding (Camdzija et al., 2018).

The Two-way ANOVA revealed a significant effect of soil mixing ratio and organic doses, along with an interaction between them. Treatments with a 1:3 mixing ratio showed the highest (13% increase over the lowest value) mean total phosphorus content (2708 mg/kg). The initial available phosphorus and its subsequent uptake may have contributed to this. Phosphorus uptake is crucial for achieving maximum grain yield. However, since this does not correlate with the apparent low yield at the 1:3 mixing ratio, there may be cases of excessive phosphorus uptake, which can lead to 'luxury consumption'. This has the potential to reduce the yield of grain by suppressing translocation of other crucial nutrients such as copper, zinc, and iron (Penn et al., 2023) (Penn et al., 2022).

Vermicompost at 8 t/ha and Mixed-compost at 4 t/ha have shown similar (around 20% increase from the control) mean grain phosphorus content (around 2800 mg/kg). That also does not correlate with the lower yield at these organic doses, which is indicative of luxury consumption.

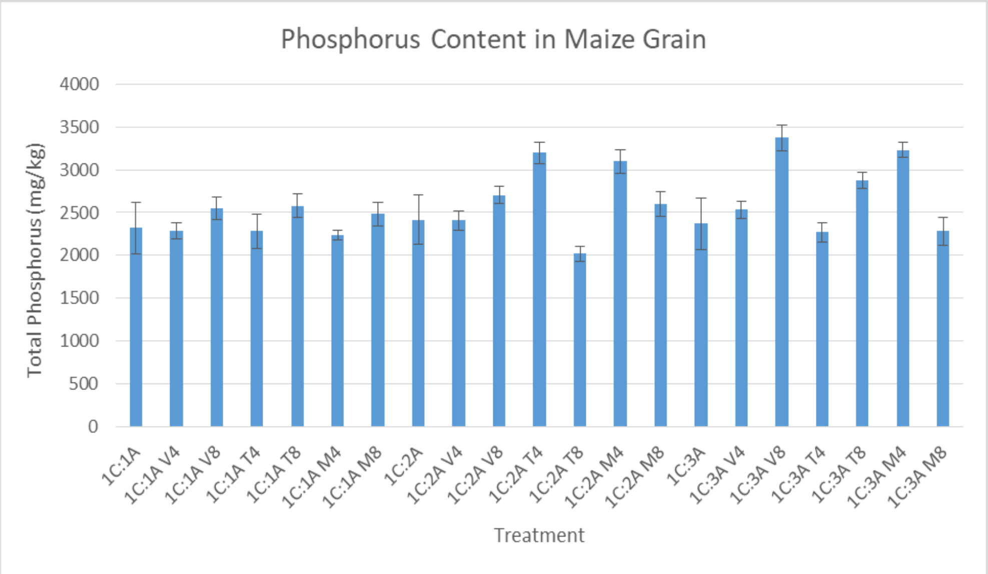

Figure 5. Total phosphorus content in Maize grain (mg/kg)

Correlation between parameters

N=63		OM (40 Days)	OM (Post Harvest)	pH (40 Days)	pH (Post Harvest)	Avl P (40 Days)	Avl P (Post Harvest)	Maize Yield	Grain P
OM (40 Days)	Pearson Correlation	1							
	Sig. (2-tailed)								
OM (Post Harvest)	Pearson Correlation	0.495**	1						
	Sig. (2-tailed)	.000							
pH (40 Days)	Pearson Correlation	0.429**	0.198	1					
	Sig. (2-tailed)	.000	.119						
pH (Post-Harvest)	Pearson Correlation	-0.216	-0.071	-0.184	1				
	Sig. (2-tailed)	.089	.580	.149					
Avl P (40 Days)	Pearson Correlation	0.432**	0.021	0.367**	-0.124	1			
	Sig. (2-tailed)	.000	.869	.003	.335				
Avl P (Post-Harvest)	Pearson Correlation	-0.016	0.089	-0.192	0.478**	-0.001	1		
	Sig. (2-tailed)	.902	.487	.132	.000	.992			
Maize Yield	Pearson Correlation	-0.143	-0.127	0.139	-0.114	0.026	-0.032	1	
	Sig. (2-tailed)	.263	.320	.276	.374	.842	.804		
Grain P	Pearson Correlation	0.021	0.237	-0.097	0.161	0.242	-0.089	-0.005	1
	Sig. (2-tailed)	.868	.062	.449	.208	.056	.488	.971	

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation analysis reveals that early-season soil conditions, especially organic matter content and pH, play a crucial role in determining phosphorus availability.

OM at 40 days indicates that there are positive relationships between soil pH (r= 0.429, $p<0.001$) and early available P (r=0.432, $p<0.001$), which means organic amendments improve the rate of P mineralization at the initial growth stage. On the same note, post-harvest available P has a positive relationship with post-harvest soil pH (r=0.478, $p<0.001$), implying that available P throughout the growing season depends on soil pH and complex mineralization and fixation dynamics.

The relationships after harvesting are compromised significantly. There are no significant differences in yield or grain phosphorus between OM and pH at harvest and this shows that nutrient uptake processes are highly dependent on the processes that take place earlier in the growth cycle. Even though, early available P has weak positive tendency with grain phosphorus, neither the yield nor grain P has significant linear relationships with the soil parameters. This means that the more intricate non-linear interactions between soil mixing ratios and organic amendments affect the plant performance which is confirmed by the significant and highly significant ANOVA interaction effects.

All in all, the correlations allow concluding that organic inputs to the soil early in the season lead to biological and chemical improvements in the soil which results in the P availability but not linear relationships with the crop response.

CONCLUSION

Soil mixing ratio and organic amendment rate had strong interactive effects on phosphorus availability, maize yield, and grain P accumulation. Overall, the 1:3 calcareous-to-acid soil ratio consistently created the most favorable conditions, such as higher organic matter, near-neutral pH, greater available P at 40 days, and increased grain P. This indicates that a higher proportion of acid soil reduces Ca-induced P fixation and expands the bioavailable P pool. Organic amendments, especially vermicompost (8 t/ha), mixed-compost (4 and 8 t/ha), and tricho-compost (8 t/ha), further enhanced organic matter, moderated pH, and improved P solubilization. This was supported by weak to moderate positive correlations between OM and available P (r=0.432) and between pH moderation and post-harvest P availability (r=0.478). Microbial stimulation, particularly from tricho-compost, likely contributed to improved P mineralization. The greater soil performance was observed under the 1:3 ratio combined with higher organic doses (vermicompost 8 t/ha), reflecting a synergistic effect. Although maize yield was not strongly correlated with individual soil parameters, the 1:2 mixing ratio with Tricho-compost 4 t/ha produced the highest yields. Based on the discussion above, there is no single ‘one size fits all’ combination for soil mixing and organic amendments. It is recommended that further research explore the use of soil mixing combined with both inorganic and organic inputs as a strategy for integrated soil management. These methods offer a stable and effective way to combat the low P availability in problematic soils of Bangladesh.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

Achat, D., Pousse, N., Nicolas, M., Brédoire, F., & Augusto, L. (2016). Soil properties controlling inorganic phosphorus availability: general results from a national forest network and a global compilation of the literature. *Biogeochemistry*, 127, 255-272. https://doi.org/10.1007/s10533-015-0178-0

Adnan, M., Fahad, S., Saleem, M., & Lal, R. (2025). Sustainable phosphorus management in calcareous soils: problems and prospects. *Journal of Plant Nutrition*, 48, 2179 - 2200. https://doi.org/10.1080/01904167.2025.2477269

Ahirwar, H., Kulhare, P., Tagore, G., Prajapati, S., & Singh, V. (2025). Effects of Organic and Inorganic Fertilizers on Soil Properties, Nutrient Dynamics, and Maize Yield (Zea mays L.). *International Journal of Plant & Soil Science*. https://doi.org/10.9734/ijpss/2025/v37i15280

Audette, Y., O'Halloran, I. P., & Paul Voroney, R. (2016). Kinetics of phosphorus forms applied as inorganic and organic amendments to a calcareous soil. *Geoderma*, *262*, 119–124. https://doi.org/10.1016/j.geoderma.2015.08.021

Benaffari, W., Boutasknit, A., Anli, M., Ait-El-Mokhtar, M., Ait-Rahou, Y., Ben-Laouane, R., ... & Meddich, A. (2022). The native arbuscular mycorrhizal fungi and vermicompost-based organic amendments enhance soil fertility, growth performance, and the drought stress tolerance of quinoa. *Plants*, *11*(3), 393.

Blackwell, M., Darch, T., & Haslam, R. (2019). Phosphorus use efficiency and fertilizers: future opportunities for improvements. *Frontiers of Agricultural Science and Engineering*. https://doi.org/10.15302/j-fase-2019274

Bolan, N., Srivastava, P., Rao, C. S., Satyanaraya, P. V., Anderson, G. C., Bolan, S., Nortjé, G. P., Kronenberg, R., Bardhan, S., Abbott, L. K., Zhao, H., Mehra, P., Satyanarayana, S. V., Khan, N., Wang, H., Rinklebe, J., Siddique, K. H. M., & Kirkham, M. B. (2023). *Chapter Two—Distribution, characteristics and management of calcareous soils* (D. L. Sparks, Ed.; Vol. 182, pp. 81–130). Academic Press. https://doi.org/10.1016/bs.agron.2023.06.002

Bononi, L., Chiaramonte, J. B., Pansa, C. C., Moitinho, M. A., & Melo, I. S. (2020). Phosphorus-solubilizing Trichoderma spp. From Amazon soils improve soybean plant growth. *Scientific Reports*, *10*(1), 2858. https://doi.org/10.1038/s41598-020-59793-8

Bray, R. H. and Kurtz, L. T. (1945) Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science*, 59, 39-45.

Camdzija, Z., Dragicevic, V., Vancetovic, J., Stevanovic, M., Pavlov, J., Filipovic, M., & Ignjatovic-Micic, D. (2018). Inheritance of inorganic and phytic phosphorus in maize (Zea mays L.) kernel. *Genetika*, *50*(1), 299–315. https://doi.org/10.2298/GENSR1801299C

Ch'ng, H. Y., Ahmed, O. H., & Majid, N. M. Ab. (2014). Improving Phosphorus Availability in an Acid Soil Using Organic Amendments Produced from Agroindustrial Wastes. *The Scientific World Journal*, *2014*, 1–6. https://doi.org/10.1155/2014/506356

Cruz, G. S. J., Hermes, P. H., Miriam, S. V., & López, A. M. (2024). Benefits of Vermicompost in

Agriculture and Factors Affecting its Nutrient Content. *Journal of Soil Science and Plant Nutrition*, *24*(3), 4898–4917. https://doi.org/10.1007/s42729-024-01880-0

Eusterhues, K., Rumpel, C., & Kögel-Knabner, I. (2005). Organo-mineral associations in sandy acid forest soils: Importance of specific surface area, iron oxides and micropores. *European Journal of Soil Science*, *56*(6), 753–763. https://doi.org/10.1111/j.1365-2389.2005.00710.x

Han, W., Li, Y., & Yin, H. (2021). The Influence of Mechanical Composition and Mineral Composition of Calcareous Soil on Slope Farmland on Phosphorus Fixation. *Applied Sciences*. https://doi.org/10.3390/app11093731

Hermansyah, H., Tani, S. A. A., & Musnandar, E. (2023). Aplikasi Kombinasi Pupuk Anorganik Dan Trichokompos Terhadap Produktifitas Dan Limbah Jagung Manis (Zea mays L. Saccharata). *Jurnal Ilmiah Ilmu-Ilmu Peternakan*, *25*(2), 107–120. https://doi.org/10.22437/jiiip.v25i2.20285

Herndon, E. M., Mann, B. F., Roy Chowdhury, T., Yang, Z., Wullschleger, S. D., Graham, D., Liang, L., & Gu, B. (2015). Pathways of anaerobic organic matter decomposition in tundra soils from Barrow, Alaska. *Journal of Geophysical Research: Biogeosciences*, *120*(11), 2345–2359. https://doi.org/10.1002/2015JG003147

Ho, T. T. K., Tra, V. T., Le, T. H., Nguyen, N. K. Q., Tran, C. S., Nguyen, P. T., Vo, T. D. H., Thai, V. N., & Bui, X. T. (2022). Compost to improve sustainable soil cultivation and crop productivity. *Case Studies in Chemical and Environmental Engineering*, *6*, 100211. https://doi.org/10.1016/j.cscee.2022.100211

Hoque, M., Islam, M., Islam, M., Rashid, M., & Saleque, M. (2016). Phosphorus Fractionations in Ganges Tidal Floodplain Soil of Bangladesh. *Bangladesh Rice Journal*, *19*(2), 57–63. https://doi.org/10.3329/brj.v19i2.28165

Hoque, M., Rashid, M., Islam, R., Islam, M., & Saleque, M. (2018). Phosphorus Sorption and Saturation in the Ganges Tidal Floodplain Soils of Bangladesh. *Sains Malaysiana*, 47, 67-76. https://doi.org/10.17576/jsm-2018-4701-08

Hu, W., Zhang, Y., Xiangmin, R., Fei, J., Peng, J., & Luo, G. (2023). Coupling amendment of biochar and organic fertilizers increases maize yield and phosphorus uptake by regulating soil phosphatase activity and phosphorus-acquiring microbiota. *Agriculture, Ecosystems & Environment*. https://doi.org/10.1016/j.agee.2023.108582

Huq, S. M. I., & Shoaib, J. U. Md. (2013). *The Soils of Bangladesh* (Vol. 1). Springer Netherlands. https://doi.org/10.1007/978-94-007-1128-0

Hussain, A., Ahmad, M., Mumtaz, M., Ali, S., Sarfraz, R., Naveed, M., Jamil, M., & Damalas, C. (2020). Integrated Application of Organic Amendments with Alcaligenes sp. AZ9 Improves Nutrient Uptake and Yield of Maize (Zea mays). *Journal of Plant Growth Regulation*, 39, 1277 - 1292.

https://doi.org/10.1007/s00344-020-10067-7

Islam, M., Saleque, M., Karim, A., Solaiman, A., & Sarker, A. (2010). Predicting Phosphorus Desorption from Acid Piedmont Rice Soils of Bangladesh. *The Agriculturists*, 5, 50-60. https://doi.org/10.3329/agric.v5i1.5198

Jackson, M. L. (1973). *Soil Chemical Analysis*. Prentice Hall Inc., Englewood Cliffs. New Jersey, USA

Jahan, I., Shopan, J., Rahman, M., Sarkar, A., Baset, M., Zhang, Z., Li, X., Ahammed, G., & Hasan, M. (2022). Long-Term Traditional Fertilization Alters Tea Garden Soil Properties and Tea Leaf Quality in Bangladesh. *Agronomy*. https://doi.org/10.3390/agronomy12092128

Jakubus, M., & Michalak-Oparowska, W. (2022). Valorization of Quality of Vermicomposts and Composts Using Various Parameters. *Agriculture*, *12*(2), 293. https://doi.org/10.3390/agriculture12020293

Javeed, H., Qamar, R., Rehman, A., Ali, M., Rehman, A., Farooq, M., Zamir, S., Nadeem, M., Cheema, M., Shehzad, M., Zakir, A., Sarwar, M., Iqbal, A., & Hussain, M. (2019). Improvement in Soil Characteristics of Sandy Loam Soil and Grain Quality of Spring Maize by Using Phosphorus Solublizing Bacteria. *Sustainability*. https://doi.org/10.3390/su11247049

Johan, P., Ahmed, O., Maru, A., Omar, L., & Hasbullah, N. (2021). Optimisation of Charcoal and Sago (Metroxylon sagu) Bark Ash to Improve Phosphorus Availability in Acidic Soils. *Agronomy*. https://doi.org/10.3390/agronomy11091803

Kätterer, T., & Bolinder, M. (2024). Response of maize yield to changes in soil organic matter in a Swedish long-term experiment. *European Journal of Soil Science,* 75. https://doi.org/10.1111/ejss.13482

Khaleeq, K., Nazir, R., Hemmat, N., Sirat, W., & Samim, M. (2023). Response of maize (Zea mays L.) to the soil application of phosphorus fertilizer. *Journal of Agriculture and Ecology*, *17*, 90–93. https://doi.org/10.58628/JAE-2317-316

Lehmann, J., Hansel, C. M., Kaiser, C., Kleber, M., Maher, K., Manzoni, S., Nunan, N., Reichstein, M., Schimel, J. P., Torn, M. S., Wieder, W. R., & Kögel-Knabner, I. (2020). Persistence of soil organic carbon caused by functional complexity. *Nature Geoscience*, *13*(8), 529–534. https://doi.org/10.1038/s41561-020-0612-3

Licitra, E., Giustra, M. G., Di Bella, G., & Messineo, A. (2024). Combination between Composting and Vermicomposting of OFMSW: A Sicilian Case Study. *Environments*, *11*(8), 183. https://doi.org/10.3390/environments11080183

Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. Y. (2015). The use of vermicompost in organic farming: Overview, effects on soil and economics. *Journal of the Science of Food and Agriculture*, *95*(6), 1143–1156. https://doi.org/10.1002/jsfa.6849

Lindsay, W. L. (1979). *Chemical equilibria in soils*. Wiley.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M., & Ullah, S. (2017).

Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition*, 17, 22-32. https://doi.org/10.4067/s0718-95162017005000002

Mañas, P., & Heras, J. D. L. (2025). Composted Sludge and Trichoderma harzianum T-22 as a Dual Strategy to Enhance Wheat Growth and Soil Microbial Diversity. *Environments*, *12*(5), 145. https://doi.org/10.3390/environments12050145

Matheus, R., Kantur, D., & Salli, M. (2023). Utilization of organic soil amendments and phosphorus fertilizer to improve chemical properties of degraded dry land Vertisol and maize yield. *Journal of Degraded and Mining Lands Management*. https://doi.org/10.15243/jdmlm.2023.102.4297

Mosharrof, M., Uddin, M., Sulaiman, M., Mia, S., Shamsuzzaman, S., & Haque, A. (2021). Combined Application of Rice Husk Biochar and Lime Increases Phosphorus Availability and Maize Yield in an Acidic Soil. *Agriculture*. https://doi.org/10.3390/agriculture11080793

Nadeem, M., Mollier, A., Vives, A., Prud´Homme, L., Niollet, S., & Pellerin, S. (2014). Short Communication. Effect of phosphorus nutrition and grain position within maize cob on grain phosphorus accumulation. *Spanish Journal of Agricultural Research*, *12*(2), 486–491. https://doi.org/10.5424/sjar/2014122-4650

Nenova, L., Benkova, M., Simeonova, Ts., & Atanassova, I. (2019). Nitrogen, phosphorus and potassium content in maize dry biomass under the effect of different levels of mineral fertilization. *Agricultural Science and Technology*, *11*(4), 311–316. https://doi.org/10.15547/ast.2019.04.052

Olsen, S.R., Cole, C.V. and Watanabe, F.S. (1954) Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. USDA Circular No. 939, US Government Printing Office, Washington DC.

Penn, C. J., Camberato, J. J., & Wiethorn, M. A. (2022). How Much Phosphorus Uptake Is Required for Achieving Maximum Maize Grain Yield? Part 1: Luxury Consumption and Implications for Yield. *Agronomy*, *13*(1), 95. https://doi.org/10.3390/agronomy13010095

Penn, C. J., Camberato, J. J., & Wiethorn, M. A. (2023). How Much Phosphorus Uptake Is Required for Achieving Maximum Maize Grain Yield? Part 2: Impact of Phosphorus Uptake on Grain Quality and Partitioning of Nutrients. *Agronomy*, *13*(1), 258. https://doi.org/10.3390/agronomy13010258

Penn, C., & Camberato, J. (2019). A Critical Review on Soil Chemical Processes that Control How Soil pH Affects Phosphorus Availability to Plants. *Agriculture*. https://doi.org/10.3390/agriculture9060120

Piper, C. S. (1950) *Soil and Plant Analysis*. The University of Adelaide, Press Adelaide, Adelaide.

Randall, P. J., Hayes, J. E., Hocking, P. J., & Richardson, A. E. (2001). Root Exudates in Phosphorus Acquisition by Plants. In N. Ae, J. Arihara, K. Okada, & A. Srinivasan (Eds.), *Plant Nutrient Acquisition* (pp. 71–

100). Springer Japan. https://doi.org/10.1007/978-4-431-66902-9_3

Ryan, J., Masri, S., & Singh, M. (2009). Seasonal Changes in Soil Organic Matter and Biomass and Labile Forms of Carbon as Influenced by Crop Rotations. *Communications in Soil Science and Plant Analysis*, *40*(1–6), 188–199. https://doi.org/10.1080/00103620802625617

Saha, M. K., Khan, M. H. R., Akter, S., & Hossain, M. B. (2023). Integrated effects of vermicompost, climatic factors and soil mixing on selected soil fertility indicators. *Dhaka University Journal of Biological Sciences*, *32*(1), 119–134. https://doi.org/10.3329/dujbs.v32i1.64196

Sarangi, S., Mainuddin, M., & Maji, B. (2022). Problems, Management, and Prospects of Acid Sulphate Soils in the Ganges Delta. *Soil Systems*. https://doi.org/10.3390/soilsystems6040095

Shi, R., Liu, Z., Li, Y., Jiang, T., Xu, M., Li, J., & Xu, R. (2019). Mechanisms for increasing soil resistance to acidification by long-term manure application. *Soil and Tillage Research*, *185*, 77–84. https://doi.org/10.1016/j.still.2018.09.004

Singh, P., Bhatt, R., & Kaur, G. (2021). Phosphorus Availability in Soils and Use Efficiency for Food and Environmental Sustainability. *Input Use Efficiency for Food and Environmental Security*. https://doi.org/10.1007/978-981-16-5199-1_12

Solaiman, S. B., Hossain, M. B., Saha, M. K., Mandal, R., & Khan, M. H. R. (2023). Impacts of Cow Dung and Poultry Manure on the Mineral Nutrient Uptake of Red Amaranth Grown in a Mixture Of Acid and Calcareous Soils. *Dhaka University Journal of Biological Sciences*, *31*(2), 329–342. https://doi.org/10.3329/dujbs.v31i2.60891

SRDI (Soil Resources Development Institute). (2012). Thana Nirdeshika reports of different districts of Bangladesh. Dhaka, Bangladesh.

Tabbasum, S., Akhtar, M., Sarwar, N., Tipu, M., Ikram, W., Ashraf, A., Ejaz, A., Murtaza, B., & Khan, M. (2020). Relative Effectiveness of Phosphorus and Potassium Along with Compost and Organic Acids on Maize Crop Grown in Calcareous Soil: a Multivariate Analysis. *Journal of Soil Science and Plant Nutrition*, 21, 437-449. https://doi.org/10.1007/s42729-020-00372-1

Tania, M., Mim, N., Moslehuddin, A., & Hoque, T. (2025). Physico-Chemical Properties and Fertility Status of Forest Soils under Aez-29 (Northern and Eastern Hills) of Bangladesh. *SAARC Journal of Agriculture*. https://doi.org/10.3329/sja.v22i2.75734

Tonon, G., Sohi, S., Francioso, O., Ferrari, E., Montecchio, D., Gioacchini, P., Ciavatta, C., Panzacchi, P., & Powlson, D. (2010). Effect of soil pH on the chemical composition of organic matter in physically separated soil fractions in two broadleaf woodland sites at Rothamsted, UK. *European Journal of Soil Science*, *61*(6), 970–979. https://doi.org/10.1111/j.1365-2389.2010.01310.x

Trowbridge, C. (2019, October 16). Leave the Leaves! Improve Soil Health and Habitat by Leaving Leaf Litter. *Tualatin Soil and Water Conservation District*.

https://tualatinswcd.org/leave-the-leaves-improve-soil-health-habitat-by-leaving-leaf-litter/

Wagner, R., Zona, D., Oechel, W., & Lipson, D. (2017). Microbial community structure and soil p H correspond to methane production in A rctic A laska soils. *Environmental Microbiology*, *19*(8), 3398–3410. https://doi.org/10.1111/1462-2920.13854

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.

Yang, W., Jiang, Y., Zhang, J., Wang, W., Liu, X., Jin, Y., Li, S., Qu, J., & Zhu, Y. (2025). Organic Materials Promote Soil Phosphorus Cycling: Metagenomic Analysis. *Agronomy*. https://doi.org/10.3390/agronomy15071693

Ye, R., Jin, Q., Bohannan, B., Keller, J. K., McAllister, S. A., & Bridgham, S. D. (2012). pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic–minerotrophic gradient. *Soil Biology and Biochemistry*, *54*, 36–47. https://doi.org/10.1016/j.soilbio.2012.05.015

Yu, X., Keitel, C., & Dijkstra, F. (2021). Global analysis of phosphorus fertilizer use efficiency in cereal crops. *Global Food Security*. https://doi.org/10.1016/j.gfs.2021.100545

Zhang, L., Chang, L., Liu, H., De Jesús Puy Alquiza, M., & Li, Y. (2025a). Biochar application to soils can regulate soil phosphorus availability: a review. *Biochar*. https://doi.org/10.1007/s42773-024-00415-1

Zhang, L., Pan, X., Zhang, Y., Guan, Y., Li, Y., Jin, Q., Cao, K., Shan, C., & Wang, Q. (2025b). Effects of addition of Trichoderma spp. On growth and soil microorganisms of continuously cropped Salvia miltiorrhiza. *Frontiers in Plant Science*, *16*, 1654385. https://doi.org/10.3389/fpls.2025.1654385

Zheng, J., Berns-Herrboldt, E. C., Gu, B., Wullschleger, S. D., & Graham, D. E. (2022). Quantifying pH buffering capacity in acidic, organic-rich Arctic soils: Measurable proxies and implications for soil carbon degradation. *Geoderma*, *424*, 116003. https://doi.org/10.1016/j.geoderma.2022.116003

Zhu, J., Li, M., & Whelan, M. (2018). Phosphorus activators contribute to legacy phosphorus availability in agricultural soils: A review. *The Science of the total environment*, 612, 522-537. https://doi.org/10.1016/j.scitotenv.2017.08.095