MODIFIED CROP STRAW DERIVED BIOCHAR INCORPORATION IMPACT ON MAIZE PLANT GROWTH AND PHOSPHORUS AVAILABILITY IN LOW-FERTILITY SOIL

A THESIS BY

MD. RAKIBUL HASAN
Student No. 1601420

Session: 2022-2023

Thesis Semester: July-December 2023

MASTER OF SCIENCE
IN SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
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DEDICATION

All the credit for the success of this study goes to my parents and teachers, who have been nothing but encouraging and helpful throughout the past several months. Their encouragement was invaluable to me.

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ABSTRACT

Phosphorus (P) is an important plant nutritional element, but its supply is limited since it is a nonrenewable resource. The objective of this study was to investigate the maize plant growth and soil available phosphorus status in modified rice straw biochar in lowfertility soils of northern Bangladesh. To fulfill the objectives of the research a 40days pot experiment was established with the following treatments: a) control (without biochar+KH_2PO_4), b) fresh rice straw biochar2%+KH_2PO_4, c) H_2O_2+2% fresh rice straw biochar+KH_2PO_4, d) H_2SO_4+2% fresh rice straw biochar+KH_2PO_4 and e) HNO_3+2% fresh rice straw biochar+KH_2PO_4 and replicated three times in a completely randomized design (CRD). The results indicated that incorporation of hydrogen per oxide modified rice straw biochar increased the pH value (5.85) of the soil significantly. On the other hand, soil available P value (95.42 ppm) also increased due to application of nitric acid modified rice straw biochar. Plants dry weight value (4.44gm pot^{-1}) also increased due to application of nitric acid modified biochar. The P availability increased due to changing of soil properties like pH, OM, CEC, base cations (Ca, Mg, K and Na) after incorporation of acid modified biochar. The maize plant growth was higher yield in nitric acid modified rice straw biochar than the other treatments. Therefore, it may be suggested to consider nitric acid modified rice straw biochar application for enhancing soil health as well as obtaining higher yield of crop.

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CHAPTER I

INTRODUCTION

Phosphorus (P) is a crucial plant nutrient element, but its availability is restricted since P is nonrenewable. There is increasing concern across the world that natural P reserves may be depleted in 50-100 years (Cordell *et al.,* 2009). Nevertheless, the use of P fertilizer is high due to higher crop demand in low-fertility soil. But, the P use efficiency of crop plants is relatively poor, accounting for only 10-15%. The remaining P is either fixed in the soil or lost during the leaching process (Roberts and Johnston, 2015; Zhang *et al.,* 2017). Thus, the efficient use of P is vital for global food security.

Biochar, or pyrolyzed biomass, is a carbon-rich porous material and can persist in soil for many years. In many studies, it has been proven that the addition of biochar to the soil can increase nutrient uptake by crop plants through improving soil physical, chemical and biological properties (Lehmann *et al.,* 2015). But, the use of biochar is still in the primary stage in Bangladesh. In some extend, biochar is produced using the akha stove in Bangladesh. Biochar quality depends on various conditions such as feedstock type, pyrolysis temperature and pyrolysis time (Nzediegwu*et al.,* 2021). As biochar can change the soil environment entirely; the quality of biochar must be addressed before it is used in large scale. Thus, the characterization of biochar must be investigated to maintain the quality of biochar.

Despite the fact that phosphorus (P) is an essential nutrient element for plant growth (Lambers*et al.,* 2008), the availability of P in the soils of many regions of the world is limited

(Holford, 1997). The lack of phosphorus, which is common in the acidic soils of northern Bangladesh, is one of the factors that limits crop production. It has been determined that the majority of crop plants will not benefit from the addition of P fertilizer to these soils. For this reason, improving the bioavailability of the applied phosphorus fertilizer is essential in order to achieve higher crop yields.

This could possibly be supported by the incorporation of crop straw biochar in acidic soils (Nelson *et al.,* 2011; Jiang *et al.,* 2015). According to Lehmann *et al.* (2006), the use of biochar, which is a carbon-rich byproduct that results from the pyrolysis of biomass under conditions that are oxygen-limited, can increase the fertility of the soil. The addition of biochar to soil can result in a reduction in bulk density, as well as increases in water holding capacity, soil pH, and cation exchange capacity (CEC) (Novak *et al.,* 2009; Laird *et al.,* 2010; Xu *et al.,* 2012; Shi *et al.,* 2017a). These findings were published in four separate studies. It is also possible to think of biochar as a direct source of nutrients for agricultural production. It has plant nutrients such as N, P, K, Mg and S as well as micronutrients (Gaskin *et al.,* 2008), and its incorporation into soil can increase the availability of nutrients to plants and their ability to take them up (Novak *et al.,* 2009; Rajkovich*et al.,* 2012). Consequently, the incorporation of biochar can improve crop growth and consequently increase crop yield, particularly in tropical and subtropical regions (Deenik*et al.,* 2011; Shi *et al.,* 2017b). This is especially true in tropical and subtropical regions. In recent years, researchers have been looking into the effect that biochar has on the availability of P in soil that is permanently charged (Novak *et al.,* 2009; Laird *et al.,* 2010). Several studies (Kolb *et al.,* 2009; Novak *et al.,* 2009; Laird *et al.,* 2010; Schneider and Haderlein, 2016) have shown that biochar has a positive impact on the amount of plant-available P and that it stimulates the growth of plants.

In addition to the positive effects, biochar can have a negative effect on the availability of phosphorus in the soil (Gaskin *et al.,* 2010; Nelson *et al.,* 2011; Borchard*et al.,* 2012; Parvage*et al.,* 2013), or it can have no effect at all. However, there is a lack of information regarding the effect of biochar on the bioavailability of P in soils with variable charges. Because of the complexity of biochars and the ways in which they interact with soils, there is a pressing need for additional research that focuses on developing a better mechanistic understanding of how the presence of biochar affects the amount of P that is bioavailable in soils.

It has been reported in existing researches that the number of carboxyl functional groups on the surface of biochar effectively increased by modification with H_2O_2 or inorganic acids (HNO_3, H_2SO_4, etc.) (Uchimiya*et al.,* 2012; Xue*et al.,* 2012; Li *et al.,* 2014; Qian and Chen, 2014; Wang and Wang, 2019). However, for the modified biochar, previous studies mainly focus on the adsorption and immobilization of heavy metals by the biochar, while there is a lack of relevant researches about their impacts on P availability in low-fertility soils.

The addition of biochar can increase soil nutrient retention capacity. Little is known about acid modified crop straw biochar characteristics, as well as the implications of biochar in lowfertility soil in terms of P availability. Therefore, to understand the potential effects of crop straw biochar on P dynamics, a thorough investigation is required.

The objectives of this study were:

a) to investigate the addition of crop straw biochar on soil P availability as influenced by biochar's higher cation exchange capacity (CEC) and a considerable amount of acid functional groups; and

b) to determine maize plant growth in low fertility soils due to changing soil environment after modified biochar application.

CHAPTER II

REVIEW OF LITERATURE

To the best of our knowledge, very little research on the impact of modified biochar on P availability in low-fertility of soils has been conducted in Bangladesh. However, some recent related works conducted globally and their findings are summarized below:

Yang and Lu (2022) conducted a study on the phosphorus availability of straw and straw biochar and demonstrated that returning straw biochar had a greater impact on P availability and crop production efficiency than returning straw directly. Due to the biochar-soluble P and pH increase, biochar-treated soils had significantly greater available P levels.

Murtoza *et al.* (2021) observed that biochar induced modifications in soil properties and its impacts on crop growth and production. This study will provide a clear picture about the role of biochar in modifying soil properties and its beneficial impacts on crop growth and yield.

Qayyum *et al.* (2021) conducted this study to determine the effect of alkaline and chemically modified biochar on soil properties and phosphorus bioavailability in maize. It is difficult to rule out the possibility that acidification of biochar is a prerequisite for P improvement in alkaline soils. For sustainable crop production, site-specific P management requires additional research.

Wu *et al.* (2021) found that magnetic biochar reduces phosphorus uptake by Phragmites australis during heavy metal remediation due to the interception of P by the iron plaque and the decrease in the concentration of soil-available P. Although magnetic biochar exhibited a strong potential for heavy metal remediation, P supplementation is recommended when applying magnetic biochar to maintain plant performance and soil health.

Yang *et al.* (2021) carried out the experiment on recovery of phosphate from aqueous solution using biochar derived from co-pyrolysis of sewage sludge with eggshell and they found that efficient recovery of phosphate from aqueous solution was obtained using biochar derived from co-pyrolysis of sewage sludge with eggshell.

Rizwan *et al.* (2020) conducted that synthesis, characterization and application of magnetic and acid modified biochars following alkaline pretreatment of rice and cotton straws and found the result adsorption capacities of the modified biochars toward both Pb^{2+} and Cd^{2+} were 23.07–82.74% and 16.90–556.33% higher than those of pristine biochars, respectively. Of the modified biochar, the Fe-Co-composite biochar showed many promising physico-chemical and adsorptive properties for adsorbing divalent metals of both Pb^{2+} and Cd^{2+} and might thus have high potential as a soil amendment and alternative adsorbent for environmental remediation.

Maroušek *et al.* (2020) conducted a study on how modified biochar present an economic challenge to wastewater treatment plant phosphate management. They discovered that the majority of used reactants are recovered from waste or their price is irrelevant (they are subsequently used for their original purpose), and there are indications that the newly proposed technology is one of the few economically viable environmentally friendly measures that can quickly become widespread in the wastewater industry.

Zhang *et al.* (2020) experimented on the effect of phosphorus-modified biochar on immobilization of Cu (II), Cd (II), and As (V) in paddy soil and this study indicated that the P-modified biochar can serve as a novel remediation agent for heavy metal polluted soils.

Masud et al.(2020) investigated the effect of chicken litter biochar on acid soil fertility using incubation and pot experiments with maize growth and discovered that the addition of biochar increased the availability of P relative to the control. They also reported that the application rate of biochar was one of the most influential factors in determining the effect of biochar on soil bioavailable P concentration. The increased biochar rate decreased soil acidity, thereby enhancing soil P availability.

Chen *et al*. (2019) conducted this topic adsorption of cadmium and lead ions by phosphoric acidmodified biochar generated from chicken feather: Selective adsorption and influence of dissolved organic matter and to get the result Electrostatic interaction, precipitation, and O–H bonds were the primary adsorption mechanisms. The increased N-containing heterocycles of CFCP accounted for the increased Cd^{2+} and Pb^{2+} adsorption.

*Li et al. (*2019) to explore this topic removal of phosphate from aqueous solution by dolomite modified biochar derived from urban dewatered sewage sludge and find the presence of SO_4^{2-}, HCO_3^-, and $C_5H_7O_5COO^-$could negatively affect the removal of phosphate, while CH_3COO^- had a positive effect on the adsorption of phosphate on the biochar. Thus, an economic assessment showed that the proposed adsorption process had a commercial attraction.

Palansooriya *et al.* (2019) conducted an experiment at the campus of the University of Rajshahi, Bangladesh, to determine the effect of rice husk biochar on the P content of wheat grains grown in alkaline soils. They found that compared to other treatments, biochar-amended treatments enhanced P translocation in wheat grain under improved physicochemical properties as a result of biochar addition to soils.

Gao *et al*. (2019) observed that biochar applications significantly increased surface soil available P by 45% and MBP by 48% across the full range of biochar characteristics, soil type, or experimental conditions.

Li *et al.* (2019) showed that biochar is a potential material for making slow-releasing phosphorus (P) fertilizers for the sake of increasing soil P use efficiency and mitigating P losses. However, the long-term effects of P-laden biochars on soil P availability remains unconcerned.

Glaser and Lehr (2019) reported that biochar can act as a short-, mid-, and long-term P fertilizer with its effect depending on feedstock, pyrolysis temperature and application amount. Overall, the addition of biochar significantly increased the P availability in agricultural soil by a factor of4.6 (95% confidence interval 3.4–5.9), independent of the used feedstock for biochar production. Only biochar application amounts above 10 Mg ha^{-1} and biochar produced at temperatures lower than 600°C significantly increased the P availability of agricultural soils. The application of biochar to acid ($pH < 6.5$) and neutral soils (pH 6.5–7.5) significantly increased plant-P availability by a factor of 5.1 and 2.4, respectively (95% confidence interval 3.5–6.7 and 1.4–3.4, respectively), while there was no significant effect in alkaline soils ($pH > 7.5$). Taken together, this meta-analysis shows that biochar significantly enhances plant-available P in biochar-amended soils at least for five years.

Chu *et al.* (2018) carried out a study and found that phosphoric acid pretreatment enhances the specific surface areas of biochars by generation of micropores and finally find out the Overall, H_3PO_4 pretreatment produced biochars with large surface area and high abundance of porous structures. Furthermore, the H_3PO_4 modified biochars can be applied as high adsorbing material as well as P-rich fertilizer.

Peng *et al.* (2017) conducted that enhanced adsorption of Cu(II) and Cd(II) by phosphoric acid modified biochar. And got this result thus, sorption of metal ions by modified biochar was controlled by the mechanism of surface complexation between oxygen containing functional groups and metals. In general, the H_3PO_4 modification was an effective method to prepare biochar with a high affinity for the sorption of heavy metals.

Shepherd *et al.* (2017) reported that P was greatly absorbed by biochar, and the content of available P in soil was reduced with the increasing content of biochar in soil.

Arif*et al.* (2017) found that biochar and organic P sources considerably and favorably altered crop and soil quality parameters during a two-year maize-wheat rotation field experiment conducted in 2015 and 2016. Soil organic carbon (SOC), accessible nitrogen (N), and phosphorus (P) concentrations were all raised by biochar, and there were no unfavorable impacts on soil pH or electrical conductivity.

Sahin*et al.* (2017) performed a study on the effect of acid modification of biochar on nutrient availability and maize growth in a calcareous soil and the findings showed that biochar made from poultry manure and modified with HNO_3 and H_3PO_4 can be used successfully in calcareous soil to improve plant mineral nutrition.

Takaya *et al.* (2016) reported that the use of biochar for the recovery of phosphate has potential for environmental and socio-economic benefits but it is often characterized by relatively low nutrient adsorption capacity. The aim of this study was to investigate the potential for improving biochar phosphate adsorption capacities following chemical modification with metal salts, acids and alkali. Modified biochar was produced from oak wood and paprika waste (greenhouse waste) following either chemical treatment of biomass (in-situ modification) or biochar (post modification). Phosphate uptake capacities were determined by laboratory batch sorption tests, and results indicated that phosphate uptake could be enhanced from relatively low levels (2.1–3.6%) to relatively high levels (66.4–70.3%) by impregnation with magnesium. These findings suggest that biochar mineral composition is a key property influencing biochar phosphate uptake while surface area has less influence on sorption.

Li *et al.* (2016) carried out a study and the Mg/Al-LDHs biochar with different Mg/Al ratios (2, 3, 4) were prepared by co-precipitation for phosphate removal from aqueous solution. Factors on phosphate adsorption including Mg/Al ratio, pH, and the presence of other inorganic anions were investigated through batch experiments. Increasing Mg/Al ratio in the Mg/Al-LDHs biochar composites generally enhanced phosphate adsorption with Langmuir adsorption maximum calculated at 81.83 mg phosphorous (P) per gram of 4:1 Mg/Al-LDHs biochar at pH 3.0.

Xu *et al.* (2016) showed that the effects of biochar application on P sorption were highly influenced by soil acidity. As the rate of biochar application increased, P sorption increased in the acidic soil but slightly decreased in the alkaline soil. Desorbed P significantly increased at all levels of biochar application in the studied soils. Inorganic P fractionation revealed that biochar addition sharply increased the Ca-bounded P and slightly enhanced the Al-retained P. However, biochar addition decreased the Fe-bounded P. These changes suggest that the increase in P sorption with biochar addition is attributed to Ca-induced P sorption or precipitation and is less affected by Fe and Al oxides. Biochar application is found to have altered P availability by changing the P sorption and desorption capacities of the soils, and these biochar effects were dependent on soil acidity, which have important implications for improving soil productivity on large scale.

Zwetsloot (2016) reported that biochar produced at temperature below 450 °C caused a statistically significant increase of plant-available P in amended soils. In addition, with increasing pyrolysis temperature the effect of biochar on P availability decreases significantly. Comparable results can also be observed among different studies, where the extractable P declined from high to low temperature biochar.

Zhang (2016) found that application of biochar to acidic soils phosphate bonded with free cations such as Fe^{3+}, Al^{3+}, Ca^{2+} and Mg^{2+} dissolved and released plant-available P.

Zhang *et al.* (2016) observed that 55% of the retained phosphorus on biochar was still available for plant uptake and calcium carbonate is mainly responsible for phosphorus chemisorption on biochar.

Shil*et al.* (2016) discovered that the status of P in Bangladesh soils looks to be low to extremely low while researching the soil fertility status in various intense crop growing locations under key agro-ecological zones of Bangladesh. While researching the use of biochar for sustainable agriculture in Bangladesh, Karim (2020) discovered the same thing.

Gul and Whalen (2016) stated that biochar can influence microbial-mediated reactions in soil N and P cycles, according to research on the biochemical cycling of nitrogen and phosphorus in biochar-amended soils. It also serves as an exchange and retention site for P ions in soil microorganism biomass.

Liu *et al.* (2015) conducted that removing phosphorus from aqueous solutions by using iron modified corn straw biochar and found that when the modified biochar-to-soil rate was 5%, thestem, root, and bean of broad bean plants demonstrated increased growth rates of 91%, 64%, and 165%, respectively.

Wang *et al.* (2015) found that thermo chemical conversion of manure into biochar seems a helpful tool to minimize the production of mineral P fertilizer. Recycling P from organic residues has environmental benefits compared to direct land application (e.g. protection of water bodies) and can provide a continuous P source for soils.

Zhai *et al.* (2015) conducted a study on the effects of corn fibre biochar revealed that the addition of 8% biochar significantly increased soil Olsen-P and soil microbial biomass P in soil, while the addition of inorganic P decreased phosphormonoesterase activity in soil.

Chintala (2014) showed that there was no significant effect on plant-available P in alkaline soils. The P solubility in alkaline soils is mainly regulated by the interaction of P with Ca^{2+}, whereas in acidic soils the plant availability of P is mainly regulated by Al^{3+} and Fe^{2+}/Fe^{3+} by forming Al- and Fe-phosphates.

Farrell *et al.* (2014) found that field study in calcareous soil, no effect on P availability could be observed by biochar application.

Morales *et al.* (2013) found that biochar supplementation in soil can decrease the adsorption of P via the competition between phosphate and the biochar surface functional groups for the adsorption sites on soil minerals.

Yao *et al.* (2012) observed that biochar produced from sugarcane bagasse, peanut hull, Brazilian pepper wood and bamboo at 200, 450 and 600°C did not indicate any clear trend in phosphorus sorption.

Kookana *et al.* (2011) stated that the P availability of biochar-amended incubated soils was lower than that of non-amended regimens. Although the addition of biochar decreased the pH of the soil from 8.3 to 8.0, this was primarily due to the P fixation with Ca at high soil pH. Biochars were shown to have several different types of N and P, both organic and inorganic, including NO_3^-, NH_4^+, ortho-P, and amide groups.

Nelson *et al.* (2011) found that Mehlich-3 P concentrations were reduced by biochar in a study of nitrogen and phosphorus availability in soils that had been amended with biochar.

Cui *et al*. (2011) investigated in their study on enhancing phosphorus availability in phosphorus fertilized zones by decreasing phosphate adsorbed on ferrihydrite using rice straw derived biochar that biochar increases P availability in soils while decreasing P adsorption on Feoxides.

Atkinson *et al.* (2010) reported that plant P uptake could also be changed with biochar application owing to direct change in available P level and to indirect change in soil environment for microorganisms.

Laird *et al.* (2010) observed that the application of 2% biochar to agricultural soil amended with swine manure resulted in reduction of P leaching by 69%.

Hartono *et al.* (2005) found that biochar has generated increasing interest to be used to improve the bioavailability of nutrition in the soil. The influence of biochar on soil P sorption processes is regulated by soil types and biochar properties. As a result, controversial findings of P sorption in biochar-amended soils have been obtained.

Guppy *et al.* (2005) carried out the study on the effect of biochar on soil P adsorption largely focuses on biochar particles. Actually, after adding biochar to the soil, the dissolved black carbon

(DBC), the biochar water-soluble fraction, can be easily released from the parent materials. The following dispersion and diffusion of DBC in soil environments would inevitably affect the soil P mobility, which, however, remains largely unknown. Previous studies have shown that adding dissolved organic matter (DOM), such as citric acid and oxalic acid, to soil raised the free P content in soil solutions.

CHAPTER III

MATERIALS AND METHODS

This chapter describes the experimental components of the research, including the materials and methods used. This section contains a concise description of experimental site, experimental soil collection, climate, plant pot experiment preparation, materials used, experimental design, collection and preparation of soil samples after pot experiment, chemical methods, and statistical analysis.

3.1 Location of the study

The experiment was conducted on the rooftop of Academic building-1 in Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh from June 2022 to July 2022. Geographically the experimental site was at 25°13'N latitude and 88°23' E longitude with an elevation of 37.5m above the mean of sea level.

3.2 Weather and climate

The experimental site is a subtropical humid climate and is characterized by moderately high temperature and heavy rainfall during the Kharif season (April-September) and moderately low temperature with low rainfall during the Rabi season (October-March). Temperature during the cropping period ranged between 20 to 35^0C with generally 60 to 85% humidity in the air.

3.3. Experimental periods

The experiment was carried out during June, 2022 to July, 2022. Seeds were sown on 15 June, 2022 and harvested on 25 July, 2022.

3.4 Collection of pots

The plastic pots were collected from Nimtola, Sadar Dinajpur. The size of the pot was 24 cm × 17 cm.

3.5 Collection and preparation of soil samples

Soils were collected from the paddy field of Dinajpur district of Bangladesh (25^0 42' 27" N and 88^0 39' 32" E). The soils of the plot are from Old Himalayan Piedmont Plain (AEZ-1). Drainage system of the land was well developed. Soil samples were taken from the top layer (0-20 cm), airdried, ground to pass through a 1-mm sieve for pot study.

3.6 Soil description

The general characteristics of the soil are presented in Table 1-3.

Table1. Morphological characteristics of the soil

Morphology	**Characteristics**
Location	Soil Science Laboratory-1, Department of Soil Science, HSTU
AEZ	Old Himalayan Piedmont plain (AEZ-1)
General soil type	Non- calcareous brown floodplain soil
Parent material	Piedmont alluvium
Drainage	Well drained
Topography	Medium high land
Flood level	Above flood level

Table-2 Physical characteristics of initial soil

Particle size distribution	Value
Sand (%)	49.6
Silt (%)	21.6
Clay (%)	28.8
Textural class	Sandy clay loamy

Table-3 Chemical characteristics of initial soil

Chemical characteristics	Analytical data
pH	6.11
OC (%)	1.68
Available P (ppm)	57.02
Cation exchange capacity (CEC)	17.38

3.7 Collection and preparation of biochar

Rice crop straws were collected from local farmers in Dinajpur district of Bangladesh. Straws were air-dried, cut into small pieces and stored properly. Crop straws were pyrolized in a doubled chambered slow pyrolysis kiln at 400 ^{0}C for 2 h. The rice straw biochar was modified using H_2O_2, H_2SO_4 and HNO_3.

Table 4: Basic properties of fresh and modified biochar derived from rice straw

Biochar	pH	Ca	Mg	K	Na	Total base cations
		meq 100 g^{-1}soil				
Fresh-biochar	7.68±0.07	1.71±0.06	0.58±0.01	0.77±0.02	0.43±0.08	3.49
H_2O_2-biochar	7.01±0.18	2.04±0.01	0.7±0.20	0.55±0.04	0.46±0.00	3.75
H_2SO_4-biochar	5.66±0.86	0.62±0.09	0.34±0.00	0.1±0.02	0.47±0.08	1.53
HNO_3-biochar	5.32±0.91	1.11±0.04	0.46±0.02	0.16±0.01	0.38±0.06	2.11

3.8 Biochar characterization

The pH will be determined in the suspension of 1:5 solid: water ratio using a glass electrode pH meter. Biochar samples of 0.2 g were leached with 20 ml distilled water 5 times. The leachates were collected together, and the Ca^{2+}, Mg^{2+}, K^+ and Na^+ in the leachate were measured as water soluble bases of biochar. The K^+ and Na^+ in the leachates were measured by a flame photometer and Ca^{2+} and Mg^{2+} by atomic absorption spectrophotometer.

3.9 Treatments

An incubation study was established in an incubator. The treatments were:

1) control (only KH_2PO_4),
2) 2% fresh rice straw biochar+KH_2PO_4
3) 2% H_2O_2 modified rice straw biochar+KH_2PO_4
4) 2% H_2SO_4 modified rice straw biochar+KH_2PO_4 and
5) 2% HNO_3 rice straw biochar+KH_2PO_4

3.10 Design and experimental setup

The 2.0 kg of air-dried soil samples were placed in each pot (2000 ml) and biochar were then added at a ratio of 2% (20 g kg^{-1}) and thoroughly mixed. After 24 hours stabilization of the biochar, KH_2PO_4 was added in each treatment @100 mg P kg^{-1} soil (0.88g of KH_2PO_4) were applied in each pot with 400ml of dissolved water. The fertilizer was dissolved in distilled water, and evenly employed to the soils to bring the final soil moisture to 70% of field water holding capacity of soil. The experiment was laid out Completely Randomized Design (CRD) with 5 treatments and 3 replications. A total of 15 experimental pots were used.

3.11 Pot preparation

There were 15 pots used in this experiment. Each treatment soil was prepared separately. 15 pots were contained 30kg of soil was mixed with proper amount of acid modified biochar (Fresh biochar, H_2O_2 modified biochar, H_2SO_4 modified biochar and HNO_3 modified biochar) and fertilizer as KH_2PO_4 to each treatment. Mixed soils were left for 4 days in the air, and then the pots were filled with biochar and soil. Prepared soil without mixing any kind biochar and fertilizers was used as control. The pots were kept for seven days in a shading place.

3.12 Seed rate and sowing seed

The recommended seed rate 1 kg ha^{-1} HEERA-109 (Hybrid-F1) verity seeds were used. Before sowing seeds in the pot, seeds were soaked in water for 12-15 hours and were sown in the pot on 08 June, 2022. Ten healthy and uniform seeds of maize were sown at equal distance in each pot. After one weeks of seedling emergence, three seedlings were kept in each pot.

3.13 Intercultural operations

Intensive care was taken during the growing period to ensure adequate growth and development of the plant, which are given bellow:

3.13.1 Weeding

Weeding was done to keep the plots free from weeds and for better aeration of soil, which ultimately ensured better growth and development. Newly emerged weeds were uprooted carefully after complete emergence of seedling of Indian Spinach. Breaking the crust of the soil was done when needed.

3.13.2 Irrigation

Over-head irrigation was provided with a watering can to the plots once immediately after germination in every alternate day in the evening. Further irrigation was provided as and when needed. Stagnant water was drained out at the time of heavy rain.

3.13.3 Insect and pest control

There was no pest and diseases during the experimental period and hence no control measures were used.

3.14 Harvesting and post-harvest process

The plants were harvested after 40 days of seedling emergence. Shoots and roots washed with distilled water, oven-dried at 65^0C for 48 hours.

3.15 Analysis of soil sample

Initial and post-harvest soil samples for chemical properties were analyzed in the laboratory of the department of Soil Science, HSTU, Dinajpur. The soil chemical properties under the study were texture, pH, available Ca, Mg, K, Na, P and cations exchange capacity(CEC).

3.15.1 Collection and preparation of soil sample

3.15.2 Initial soil sample

The initial soil sample was collected before pot preparation from the depth plough layer (0-15cm). Samples were taken by means of an auger from 5 locations covering the whole area from where soils were collected and mixed thoroughly to make a composite sample, the composite sample was air dried, grounded and sieved through a 20-mesh sieve and stored in a plastic bag for physical and chemical analysis.

3.15.3 Post harvest soil samples

After harvesting the crop soil samples were collected from each pot at 0-15 cm depth. The soil samples were air dried, grounded and sieved through a 20-mesh sieve. Prepared soil samples were stored in plastic bags for chemical analysis only.

3.15.4 Particle size analysis of soil

Particle size analysis of the soil was done by hydrometer method. The textural class was determined by plotting the values of 49.6 % sand, 21.6 % silt and 28.8 % clay using Marshell's Triangular coordinate as designated by USDA.

3.15.5 Soil pH

Soil pH was determined by glass-electrode pH meter in a 1:2.5 w/v ratio. Organic matter was measured with the wet oxidation and colorimetric method (Pansu and Gautheyrou, 2006).

3.15.6 Soil available P (ppm)

Soil available P was determined by the Olsen method (Pansu and Gautheyrou, 2006).

3.15.7 Soil available Ca, Mg, K, Na (ppm)

Soil available Ca^{2+} and Mg^{2+} were then measured using atomic absorption spectrophotometer and K^{+} and Na^{+} with flame photometer.

3.15.8 Soil available CEC (ppm)

The CEC was measured with an ammonium acetate method after 40 days of incubation (Pansu and Gautheyrou, 2006).

3.16 Plant analysis

Above ground plant parts were harvested and dried at 65 ^{0}C in a forced oven drier until constant weight. After that plant shoot dry weight was measured.

3.17 Data analysis

All statistical analyses were performed with SPSS (version 22.0, USA), and the graphs were created by Origin (version Origin Pro 2018, USA). All data were presented as the mean of three replicates with standard deviation. Using a multivariate general linear model, an analysis of variance (ANOVA) was conducted to identify the differences and interactions between the treatments.

CHAPTER IV

RESULTS AND DISCUSSION

The current experiment was plotted to investigate the effect of modified biochar on the P availability in low-fertility soils of Bangladesh. Data on different parameters were analyzed statistically and the result has been presented in tables, graphs and figures. The results of the present study have been demonstrated and discussed with possible interpretations under the following headings.

4.1 Effects of modified biochar incorporation on soil available phosphorus after 40 DAS

The impact of modified biochar incorporation on soil available P after 40-days of plant grow this presented in Fig. 1. The results indicated that the soil available P increased significantly influenced by different treatments. The highest value (95.41 ppm) was found in HNO_3 modified rice straw biochar amended treatment and the lowest value (33.47 ppm) was found in H_2SO_4 modified.

It is noted that there was a relationship between soil pH changes and P availability.

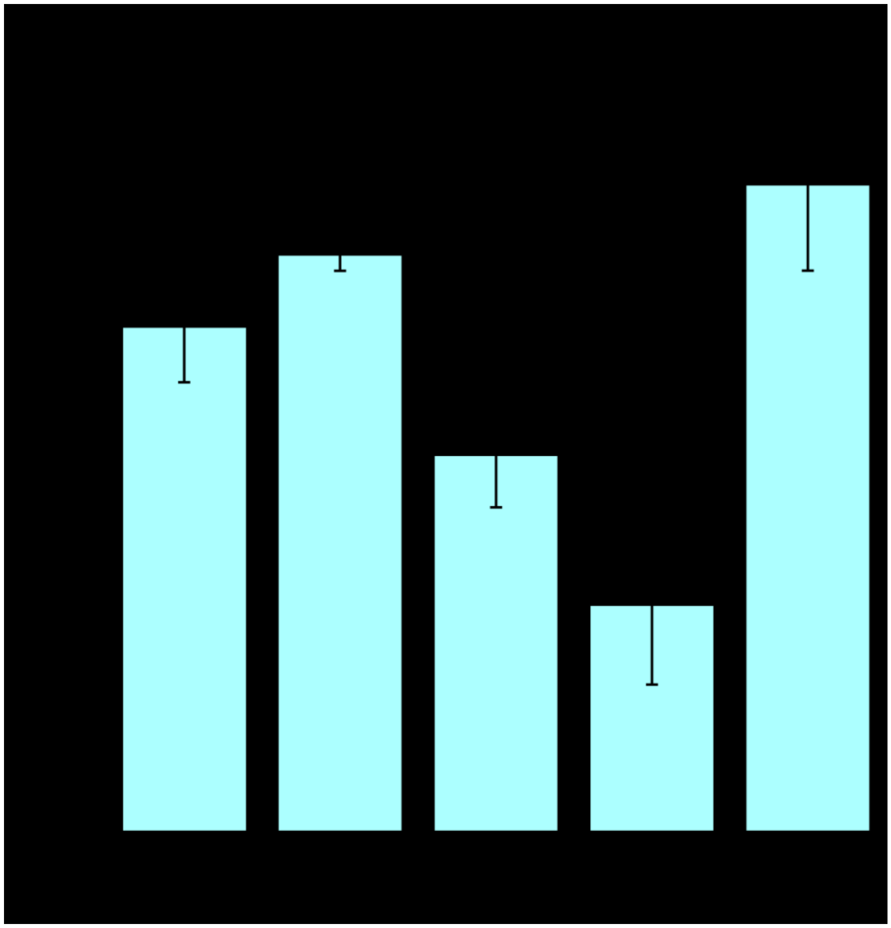

Fig.1: Soil available P after 40 DAS. Vertical bar indicates the standard error mean

Here,

FBC= Fresh biochar

H_2O_2-BC= Hydrogen peroxide modified biochar

H_2SO_4-BC= Sulfuric acid modified biochar

HNO_3-BC= Nitric acid modified biochar

4.2 Effects of modified biochar incorporation on plants dry weight

The impact of modified biochar incorporation on plants dry weight after 40 days plant growth are presented in Fig.2. The values of dry weight were significantly influenced by the different treatments. The highest value (4.44 gm pot^{-1}) was found in HNO_3 modified rice straw biochar and the lowest value (1.10 gm pot^{-1}) was found in H_2SO_4 modified rice straw biochar treatment. Other treatments were moderate with statistically similar value.

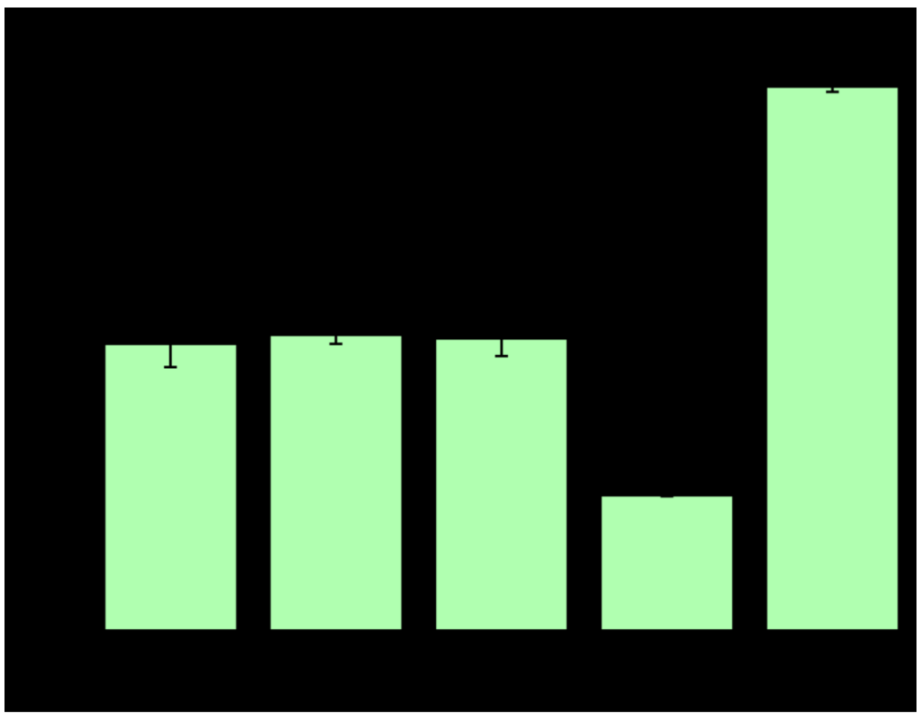

Fig.2. Plants dry weight after 40 DAS. Vertical bar indicates the standard error of mean.

Here,

FBC= Fresh biochar

H_2O_2-BC= Hydrogen peroxide modified biochar

H_2SO_4-BC= Sulfuric acid modified biochar

HNO_3-BC= Nitric acid modified biochar

4.3 Effects of modified biochar incorporation on plant available P

The impact of modified biochar incorporation on plant available P after 40-days of plantation are presented in Fig.3.The values of plant available P were significantly influenced by different treatments. The highest value (13.10 mg pot^{-1}) was found in HNO_3 modified rice straw biochar and the lowest value (5.14 mg pot^{-1}) was found in H_2SO_4 modified rice straw biochar treatment. Other treatments were moderate with statistically similar value

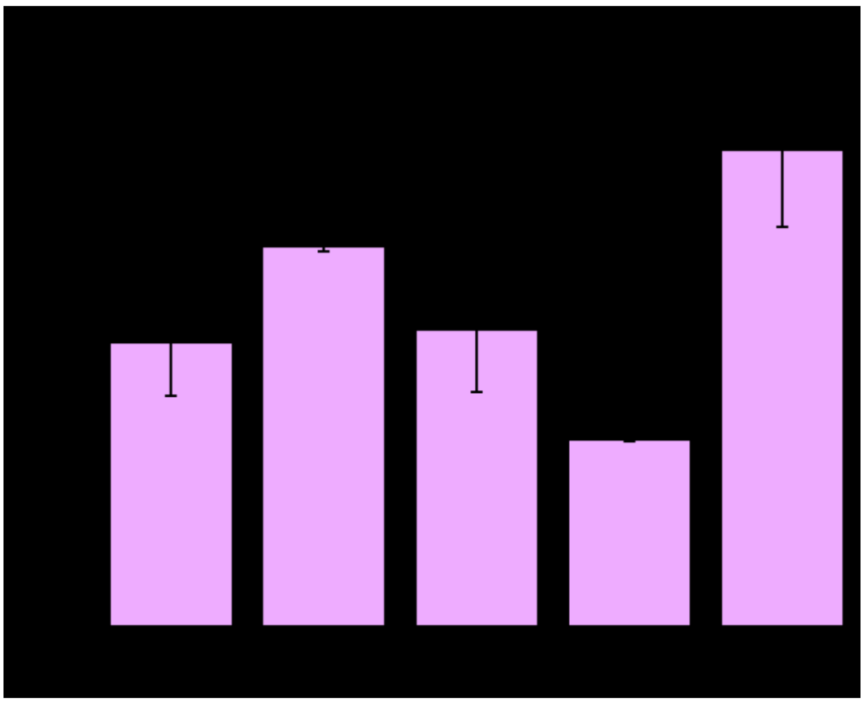

Fig.3. Plant available P after 40 DAS. Vertical bar indicates the standard error mean.

Here,

FBC= Fresh biochar

H_2O_2-BC= Hydrogen peroxide modified biochar

H_2SO_4-BC= Sulfuric acid modified biochar

HNO_3-BC= Nitric acid modified biochar

4.4 Effects of modified biochar incorporation on soil pH, CEC and base cations (Ca, Mg, K, Na) after 40 DAS

4.4.1. Effects of modified biochar incorporation on soil pH.

When modified biochar applied in soil, there is observed a significant difference in pH. In this study, the lowest value was observed where H_2SO_4 modified biochar was applied and the highest value was found in H_2O_2 acid modified biochar which indicate that sulfuric acid biochar is suitable for applying acidic soil while H_2O_2 biochar is suitable for alkali soil.

4.4.2. Effects of modified biochar incorporation on OM

They were statistically similar as OM supply was higher at HNO_3modified biochar compared to H_2SO_4 modified biochar and the lower value was control.

4.4.3. Effects of modified biochar incorporation on soil CEC

There was no significant difference of CEC after applying modified biochar which assumed that modified biochar has no considerable contribution of changes of soil CEC

4.4.4. Effects of modified biochar incorporation on base cation Ca

They were statistically similar as a nutrient element Ca supply was higher at H_2O_2 modified biochar application and the lower value is H_2SO_4 modified biochar. So it was clearly noticed that H_2O_2 modified biochar application is better than other compared to control and H_2SO_4 biochar.

4.4.5. Effects of modified biochar incorporation on base cation Mg

They were statistically similar as a nutrient element Mg supply was higher at H_2SO_4 modified biochar application and the lower value is control.

4.4.6. Effects of modified biochar incorporation on base cation K

As a nutrient element K supply was higher at fresh biochar application. So, it is clearly assumed that fresh biochar application is better than other compared to others.

4.4.7. Effects of modified biochar incorporation on base cation Na

There was no significant difference of soil available Na after applying modified biochar which assumed that modified biochar has no considerable contribution of changes of soil Na

The impact of modified biochar incorporation on soil pH, OM, CEC and base cations (Ca, Mg, K,

Na) after 40 DA presented in Table 5.

Table 5: Different soil properties after end of pot study

Treatments	pH	OM (%)	CEC	Ca	Mg	K	Na	Total base cations
			meq 100 g soil^{-1}					
Control	5.31±0.20b	1.76±0.07c	18.46±0.50a	1.51±0.03bc	0.41±0.01b	0.65±0.06b	0.31±0.02a	2.88
FBC	5.44±0.03b	1.83±0.05bc	19.21±2.47a	1.63±0.04ab	0.45±0.01b	0.97±0.05a	0.30±0.02a	3.35
H_2O_2-BC	5.85±0.08a	1.87±0.03bc	19.54±2.05a	1.75±0.10a	0.43±0.02b	0.79±0.10ab	0.28±0.02a	3.25
H_2SO_4-BC	3.42±0.27c	1.89±0b	18.16±1.01a	1.45±0.13c	0.70±0.11a	0.41±0.24c	0.28±0.03a	2.85
HNO_3-BC	5.23±0.20b	2.02±0.07a	20.08±1.15a	1.45±0.09c	0.46±0.02b	0.63±0.03bc	0.28±0.02a	2.82

The data were presented as means ±SE and means sharing dissimilar letter in column are statistically significant and similar letters are non- significant (P>0.05).

Here,

FBC= Fresh biochar

H_2O_2-BC= Hydrogen peroxide modified biochar

H_2SO_4-BC= Sulfuric acid modified biochar

HNO_3-BC= Nitric acid modified biochar

Ca = Calcium

Mg= Magnesium

K= potassium

P= phosphorus

CEC= Cation exchange capacity

OM= Organic matter

CHAPTER V

SUMMARY AND CONCLUSION

Phosphorus (P) is a crucial plant nutrient, but its availability is limited because it is a nonrenewable resource. The purpose of this study was to examine the availability of P in modified rice straw biochar in low fertility soils of northern Bangladesh. The growing period was 40 DAS. The included treatments: a) control (without biochar+KH_2PO_4,), b) fresh rice straw biochar2%+KH_2PO_4,, c) H_2O_2+2% fresh rice straw biochar+KH_2PO_4, d) H_2SO_4+2% fresh rice straw biochar+KH_2PO_4 and e) HNO_3+2% fresh rice straw biochar+KH_2PO_4 and replicated three times in a completely randomized design (CRD). The results indicated that incorporation of hydrogen per oxide modified rice straw biochar increased the pH value (5.85) of the soil and the lowest value (3.42) was sulfuric acid modified biochar. On the other hand, soil available P value (95.42 ppm) also increased due to application of nitric acid modified rice straw biochar besides the lowest value (33.42ppm) was observed in sulfuric acid modified biochar. Plants dry weight value (4.44gpot^{-1}) was also increased due to application of nitric acid modified biochar and the lowest value (1.10gpot^{-1}) was showed on sulfuric acid modified biochar. pH value showed the highest value (5.85) at the hydrogen per oxide modified biochar and lowest value (3.42) showed in sulfuric acid modified biochar. Calcium availability highest value (1.75 meq 100 g soil^{-1}) compared to lowest value sulfuric and nitric acid modified biochar. Cation exchange capacity and

Na availability there was no significant, The results showed that the soil pH might have dramatically raised with the addition of H_2O_2 modified rice straw biochar. On the other hand, using biochar made from nitric acid-modified rice straw enhanced the amount of P in the soil. After incorporating acid-modified biochar, soil attributes such as OM, CEC, and base cations (Ca, Mg, K and Na) were altered, increasing P availability.

The treatment of HNO_3 modified biochar followed by sulfuric and H_2O_2 modified biochar produced higher yield. However for maximum P uptake in plant to applied HNO_3 modified biochar.

Recommendation

Considering the above observation the experiment further studies in the following may be suggested .

- Further study may be needed to ensure the growth and yield performance of maize in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability.
- More crop may be needed to include for future study.

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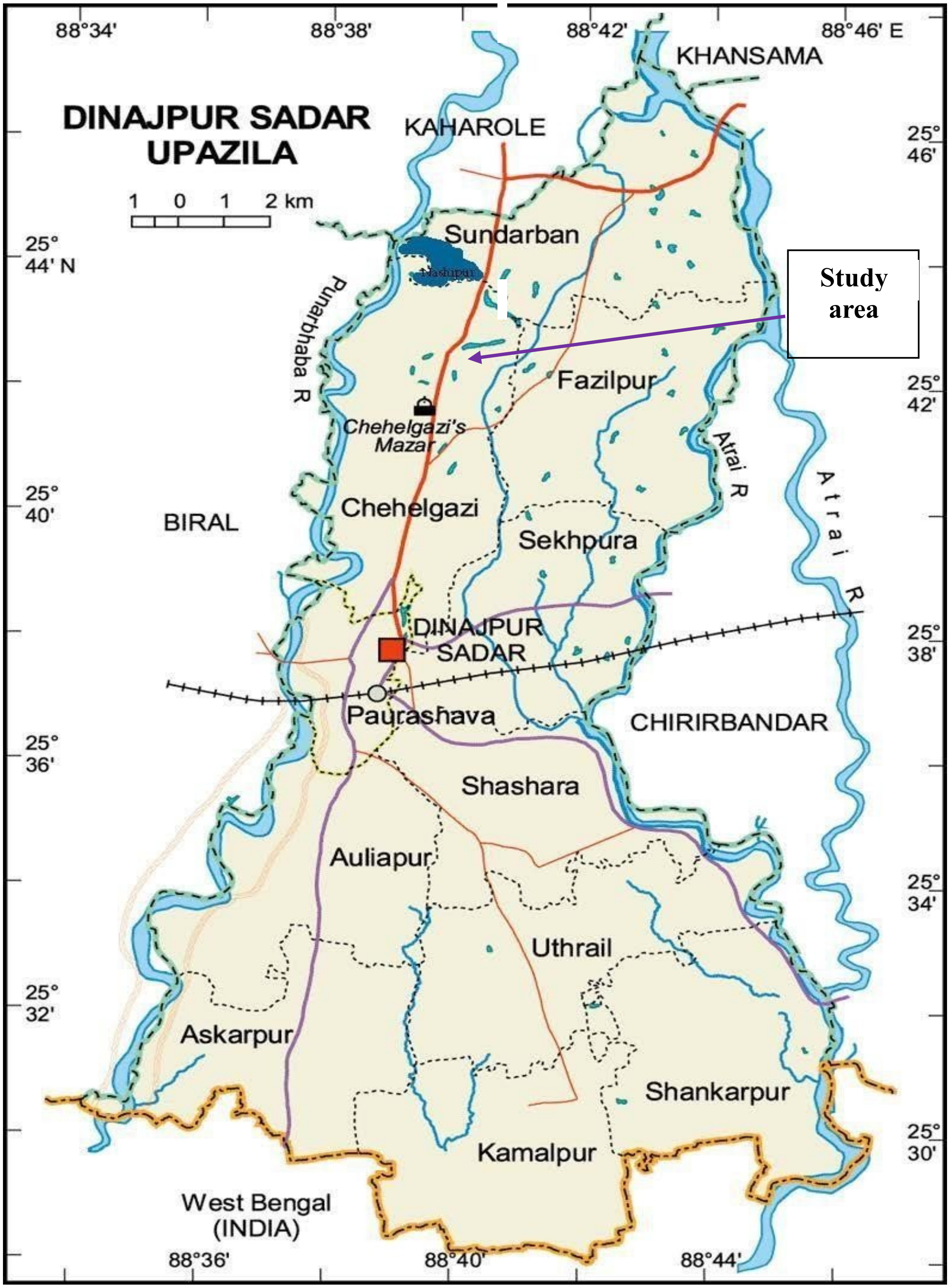
APPENDICES

Appendix I. Location of the experimental site (map of Dinajpur SadarUpazila showing the research plot)



Appendix II. Monthly recorded air temperature, relative humidity, and rainfall during the research period (From March to July 2022)

Year	Month	**Temperature (^{0}C)		**Relative Humidity (%)	**Rainfall (mm)
		Minimum	Maximum		
2022	March	16.9	31.1	63	11.3
	April	20.8	33.3	68	67.1
	May	23.0	32.6	76	232.5
	June	25.5	32.7	82	335.3
	July	25.5	32.8	84	433.6

**Monthly average

Source: Bangladesh Meteorological Department.

Appendix III. Some photographs during research period