ROLE OF UREA, POTASSIUM AND BIOCHAR ON YIELD AND QUALITY OF POTATO

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*This is to certify that thesis entitled, "**ROLE OF UREA, POTASSIUMAND BIOCHAR ON YIELD AND QUALITY OF POTATO**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **TAPOSH KUMAR BHATTACHARJEE**, Registration no. **19-10220** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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ROLE OF UREA, POTASSIUM AND BIOCHAR ON YIELD AND QUALITY OF POTATO

ABSTRACT

The pot experiment was conducted at Agronomy Research Field, Sher-e-Bangla Agricultural University during the period from 3rd November, 2020 to 28th February, 2021 to find out the effect of urea form, source of potassium and biochar on yield and quality of potato. The experiment consisted of three factors. The factors were: factor A: Form of nitrogen (2); i. N_1: Prilled urea and ii. N_2: Urea Super Granule (USG); factor B: Source of potassium (3), i. K_1: KCl, ii. K_2: KH_2PO_4 and iii. K_3: K_2SO_4; factor C: Source of biochar (3), i. B_1: Maize cob biochar, ii. B_2: Mahogany biochar and iii. B_3: Cowdung + Sawdust biochar. The variety used in this experiment was BARI Alu-29 (Courage). The experiment was laid out in a RCBD factorial design with three (3) replications. Data on different growth, qualitative, yield contributing and yield parameter of potato were recorded and significant variation was recorded for different treatments. It was observed that the plants treated with N_2 (Urea Super Granule or USG) out-yielded over N_1 (Prilled urea) by producing the highest weight of tubers (313.40 g pot^{-1}). The treatment N_2 (Urea Super Granule or USG) also showed significantly the highest weight of marketable tubers (261.93 g pot^{-1}), lowest weight of non-marketable tubers (51.48 g pot^{-1}), highest starch content (16.80 mg g^{-1} FW) and the lowest reducing sugar (0.28 mg g^{-1} FW) in compare to prilled urea treated plants. Significant differences existed among different sources of potassium with respect to yield parameters in potato. The plants which were treated with K_1 (KCl) out-yielded over K_2 (KH_2PO_4) by producing the highest weight of tubers (317.89 g pot^{-1}). The treatment K_1 (KCl) also showed significantly the highest weight of marketable tubers (256.44 g pot^{-1}), highest number of tubers plant^{-1} (8.61) and the highest average weight of tuber plant^{-1} (37.75 g) in compared to K_2 (KH_2PO_4) treated plants. The results revealed that B_1 (Maize cob biochar) exhibited its superiority to other biochar sources B_2 (Mahogany biochar) and B_3 (Cowdung + Sawdust biochar) in terms of tuber yield of potato. It was observed that the plants treated with B_1 (Maize cob biochar) out-yielded over B_2 (Mahogany biochar) and B_3 (Cowdung + Sawdust biochar) by producing the highest weight of tubers (311.61 g pot^{-1}). The treatment B_1 (Maize cob biochar) also showed significantly the tallest plant at 65 DAP (66.69 cm), the highest average weight of tuber plant^{-1} (39.77 g), the highest weight of marketable tubers (250.44 g pot^{-1}) and the highest starch content (16.20 mg g^{-1} FW) in comparison on mahogany biochar and cowdung + sawdust biochar treated plants. Interaction effects of urea form, source of potassium and biochar showed significant variation for most of the studied parameters. Among the interactions, $N_2K_1B_1$ was superior in producing the tallest plant at 65 DAP (72.17 cm), the highest weight of tuber (340.00 g pot^{-1}), highest weight of marketable tuber (290.67 g pot^{-1}), highest weight of non-marketable tuber (81.00 g pot^{-1}), highest yield of potato for flakes production (30–45 mm) (201.33 g pot^{-1}), highest yield of potato for chip production (45–75 mm) (121.00 g pot^{-1}), highest firmness (38.15%), total soluble solid (5.80 °brix), tuber dry matter (22.79%) and starch content (18.60 mg g^{-1} FW).

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LIST OF ABBREVIATIONS

ABBREVIATIONS	ELLABORATION
Agric.	Agriculture
Agra.	Agricultural
Agron.	Agronomy
Annu.	Annual
Appl.	Applied
Vm	Vermicompost
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV	Coefficient of Variance
DAS	Days After Storage
DAP	Days After Planting
Dev.	Development
Ecol.	Ecology
Environ.	Environmental
etci	and others
Exptl.	Experimental
g	Gram (s)
Hortc.	Horticulture
i.e.	that is
J.	Journal
kg	Kilogram (s)
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
mg	Milligram
Nutr.	Nutrition
Physiol.	Physiological
Progress.	Progressive
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
T	Tuber size
Soc.	Society
SRDI	Soil Resource Development Institute
t ha^{-1}	Ton per hectare
UNDP	United Nations Development Programme
Viz	*videlicet* (L.), Namely
%	Percentage
@	At the rate of
µMol	Micromo

LIST OF ABBREVIATIONS

ABBREVIATIONS	**ELLABORATION**
AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
eds.	Editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
i.e.	id est (that is)
L.	Linnaeus
LSD	Least Significant Difference
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TDM	Total Dry Matter
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	Variety
viz.	Namely

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) popularly known as alu 'The king of vegetable', is a tuber crop under the family of Solanaceae. It originated in the central Andean area of South America (Keeps, 1979). It is the 4th world crop after wheat, rice and maize. Bangladesh is the 8th potato producing country in the world (FAOSTAT, 2018). It contributes not only energy but also substantial amount of high-quality protein and essential vitamins, minerals and trace elements to the diet (Horton, 1987).

In Bangladesh, potato ranks 2nd after rice in production (FAOSTAT, 2018). The total area under potato crop, national average yield and total production in Bangladesh are 475488 hectares, 19.925 t ha^{-1} and 9474098 metric tons, respectively (BBS, 2018). It is a staple diet in European countries and its utilization both in processed and fresh food form is increasing considerably in Asian countries. The yield of potato in Bangladesh is very low (19.36 t ha^{-1}) in comparison to those of the other leading potato growing countries of the world, 74.45 t ha^{-1} in Kuwait, 59.53 t ha^{-1} in Belgium, 52.89 t ha^{-1} in France, 51.97 t ha^{-1} in USA, 47.53 t ha^{-1} in Denmark and 46.21 t ha^{-1} in UK (FAOSTAT, 2018).

Bangladesh has a great agro-ecological potential of growing potato. Potato has a great importance in rural economy in Bangladesh. It is not only a cash crop but also an alternative food crop compares to rice and wheat. The area and production of potato in Bangladesh has been increasing during the last decades but the yield per unit area did not change. The organic matter of most of the soils of Bangladesh is below 2% as compared to an ideal minimum value 4% (Bhuiyan, 1994). The reasons for such a low yield of potato in Bangladesh are imbalanced fertilizer application, use of low-quality seed and use of sub-optimal production practices. Available reports indicated that potato production in Bangladesh can be increased by improving cultural practices among which optimization of manure and fertilizer, planting time, spacing and use of optimal sized seed are important which influences the yield of potato (Divis and Barta, 2001).

Potato is considered as a gross feeder and requires adequate supply to different plant nutrients, particularly nitrogen for optimum growth of plants and high yield of tubers. Under Bangladesh conditions, use of both under and over doses of nitrogen has been reported (Hussain, 1998). The use of low nitrogen results in reduction of yield of potato. On the other hand, excess use of nitrogen results in wastage of fertilizer and high cost of production.

Total production is increasing day by day as such consumption also rapidly increasing in Bangladesh (BBS, 2013). A challenge of potato production is effective management of nitrogenous fertilizers (Fageria and Baligar, 2005). Nitrogen is the most essential element in increasing crop yields; thus nowadays, nitrogenous fertilizers are extensively used worldwide (Fageria and Baligar, 2005). A plant absorbs most nitrogen in nitrate form. Nitrogen is an important and essential structural component of chlorophyll and various proteins (Koochaki, 2006). Application of extraneous nutrients like fertilizers is necessary in potato production because its high rate of dry matter production rapidly discharges soil nutrients (Imas and Bansal, 1999). The research showed that adequate nitrogen application in growing season is required to realize high potato yield and quality. Over dose of nitrogen application or its early or late application adversely affect its produced tubers. N deficiency decreases growth and yield and N excessive application stimulates shoot growth, retards tuber formation and filling period, decreases tuber specific weight and shortens tuber storage time (Rezaee and Sultani, 1996).

Potassium is the only essential plant nutrient that is not a constituent of any plant part. Potassium is a key nutrient in the plants tolerance to stresses such as cold/hot temperatures, drought, and wear and pest problems. Potassium (K) in soil is present in three different forms that is total K, exchangeable and K in soil solution (Mengel and Kirkby, 1987). Soil solution K has a high chance of leaching and thus loss from the soil system. Exchangeable K plays an important role in soil plant availability. Potassium from mica as dominant mineral in Nepalese soil (Schrier *et al.*, 1994) and K from mica contributes a part of soil potassium (Mengel and Rahmatullah 1994; Baeumler *et al.*, 1997). When increase potassium application then decrease weight loss and rottage of tubers (Singh and Lal, 2012).

Of the essential elements, potassium (K) is the third most likely, after nitrogen and phosphorus, to limit plant productivity (Brady and Weil, 2002). It plays a critical role in lowering cellular osmotic water potentials, thereby reducing the loss of water from leaf stomata and increasing the ability of root cells to take up water from the soil (Havlin *et al.*, 1999) and maintain a high tissue water content even under drought conditions (Marschner, 2002). Potassium is essential for photosynthesis, nitrogen fixation in legumes, starch formation, and the translocation of sugars. As a result of several of these functions, a good supply of this element promotes the production of plump grains and large tubers. When K is deficient, growth is retarded, and net retranslocation of K^+ is enhanced from mature leaves and stems, and under severe deficiency these organs become chlorotic and necrotic (Marschner, 2002). K deficient plants are highly sensitive to fungal attack (Marschner, 2002), bacterial attack, and insect, mite, nematode and virus infestations (Havlin *et al.*, 1999). Potassium deficiency affects nutritional and technological (processing) quality of harvested products particularly fleshy fruits and tubers. In potato tubers, for example, a whole range of quality criteria are affected by the potassium content in tuber tissue (Marschner, 2002).

Biochar application changes different soil physical properties, aggregate structure, increase soil C : N ratio. It reduces soil bulk density, increase soil porosity, cation exchange capacity, soil pH, nutrient availability, increase C content and trap CO_2 gas within soil. Biochar compensate climate change through slower return of terrestrial organic C as CO_2 gas to the atmosphere. It decreases leaching loss which is main problem for N fertilizer by retain water into soil. Biochar has been described as a possible means to upgrade soil fertility as well as other ecosystem services and sequester carbon (C) to mitigate climate change (Sohi *et al.*, 2010). The observed effects on soil fertility have been described mainly by a pH increase in acid soils (Van Zwieten *et al*., 2010) or improved nutrient conservation through cation adsorption (Liang *et al.*, 2006). Biochar increase N availability into the soil, reduce leaching loss of N by retaining water. Mineralization of N could be enhanced by application of biochar derived from slow pyrolysis rather than fast pyrolysis (Bruun *et al.*, 2012). Nitrogen is of more important for plant growth due to being a part of amino acid, protein and chlorophyll molecule.

It is evident that uses of nitrogen, potassium and biochar are the very important variables in potato production. The aim of this work was to evaluate the effect of nitrogen, potassium and biochar on the growth, yield and quality which have an effect on potato production in Bangladesh with the following objectives:

1. To find out the suitable form of nitrogen for better yield and quality of potato.
2. To find out the suitable sources of potassium for better yield and quality of potato.
3. To find out the suitable sources of biochar for maximizing potato yield with superior quality.
4. To determine the suitable combination of nitrogen form, potassium sources and biochar on growth, yield and quality of potato.

CHAPTER II

REVIEW OF LITERATURE

Nitrogen is one of the macro-nutrients used in Bangladesh in the form of urea. There is different form of urea. USG is one of them which greatly influences crop yield. Prilled urea is another form of urea. A number of studies were conducted in Bangladesh on different forms of urea as the source of nitrogen especially prilled urea dose and dose of USG also an important factor in research farms and farmers filed under different agro-ecological conditions. Very few information was available regarding the effect of different source of potassium fertilizer and biochar on yield and processing quality of potato. An attempt has been made in this chapter to review the literatures and research finding on the level of prilled urea and USG application as the source of nitrogen, different source of potassium fertilizer and biochar on yield and processing quality of potato.

2.1 Effect of nitrogen fertilizer form on potato

Hossain (2017) carried out a research work in order to determine the suitable nitrogen source to observe the growth performance of potato plant with a view to increasing the yield of potato tuber. The experiment consisted of eight treatments: T_1 = Control; T_2 = Recommended fertilizer dose ($N_{150}P_{30}K_{140}S_{15}Zn_3$) Kg ha^{-1}; T_3 = 2.7 g size USG (2 granule at both side) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1}; T_4 = 1.8 g size USG (2 granule at both side) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1}; T_5 = 1 USG (2.7 g) + 1 USG (1.8 g) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1}; T_6 = 1 USG (2.7 g) + 2 USG (1.8 g) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1}; T_7 = 1 USG (2.7 g) + 1 time top dress $\frac{1}{4}$th dose of N (tuber bulk stage) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1} and T_8 = 1 USG (1.8 g) + 1 time top dress $\frac{1}{4}$ th dose of N (tuber bulk stage) with $P_{30}K_{140}S_{15}Zn_3$ Kg ha^{-1}. Diamant (BARI ALU-7) variety was the test crop. Experimental results showed that potato production increased significantly due to the application of USG. The highest tuber production was observed in T_3 treatment. The application of T_3

treatment showed the highest number of stem hill^{-1} (7), maximum number of tubers per hill (8), higher stem dry matter content (23.10%), highest wt. of tuber hill^{-1} (57.53 g), the highest tuber yield kg per plot (25.77), the highest tuber yield (29.45 t ha^{-1}) and the highest specific gravity of tuber (1.076) than any other sources of nitrogen treatments. The mean apparent recovery of N by tested varieties (Diamant) was obtained with the application of USG in other treatment (except control) but the nitrogen use efficiency was the highest in T_3 treatment. Findings revealed that application of USG showed the superiority over other sources of nitrogen to produce the highest tuber yield of potato and for all cases while the lowest results were found in T_1 treatment receiving no fertilizer (control).

Yuan *et al.* (2014) mentioned that potato tuber initiation and its growth are key processes determining tuber yield, which are closely related to stolon growth, and are influenced by many factors including N nutrition. They investigated the influences of different forms of nitrogen (N) on stolon and tuber growth in sand culture with a nitrification inhibitor using two potato cultivars. Seed potatoes used in this study were all virus-free mini seed tubers: Cultivars of potato were Kexin-1 and Shepody. Three N forms: 100% NO_3-N, 100% NH_4-N, and NO_3^- and NH_4^+ at a 1∶1 ratio (NO_3/NH_4-N) were tested. The NH_4-N resource was delivered as $(NH_4)_2SO_4$, and the NO_3-N resource as $Ca(NO_3)_2$. Nitrification inhibitor dicyandiamide (DCD) was added (5% of total ammonium N content) to the pots with NH_4-N and NO_3/NH_4-N, to impede transformation of ammonium to nitrate. Plants supplied with NO_3-N (N as nitrate, NO_3^-) produced more and thicker stolons than those supplied with NH_4-N (N as ammonium, NH_4^+) at tuber initiation stage. In the plants fed NO_3-N, the stolon tips swelled or formed tubers earlier and produced more tubers than in those fed with NH_4-N. However, no significant difference was observed among N forms in terms of tuber yield at harvest, this may have been because of the shoot growth rate at tuber initiation stage was lower in the plants fed NO_3-N. During the tuber bulking stage, the difference in shoot DWs among N forms began to decrease, and the shoot DW of plants fed NO_3-N was even heavier than those fed NH_4-N in some cases. The influence of N form on potato plant growth may therefore vary with the potato growth stage. In dry land fields, inorganic N pool is mainly NO_3^- in soils, and the NH_4^+ applied could be easily transformed into NO_3^-. These soil characteristics could be beneficial to tuber initiation. However, a certain amount of NH_4-N fertilizer with nitrification inhibitor may be necessary because NH_4-N improves shoot growth at the early stage of potatoes.

Azam *et al.* (2012) conducted a field experiment to investigate the effect of urea super granule (USG) on the growth and yield of potato at the multilocation testing (MLT) site during rabi seasons 2008–09 and 2009–10. Five treatments were the same in two rabi seasons. *viz.* T_1 = Recommended dose of nitrogen as prilled urea (PU), T_2 = Recommended dose of nitrogen as urea super granule (USG), T_3 = 10% less of recommended dose of nitrogen as USG, T_4 = 20% less of recommended dose of nitrogen as USG and T_5 = Farmers practice (average of 20 farmers N dose used as PU). The recommended dose of nitrogen was 190 kg ha^{-1}. The results showed that plant height, plant populations/m^2, tuber/hill, tuber weight/hill and tuber yield of potato were significantly affected by the treatments. In both years, the highest plant height (67.20 cm and 71.21 cm) was recorded from T_2 but T_2 and T_3 were significantly identical in 2008–09 and significantly difference in 2009–10. The treatment T_2 produced maximum number of plant per m^2 (38.62) in 2008–09 and in 2009–10, similar trend was observed which was statistically similar with T_5 treatment in both the years. The highest tuber per hill was observed from T_2 treatment, which was statistically similar with T_3 and T_4 treatments in 2008–09. The highest Tuber per hill was recorded from T_3 treatment followed by T_2 treatment but there was no significance difference among the T_1, T_4 and T_5 treatments in 2009–10. Higher tuber weight/hill (335.01 and 325.25 gm) were found in treatment T_2, that were statistically identically with T_5 (325.25 and 314.34 gm) followed by T_3 (300.15 and 305.95 gm) for both the years, respectively. The highest yield of potato (33.21 t ha^{-1}) were obtained from the recommended N dose of USG followed by

USG 10% less than recommended dose of N (31.51 t ha^{-1}) during 2008–09. In the year 2009–10, higher yield was obtained from the T_2 treatment (32.33 t ha^{-1}) followed by T_3 (30.87 t ha^{-1}). In 2008–09, maximum tuber yield was observed from T_2 treatment (33.21 t ha^{-1}) which was statistically identical with T_3 (31.51 t ha^{-1}) and statistically dissimilar with T_4 (29.89 t ha^{-1}) and T_5 (29.56 t ha^{-1}) treatments. In 2009–10, significantly the maximum tuber yield was found from T_2 (32.33 t ha^{-1}) treatment closely followed by T_3 (30.87 t ha^{-1}) treatment. It can be assumed from the better performance of USG that N loss from this fertilizer was remarkably less than that of prilled urea. The treatments T_1 gave the lowest yield (26.56 t ha^{-1} and 27.52 t ha^{-1}) in both years. However, average yield of the two years revealed that maximum yield (32.77 t ha^{-1}) was found in T_2 followed by T_3, T_5 and T_4 treatments. T_2, T_3 and T_4 treatments gave 21.19%, 14.64% and 7.69% higher yield over T_1 treatment which was PU of urea fertilizer. By reducing 10% N lost through USG application more or equal returns can be obtained over prilled urea application. Cost and return analysis revealed that the treatment T_2 was recorded to have higher gross returns as well as the highest benefit cost ratio (BCR) (2.74) followed by T_3 treatment (2.64).

El-Sayed *et al.* (2009) conducted field experiments to investigate the performance of potato (*Solanum tuberosum* L.) cv. 'Valor' in relation to three different nitrogen (N) fertilizer forms [ammonium sulphate, $(NH_4)_2SO_4$ (20.6% N), urea, $CO(NH_2)_2$ (46% N) and ammonium nitrate, NH_4NO_3 (33.50 % N)] and four N fertilizer rates (130, 180, 230 and 280 Kg N/feddan; 1 feddan (fed) = 4200 m^2) on the growth, yield and tuber quality of potato plants. Using NH_4NO_3 significantly increased vegetative growth characters, leaf chlorophyll content, tuber yield/plant, total tuber yield (ton/fed), specific gravity and tuber starch content followed by $(CO(NH_2)_2$ then $(NH_4)_2SO_4$. There was no significant effect of N source on the tuber number/plant, N, P and K and protein content. It was clear from the obtained data that using NH_4NO_3 at 230 kg N/fed resulted in the highest tuber number per plant followed by $CO(NH_2)_2$ at the same rate and NH_4NO_3 at 280 kg N/fed with no significant difference between them. Generally

$(NH_4)_2SO_4$ reduced the number of tubers per plant and the lowest number was obtained when using low application rates of 130 and 180 kg N/fed with no statistical difference between these two treatments. Regarding average tuber weight, it was evident that NH_4NO_3 (in general) at 280 kg N/fed was superior in increasing average tuber weight followed by $CO(NH_2)_2$ at the same rate then NH_4NO_3 at 180 kg N/fed with no significant difference among these treatments. The least values for average tuber weight were obtained when using $(NH_4)_2SO_4$ and NH_4NO_3 at 130 kg N/fed. When total tuber yield per plant was measured, a close pattern was also obtained where NH_4NO_3 gave the highest tuber yield per plant (g) with no statistical difference between using 230 or 280 Kg N/fed with the exception of the low application rate of 130 Kg N/fed which caused a severe reduction in tuber yield per plant. Also using $(NH_4)_2SO_4$ reduced the tuber yield per plant and the lowest was obtained with using $(NH_4)_2SO_4$ at 130 kg N/fed followed by 180 Kg N/fed with a statistical difference between both rates. As for total tuber yield/fed, it showed the same pattern as tuber yield/plant. The percentage marketable tubers were also statistically affected by N source and rate. NH_4NO_3 at 230 and 180 kg N/fed and $CO(NH_2)_2$ at 230 kg N/fed increased the marketable tubers with no significant difference among them. On the other hand, ammonium sulphate at 130 and 180 kg N/fed resulted in the lowest tuber marketable percentage with no statistical difference between both rates. Generally, using NH_4NO_3 increased both specific gravity and starch content and the least values were obtained when using $(NH_4)_2SO_4$ while $CO(NH_2)_2$ was intermediate. In all N sources used, the higher the N application rate, the lower the tuber specific gravity and starch content. Least specific gravity and starch content values were obtained with using $(NH_4)_2SO_4$ at 280 kg N/fed while the highest values resulted from NH_4NO_3 application at 130 kg N/fed. Dry matter percentage behaviour was similar to specific gravity and starch content where it was increased with applying N mineral fertilization in form of NH_4NO_3 followed by $CO(NH_2)_2$ then $(NH_4)_2SO_4$. Using NH_4NO_3 at 130 kg N/fed produced tubers with the highest percentage of dry matter while the lowest values were obtained when using $(NH_4)_2SO_4$ at 280 kg N/fed. It could be recommended that using N fertilizers in the form of NH_4NO_3 at a rate of 230 Kg N/fed gave the best growth characters, yield and % marketable tubers while using 130 Kg N/fed of the same source of N fertilizer gave the highest of tuber quality characters as expressed by specific gravity and % starch content.

Shahidullah *et al.* (2009) conducted a field experiment to investigate the effect of Urea Super Granule (USG) on potato production at two locations; Shibganj and Sadar Upazilla. Five treatments were considered which were the same in two locations, *viz.* T_1 = Control (N = Zero), T_2 = 150 kg N ha^{-1} as prilled Urea, T_3 = 20% less N (120 kg N ha^{-1}) as USG, T_4 = 10% less N (135 kg N ha^{-1}) as USG and T_5 = 150 kg N ha^{-1} as USG. The cultivar Granola whole tuber of Potato was planted. The highest yield was found in T_5 treatments at Shibganj (22.64 t ha^{-1}) and Bogura Sadar (24.32 t ha^{-1}). The yield recorded in T_2, T_4 and T_5 were statistically identical at both the location. The lowest yield was found in control plot at Shibganj (13.65 t ha^{-1}) and Bogura Sadar (12.35 t ha^{-1}). There was a quantum of jump in potato yield with the lowest 120 kg N ha^{-1} application as USG with treatment T_3 at Shibganj (20.74 t ha^{-1}) and Bogura Sadar (21.44 t ha^{-1}) indicated the conspicuous effect of N over control. Increasing the application of N-as USG increased the plant vigour, tuber weight $hill^{-1}$ and yield significantly compared to control and same rate of N-as prilled Urea at Bogura Sadar site. Similar trend was found at Shibganj site. The highest plant vigour was found from T_5 treatment (8.0) followed by T_4 (7.0), T_2 (6.33), T_3 (5.67) and T_1 (3.0) treatment, respectively. Tuber weight per hill ranged from 190–385 gm $hill^{-1}$. The highest tuber weight was obtained from T_5 treatment (385 gm) at Shibganj site and the lowest was found T_1 treatment (190 gm) from Bogura Sadar site. At Shibganj, the highest yield increase, i.e. 80.51% was found from T_5 (150 kg N ha^{-1} as USG) treatment compare to control (T_1) and also 11.59% yield increase was found in T_5 compare to T_2 (150 kg N ha^{-1} as prilled Urea). At Bogura Sadar site, compared to control (T_1), and over Urea (T_2) the highest yield increase was found from T_5 (100 % recommended N as USG) i.e., 96% and 8.5%, respectively. The second highest yield increase over control and over Urea increase was found from T_4 (10% less of recommended N as USG) treatment i.e. 84% and 1%. Compared to USG, T_5 performed better followed by T_4 and the yield increase was 7% and 5.9%. The ratio of gross return (GR) : Total Variable cost (TVC) was the highest in T_5 at Shibganj (2.64:1) and Bogura Sadar (2.61:1). Therefore, by reducing 10% N costs through USG application more or equal returns can be obtained over Prilled Urea application. So, farmers can easily reduce 10 kg N as USG without significant yield reduction in potato cultivation.

Haque (2005) carried out an experiment to study the efficiency of urea super granule (USG) point placement on potato. The researcher recorded the maximum yield of potato (26.50 t ha^{-1}) with point placement of USG (109 kg N ha^{-1}).

El-Khider (2003) carried out experiments to study the response of potato plant to two types of urea fertilizer using the cultivar "Alpha". Nitrogen fertilizer in form of urea, was applied in bands at the rate of (0, 40, 80, 120 kg/fed) to individual plant (0, 17, 3.3, 5 g/plant) using two equal doses. The treatments were as follows: 0N as control, 1N (g/s) as 1.7 g / plant, 2N (g/s) as 3.3 g / plant and 3N (g/s) as 5.0 g / plant. N(g) represents the application of nitrogen (urea) in the form of granules and N(s) in the form of soluble urea. The soluble urea for three applications was dissolved in 250 ml of water. The treatment N(3g) resulted in the highest plant height, whereas, the N(1s) gave the lowest results. The 3rd rate of urea (applied as granules) increased the number of tuber and weight of tubers over all other treatments and the control. The number of tuber per plant may be increased with increased number of stem per plant. The 3rd dose N(3g) gave significantly better dry matter of potato tubers. The total yield per hectare was greater when fertilizer was applied compare to the control. Generally, total yield per hectare at N(3g) in the first season was lower (14.20 t ha^{-1}) than in 2^{nd} (28.40 t ha^{-1}) and 3rd (28.30 t ha^{-1}) seasons. While the 2nd season yield was similar to 3rd season. This was attributed mainly to the adverse effects of high temperature in the first season and probably to factors related to the soil, this might have been due to earlier tuber initiation. The first treatment of fertilizer N(1s) (solution) showed the lowest effect, and was not significant when compared to other treatments.

Maier *et al.* (2002) showed that tuber yield of potato cvs. 'Russet Burbank' and 'Atlantic' decreased when using $(NH_4)_2SO_4$ compared to NH_4NO_3 or $CO(NH_2)_2$ at the rate of 50 kg N ha^{-1}. Tuber yield of potato cv. 'Russet Burbank' was decreased when $(NH_4)_2SO_4$ was used as the N source but it was increased with $CO(NH_2)_2$ followed by NH_4NO_3 with no significant difference between them.

Soliman *et al.* (2000) showed that the N sources had significant effects on vegetative growth and tuber yield of potato cv. 'Nicola' with superiority of $(NH_4)_2SO_4$ when compared with NH_4NO_3 or $CO(NH_2)_2$. $(NH_4)_2SO_4$ was superior in increasing total tuber yield followed by $CO(NH_2)_2$ and NH_4NO_3, respectively and 180 kg N/fed was the optimum N application rate. As for % marketable tubers, fertilizing potato plants with NH_4NO_3 as the N source produced the highest marketable tuber yield.

Westermann and Sojka (1996) showed that vegetative growth characters of potato plant were higher by using $(NH_4)_2SO_4$ rather than NH_4NO_3.

Karadogan (1995) indicated that the greatest growth of potato plants resulted by supplying N as NO_3-N followed by NO_3 + NH_4 and the least with NH_4-N.

Shaheen *et al.* (1989) reported that both urea and ammonium sources had similar effects on potato tuber yield and specific gravity.

Dabis *et al.* (1986) reported changing the N source from NO_3 or NH_4 + NO_3 to NH_4 reduced both shoot and root growth and also tuber yield of potato while changing the N source from NH_4 to NH_4 + NO_3 improved growth and yield. They concluded that some NO_3-N should be available to potatoes for proper growth, development and yield.

Polizotto *et al.* (1975) found that growth of tops, roots, and tubers of potatoes in solution cultures was greatest with N supplied as NO_3, intermediate with NH_4 + NO_3, and the least with NH_4.

Lorenze *et al.* (1974) and Baker *et al.* (1980) indicated that in alkaline soils, higher yields of potato were obtained by ammoniacal sources than by its counterpart urea.

2.2 Effect of potassium fertilizer source on potato

Badrunnesa *et al.* (2021) conducted the experiment to assess the effect of potassium sources and vermicompost level on yield and grading of potato tuber. The potato tuber of variety BARI Alu-25 (Asterix) was used as the planting material for this experiment. The experiment consisted of two factors: Factor A: 3 sources of Potassium, viz. K_1: KCl, K_2: KNO_3, K_3: K_2SO_4; Factor B: 4 levels of vermicompost, viz. Vm_0: 0 t ha^{-1}, Vm_1: 4 t ha^{-1}, Vm_2: 8 t ha^{-1} and Vm_3: 12 t ha^{-1}. The highest yield of potato tubers (27.86 t ha^{-1}) was recorded from K_2SO_4, whereas, the lowest (26.02 t ha^{-1}) was found from KNO_3. Grading (Canned 20–35 mm; Flakes 35–45; Chips- 45–75 mm; and French fry- >75 mm) of potato tubers due to different sources of potassium was not significant. For Canned, Chips and French fry potato, the highest category (35.56%, 31.69% and 5.25%, respectively) was observed from K_1, whereas, the lowest (34.48%, 30.43% and 5.14%, respectively) was recorded from K_2. But for potato tubers used for flakes, the highest result was recorded from K_2 (29.95%) while lowest (27.51%) from K_1. Among potassium sources, KCl may be economic and is found available for producing good quality potato in Bangladesh.

Silva *et al.* (2018) reported that many potato producers for fry industry changed from the use of potassium chloride to potassium sulfate, as there is a concept that the use of this source improves tuber quality. The aim of this work was to evaluate the effect of these two potassium sources on yield, specific gravity and chip color of potato chipping cultivars. Treatments consisted of two potato cultivars, BRSIPR Bel and Atlantic, and two sources of potassium, potassium chloride (KCl, 60% of K_2O) and potassium sulfate (K_2SO_4, 50% of K_2O), applied in the furrow at the planting time, in rates based on soil analysis. There was no significant effect of potassium source on yield components, specific gravity and chip color of BRSIPR Bel and Atlantic.

Abd El-Nabi *et al.* (2013) carried out two separate experiments to study the effect of potassium sources [potassium mono phosphate (52% K_2O), potassium sulphate (50% K_2O) and potassium citrate 38% K)], levels (0, 60 and 120 kg K_2O/fed for each source), phosphorus sources [(calcium super phosphate 15.5 % P_2O_5), rock phosphate (30% P_2O_5) and phosphoric acid (85% P_2O_5)] and levels (0, 30 and 60 kg P_2O_5/fed for each source) on vegetative growth, tuber yield and chemical constituents of potato (*Solanum tuberosum* L.) c.v. 'spunta' cultivar. Concerning the effect of potassium fertilization sources, results reveal that the mean values of plant length (cm), fresh weight (g/plant) and dry weight (%) of plant foliage after 110 days from planting were significantly affected from different sources of application except numbers of stem/plant had insignificant effect and the highest mean values were recorded with using potassium mono phosphate (52% K_2O). Application of potassium fertilization sources showed significant effects on the mean values of tuber fresh weight (g/plant), tuber dry weight (%) and total yield (ton/fed) and had insignificant effect on No. of tuber/plant and average weight of tuber. Potassium mono phosphate was superior to other treatments. As for the effect of potassium levels, results showed significant effects on tuber fresh weight (g/plant), tuber dry weight percentage and total yield (ton/fed) after 110 days from planting by increasing potassium levels up to 120 kg K_2O/fed. It appeared from the data that adding K monophosphate as K-source gave the highest mean values of TSS %, total sugar%, starch% and Vit C (mg/100 g) of tuber after 110 days from planting.

Khan *et al.* (2010) conducted field experiments for two consecutive seasons to study comparative effect of source, levels and methods of K fertilization on yield and quality of potato produce. Potassium was applied @ 0, 150, 225 kg K_2O ha^{-1}

from two sources; sulphate of potash, (SOP) and muriate of potash, (MoP). Potassium was also applied as foliar spray at 1% K_2O solution at 30, 45 and 60 days after germination (DAG) and soil was also amended by 150 kg K_2O ha^{-1}. The highest average yield of 17.18 t ha^{-1} was produced in plots where 150 kg K_2O ha^{-1} was applied along with 1% K_2O foliar spray of SOP followed by 16.9 t ha^{-1} in case of 150 kg K_2O ha^{-1} + 1% K_2O foliar spray from MOP source. Potato tuber yield was 15.40 and 15.49 t ha^{-1} with K_2O application as SOP at 150 and 225 kg ha^{-1}, respectively while 15.49 and 15.80 t ha^{-1} with K_2O as MOP at 150 and 225 kg ha^{-1}, respectively. Superimposing foliar spray of K_2O @ 1% solution increased potato tuber yield up to 11% over that of applied soil K at 150 kg ha^{-1} from both sources of K which indicated that K application in latter crop growth stage, potato can compensate in optimizing the yield. Hence potato tuber yield increased with K application alone in soil as basal dose from both the sources (SOP and MoP) and further application as foliar spray contributed a lot in enhancing potato tuber yield. Application of K_2O at 150 kg ha^{-1} enhanced the marketable potato tuber yield significantly; the increase in yield was more with MOP as compared to SOP. K_2O application as SOP and MOP at 150 kg K_2O ha^{-1} increased vitamin C content by 10.8% and 14.7%, respectively. The difference in vitamin C content regarding sources of K was significant, while for the levels and methods of K application were non-significant. It means that MOP could be more favorable for enhancing vitamin C content than that of SOP. The specific gravity was more in potato tubers harvested from plots treated with SOP than those treated with MoP ones. The potato tubers obtained from the plants treated with foliar K had specific gravity at par with those from the plants treated with soil applied K_2O at 150 kg ha^{-1} from both the sources. Higher the specific gravity the higher will be the quantity of dry matter and the greater the yield of produce. Potatoes with high specific gravity are preferred for preparation of chips and French fries. Potatoes with low specific gravity are used for canning. However, potatoes with very high specific gravity (1.10) may not be suitable for French fries' production because they become hard or biscuit like. So, purpose of growing potato should be kept in mind.

Quadros *et al.* (2009) reported that the chloride source of potassium provides higher potassium uptake in the potato tuber than the sulfate source, but this effect is dependent on the cultivar. So, the chloride source would have a deleterious effect on potato crop, especially when applied late, since the assimilation of chlorine ion affects combinations with phosphorus, decreasing the carbohydrate synthesis.

Quadros *et al.* (2009), Kumar *et al.* (2007) and Beringer *et al.* (1990) reported in their individual research works that potassium sulfate represented superior results regarding vitamin C, ash, carbohydrates, energy and starch, and worse results in relation to tuber water content of potato compared to potassium chloride; but it depended on potato cultivars.

Kumar *et al.* (2007) mentioned that chloride source of potassium slowers translocation of carbohydrate synthesizing photo assimilates to potato tubers in comparison to sulfate source.

Kumar *et al.* (2007) and Reis Junior and Monnerat (2001) mentioned that potassium chloride (KCl) is the main potassium source used in fertilization in potato field, due to its lower price. However, many producers adopted potassium sulfate (K_2SO_4) as potassium source, since it is believed to improve tuber quality of potato.

Chettri and Thapa (2002) conducted a field experiment to investigate the effect of K fertilizer sources (KCl and K_2SO_4) and NPK rates (75 and 100% of the recommended, N:P:K at 180:150:150 kg ha^{-1}) with or without farmyard manure (FYM) at 10 tha^{-1} on potato cv. Kufri Badshah production. They concluded that K as K_2SO_4 produced higher dry matter production compared to KCl.

Sharma and Sud (2001) mentioned that the tuber quality of potato is greatly influenced by the source of potassium (K) fertilizer. Application of K as potassium chloride (MOP) or potassium sulphate (SOP) is recommended for potato crop.

Singh and Bansal (2000) from their studies conducted on alluvial soils of prominent potato growing region of western UP showed that potassium application through potassium chloride improved the crude protein content in the tubers of potato as well as its agronomic efficiency.

Singh *et al.* (1996) from their research data from alluvial soils of Jalandhar showed that potassium sources viz. potassium chloride (MOP) and potassium sulphate (SOP) did not differ much in dry matter content in potato tubers harvested at 100 days.

Joshi *et al.* (1982) stated that potato industry requires large grade tubers with better chipping quality. Potassium application through potassium chloride was found to improve chipping quality of tubers. The improvement in tuber quality is mainly attributed to low reducing sugar content of tubers produced with potassium chloride. Potassium chloride (MOP) was found to be better than potassium sulphate (SOP) as it decreases enzymatic discoloration and phenol content of the tubers thereby improving the chip color.

Sharma *et al.* (1976) conducted studies on acidic soil of Shimla (HP) and alluvial soils of Dauralla (UP) and shown that potassium sulphate was superior to potassium chloride in terms of tuber dry matter content, ascorbic acid and starch content of potato.

2.3 Effect of biochar produced from different sources on potato

El-Metwaly (2020) conducted two field trials on potato cv. Spunta to study the effect of NPK levels (100%, 75% and 50% NPK of the recommended rate) either single or in combination with some applications of fulvic acid and biochar treatments (untreated, fulvic acid at 10 kg/fed, biochar at 5 m^3/fed and fulvic acid at 10 kg/fed + biochar at 5 m^3/fed)) on plant growth, yield and its quality as well as chemical constituents of plant foliage and tubers. Application of fulvic acid, biochar singly or in combination had a significant effect on all plant growth parameters compared with untreated plants in both 2018 and 2019 seasons. The highest values of stem length, number of leaves/plant, leaf area/plant and foliage dry weight were recorded at application of fulvic acid + biochar, followed by treated with biochar alone in both seasons. The increases in total dry weight were about (57.0% and 60.3%) for the fulvic acid + biochar treatment and (48.9% and 41.9%) for biochar treatment over untreated plants in the 1st and 2nd seasons, respectively. It was evident from the data that treated potato plants with fulvic acid and biochar singly or in the mixture had a significant effects on total yield and its components compared with untreated plants in both seasons. Application of fulvic acid + biochar treatment recorded the maximum increment of average tuber weight, yield/plant and total yield, followed biochar treatment in both seasons. The relative increases in total yield due to treated potato plants with the fulvic acid + biochar treatment was about (30.6% and 25.4%) followed by (18.8% and 16.5%) at plants treated by biochar and (17.6% and 14.4%) at treated by fulvic acid over untreated plants in the first and second seasons, respectively. The increase in total yield might be due to the favourable effect of fulvic acid + biochar on vegetative growth. Furthermore, Lehmann *et al*. (2006) found that Biochar addition may enhance the productivity of plants directly due to their nutrient content and release features or indirectly due to enhanced nutrient retention. Besides, Nair *et al.* (2014) stated that increases in potato crop yields cv. Atlantic was ascribed to improved water holding capacity, enhanced cation exchange capacity, enhanced nutrient retention, and biochar's ability to decrease bulk density.

Upadhyay *et al.* (2020) evaluated the response of five types of biochar (*Lantana camara*, *Ipomoea carnea* var. *fistulosa*, rice husk, sawdust, no biochar) on growth and yield attributes of potato in rainfed areas of two different environments (Jiri in 2018 and Pawati in 2019) of Nepal. The popular early maturing potato variety 'Desiree' was used in the experiment. The results revealed that the total yield and marketable yield of potato varied with biochars types. The potato tuber yield was found higher and red ants' infestation was lower in plots applied with biochars as compared to control plots (without biochars). At Jiri in 2018, among the plant characteristics, significant differences were observed for ground cover, plant height and the number of main stems per plant. The differences were also observed for the percentage of the number of undersized tubers, percentage of the weight of oversize tubers and weight of tubers per plant, total yield, yield loss by red ants and marketable yield. Plant uniformity, per cent of the weight of undersized tubers, number of seed size tubers, the weight of seed size tubers, number of oversize tubers and number of tubers per plant remained statistically non-significant. The effect of no biochar was greater on ground cover followed by *Ipomoea carnea* whereas all biochars had similar but greater positive effect on plant height and the number of main stems per plant compared to the effect of no biochar. The minimum percentage of the number of undersized tubers was recorded in the plots treated with *Lantana camara* biochar. The percentage of the weight of oversize tubers was higher in biochar-added plots compared no biochar-added plots except rice husk biochar applied plots. Weight of tubers per plant was greater in biochar treated plots compared to no biochar. Among the biochars, biochar produced from *Lantana camara* produced a significantly greater weight of tubers per plant compared to other biochars. Biochars were also effective for increasing total yield compared to no biochar. However, the influence of all biochars was similar for total yield. Yield loss by red ants was less in the plots treated with *Lantana camamra* and rice husk biochars. Marketable yield was higher in biochar-added plots showing *Lantana camara* biochar the most effective to produce marketable yield followed by rice husk and sawdust biochar. At Pawati in 2019, significant differences were observed for ground cover, plant height and the number of main stems per plant. The differences were also observed for the percentage of the number of undersized tubers, percentage of the weight of undersized tubers, number of tubers per plant, the weight of tubers per plant, total yield, yield loss by red ants and marketable yield. Plant uniformity, percentage of the number of seed size tubers, the weight of seed size tubers, number of oversize tubers and weight of oversize tubers remained non-significant. The effect of no biochar was greater on ground cover and plant height whereas all biochars had similar but greater positive effect on the number of main stems per plant compared to the effect of no biochar. The minimum percentage of the number of undersized tubers and the percentage of the weight of undersized tubers was recorded in the plots treated with *Lantana camara* biochar. *Lantana camara* biochar also produced the highest number of tubers per plant and weight of tubers per plant. The effects of *Lantana camara*, sawdust and rice husk biochars were greater on total yield. Yield lossless in biochar-added plots compared to no biochar. Among the biochars, *Lantana camara* showed less yield loss by red ants followed by rice husk and sawdust biochar. Biochars were also beneficial for producing marketable yield showing *Lantana camara* biochar the most effective to produce marketable yield followed by sawdust and rice husk biochar. The use of biochars derived from *Lantana camera* produced the highest number of tubers (6.1 tubers plant^{-1}), the greatest weight of tubers (286.1 g plant^{-1}) and the least damage of red ants on tubers (4.7%) followed by sawdust (6.0 tubers plant^{-1}, 263.6 g tuber weight plant^{-1} and 7.8% damaged tubers by red ants). The findings provide new information on the understanding of biochar effect on increased marketable yield of potato in rainfed lands by reducing damage from red ants. Laboratory analysis of biochar showed that the biochar produced from *Lantana camara* L. contained higher water holding capacity, phosphorus and total nitrogen than the other biochars. Total ash, potassium and electrical conductivity were higher in sawdust biochar compared to others. The pH value was the greatest in the biochar produced from *Ipomoea carnea* var. *fistulosa*.

Nzediegwu *et al.* (2019) investigated the effects of biochar, produced from plantain peel, on the yield of potatoes (*Solanum tuberosum* L.) irrigated with wastewater in two consecutive seasons. The treatments were (i) wastewater with biochar, (ii) wastewater without biochar, and (iii) freshwater without biochar. The plant health parameters (e.g., photosynthesis rate) varied with time but were not affected by biochar amendment. Also, the total fresh tuber weights as well as the total number of tubers were similar in all treatments although the biochar showed a significant positive effect on the pH and the cation exchange capacity of the soil. Thus, it was concluded that application of the plantain peel biochar as soil amendment showed no significant effect on the yield of potatoes irrigated with wastewater.

Meilin and Rubiana (2018) stated that high intensity of disease infection and the intensive use of fertilizers and pesticides cause saturated fertilizer and pesticide to the land. Remediation using biochar rice husk is one of the technology to decrease fertilizer and pesticide residue. The diversity of soil insects can be used as bioindicators because of their existence depends on soil structure and condition. This study was aimed to study the diversity and structure communities of soil insect in potatoes on difference husk rice biochar application. The sampling of soil insects was done on potato farmer's land with four treatments i.e. 1) Control (using the farmer's way that only with basic fertilizer before planting); 2) Trichokompos 10 tons / ha; 3) Trichokompos 10 tons / ha + Biochar / rice husk charcoal 1 ton / ha; 4) Trichokompos 10 ton / ha + Biochar / rice husk charcoal 2 ton / ha. Biochar was produced in a traditional way made from raw rice husks. The results showed that biochar application had significant effect on the number of soil insect species. The soil insect species composition pattern also showed significant differences between the four treatments. The higher rice husk biochar dosage was showed fewer abundances than some herbivorous insects' species. The structure of insect community showed the composition of soil insects dominated by herbivorous insects' species at control, and trichokompos + rice husk biochar treatments showed soil insect composition dominated by insects omnivorous, detrivor, parasitoid and predator role. This mean that the application of biochar affects the number of insects' species and plays a role in the formation of soil insect diversity beta patterns.

Delisle (2017) carried out this study to determine the effects of biochar type and biochar application rate on potato crop response and on physico-chemical indicators of soil quality in a potato cropping system. The treatments were an untreated control and a factorial combination of two biochar products (Airex and Maple Leaf), amended at two application rates (10 and 20 t ha^{-1}). Maple Leaf biochar was produced from unprocessed hardwood (82% maple, 18% beech logs). Airex biochar was produced from softwood (75% spruce and 25% fir) sawdust. Potato tuber yield at harvest did not differ significantly among biochar treatments, or when biochar type or application rate were considered, compared to the control treatments. Results from this experiment suggest that wood-based biochars that are not manufactured to address specific soil quality issues will affect soil quality in a manner similar to other organic amendments (increase the pH, lower bulk density, increase aggregate stability, and improve the concentration of some soil nutrients). It was suggested that biochar will not necessarily increase yield in a well-managed potato cropping system.

Liu *et al.* (2017) carried out a study to explore interactive effects of biochar with Arbuscular mycorrhizal fungi (AMF), P fertilization levels and irrigation strategies on growth of potato plants. Potato plants were amended with wood biochar of 0.74% w/w (B+) or not (B−), fertilized with phosphorus of 0.11 mg P g^{-1} soil (P1) or not (P0), irrigated with full irrigation (FI) or partial root-zone drying irrigation (PRD) and inoculated with AMF of *Rhizophagus irregularis* (M+) or not (M−) in split-root pots in a sandy loam soil. Two biochar levels (B+ and B−) were applied: B+, in which the topsoil layer of each pot was supplemented with biochar 40.2 g pot^{-1} (20-ton ha^{-1}, equal to a rate of 0.74% w/w) before packing; and B−, the control without biochar application. Potato plants which were amended with wood biochar (B+) significantly decreased plant biomass production except under P0 FI M−, where B+ increased plant biomass. This growth stimulation was counteracted by treatments of P1, PRD and M+. B+ significantly decreased plant leaf area, P and N uptake and WUE, but had no significant effect on root biomass and soil pH. The positive plant growth response to AMF was substantially reduced by biochar amendment. The wood biochar had no adsorption for mineral N, and it had 0.96% adsorption for mineral P in aqueous solution. The results suggested that the negative effect of wood biochar application on plant growth may due to the reduced plant uptake of P and N and the possibility of phytotoxic effects of wood biochar on potato growth. It was concluded that the wood biochar used in current study had negative impact on plant growth and P/N uptake and it is not recommendable to apply this wood biochar to mycorrhizal agro-system, to soil fertilized with high rate of P or to soil suffering water deficiency.

Jay *et al.* (2015) determined the impact of biochar, as a supplement, on soil nutrient availability and yields for field-grown spring barley, strawberry and potato crops within commercial management systems in a temperate environment. Biochar was produced from predominantly sweet chestnut (*Castanea sativa*) [and species *Acer*, *Fraxinus, Fagus* and *Quercus*] wood, was incorporated into a sandy loam soil at 0, 20 and 50 t ha^{-1} as a supplement to standard crop management practice. Biochar had no effect on shoot height, leaf growth rate (4.4, 4.3 and 4.6 cm d^{-1} between 18 to 29 June) or tuber yield of potato. Mean number of class 1 tubers was 10.8, 13.1 and 10.9 plant^{-1}, and weighed 1.81, 2.14 and 1.85 kg (FW) for the 0, 20 and 50 t ha^{-1} biochar treatments respectively. Estimated yield of tubers hectare^{-1} was 70.0, 82.8 and 71.6 t for the 0, 20 and 50 t ha^{-1} biochar rates respectively, which was similar to commercial practice (i.e. 69 t ha^{-1}). There were no treatment effects on weight, or number of tubers in the waste category. *Streptomyces scabies* (common scab) infection increased with biochar incorporation with 12, 14 and 21 potatoes per 10 plants affected for the 0, 20, 50 t ha^{-1} treatments respectively. There were no treatment effects on tuber firmness. These experiments showed a single rotational application of biochar to soil had no effect on the growth or harvest yield of potato. Heavy metal analysis revealed small concentrations in the biochar (i.e. < 10 μg g^{-1} biochar), with the largest levels for Ni, V and Cu. Potentially biochar toxic metal contamination was within acceptable guidelines. The absence of yield promotion is linked to soil fertility status and supports the notion that well managed fertile temperate soils will have limited response to biochar.

Upadhyay (2015) mentioned that the nutrient content, ash content and other properties greatly differed when biochars were produced from Sugarcane Trash and Green Wastes.

Upadhyay *et al.* (2014) reported that there was no consistent effect of green waste biochar on growth of true potato seedlings and node cuttings of true potato seedlings when biochar was applied to sand medium nourished with additional nutrient solution.

Kochanek (2014) concluded that nutrients and other properties may vary with the type of biochar.

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experimental materials and methods are described below:

3.1 Experimental period

The pot experiment was conducted at the Agronomy Research Field, Sher-e-Bangla Agricultural University during the period from 3rd November, 2020 to 28th February, 2021.

3.2 Geographical location

The experimental area was situated at 23°77′N latitude and 90°33′E longitude at an altitude of 8.6 meter above the sea level.

3.3 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of “Modhupur Tract”, AEZ-28. This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as ‘islands’ surrounded by floodplain. The experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

3.4 Climate of the experimental site

Experimental site was located in the sub-tropical monsoon climatic zone, set a parted by winter during the months from November 2020 to February 2021. Plenty of sunshine and moderately low temperature prevails during experimental period, which is suitable for potato growing in Bangladesh. The weather data during the study period at the experimental site are shown in Appendix II.

3.5 Soil

Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The soildata during the study period at the experimental site are shown in Appendix III.

3.6 Experimental treatments

The experiment consisted of three (3) factors such as form of nitrogen, source of potassium and source of biochar. The treatments were as follows:

Factor A: Form of nitrogen (2)

i. N_1: Prilled urea and

ii. N_2: Urea Super Granule (USG).

Factor B: Source of potassium (3)

i. K_1: KCl,

ii. K_2: KH_2PO_4 and

iii. K_3: K_2SO_4.

Factor C: Source of biochar (3)

i. B_1: Maize cob biochar,

ii. B_2: Mahogany biochar and

iii. B_3: Cowdung + Sawdust biochar.

Treatment combinations were as $N_1K_1B_1$, $N_1K_1B_2$, $N_1K_1B_3$, $N_1K_2B_1$, $N_1K_2B_2$, $N_1K_2B_3$, $N_1K_3B_1$, $N_1K_3B_2$, $N_1K_3B_3$, $N_2K_1B_1$, $N_2K_1B_2$, $N_2K_1B_3$, $N_2K_2B_1$, $N_2K_2B_2$, $N_2K_2B_3$, $N_2K_3B_1$, $N_2K_3B_2$ and $N_2K_3B_3$.

3.7 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Total 54 unit pots were made for the experiment with 18 treatments. Each pot was of required size (Appendix IV).

3.8 Planting material

The planting materials comprised the certified seed tubers of one potato variety. The variety was BARI Alu-29 (Courage).

3.9 Collection of tuber

The variety of seed potato (certified seed) was collected from, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur and from BARI sub-station. Individual weight of seed potato was 60–70 g.

3.10 Crop management

3.10.1 Preparation of tuber

Collected seed tubers were kept in room temperature to facilitate sprouting. Finally sprouted potato tubers were used as planting material.

3.10.2 Pot preparation

The experimental pots (Length = 10.50 and Diameter = 9.50 inch) were first filled at 3rd November 2020 with 10 kg soil. Potted soil was brought into desirable fine tilth by hand mixing. The stubble and weeds were removed from the soil and then biochar was mixed. The final pot preparation was done on 9th November 2020. The soil was treated with insecticides (cinocarb 3G @ 4 kg ha^{-1}) at the time of final pot preparation to protect young plants from the attack of soil inhibiting insects such as cutworm and mole cricket.

3.10.3 Manure and fertilizer application

The experimental soil was fertilized with following dose of Triple Superphosphate (TSP), gypsum, zinc sulphate and boric acid.

Fertilizers	Dose (kg ha^{-1})
TSP	150
Gypsum	120
Zinc Sulphate	10
Boric Acid	10

Source: Mondal *et al.*, 2011.

Total amount of triple superphosphate, gypsum, zinc sulphate, magnesium sulphate, boric acid was applied in the time of pot preparation.USG was applied in base placement and prilled urea also used in three installment.

3.10.4 Biochar application

The different types of biochar was applied at 7 days before planting as per treatment.

3.10.5 Planting of seed tuber

The well-sprouted healthy and uniform sized potato tubers were planted according to treatment. Seed potatoes were planted in such a way that potato does not go much under soil or does not remain in shallow. On an average, potatoes were planted at 4–5 cm depth in soil on 18th November 2020.

3.11 Intercultural operations

3.11.1 Weeding

Weeding was necessary to keep the plant free from weeds. The newly emerged weeds were uprooted carefully from the pot after complete emergence of sprouts and afterwards when necessary.

3.11.2 Irrigation

Just after full emergence the crop was irrigated by hand Sprinkler at 15 days after planting (DAP) so that uniform growth and development of the crop was occurred and moisture status of soil retain as per requirement of plants. The second, third and fourth irrigation were done at 25, 45 and 65 DAP, respectively.

3.11.3 Mulching

Mulching were necessary to keep the pots to conserve soil moisture. Natural mulching was done for breaking the surface crust as and when needed.

3.11.4 Earthing up

Earthing up process was done in the pot at two times, during crop growing period. First was done at 35 DAP and second was at 50 DAP.

3.11.5 Plant protection measures

Dithane M-45 was applied at 30 and 60 DAP as a preventive measure for controlling fungal infection. Ridomil Gold (0.25%) was sprayed at 45, 55, 65 and 75 DAP to protect the crop from the attack of late blight.

3.11.6 Haulm cutting

Haulm cutting was done at 11 February 2021 at 90 DAP, when 40–50% plants showed senescence and the tops started drying. After haulm cutting the tubers were kept under the soil for 7 days for skin hardening. The cut haulm was collected, bagged and tagged separately for further data collection.

3.11.7 Harvesting of potatoes

Harvesting of potato was done on 15th February 2021 at 7 days after haulm cutting. The potatoes of each pot were separately harvested, bagged and tagged and brought to the laboratory. The yield of potato hill^{-1} was determined in gram. Harvesting was done manually by hand.

3.12 Recording of data

The following data were recorded during experimentation period:

i. Days to emergence (DAP),
ii. Plant height (cm),
iii. Number of total tubers plant^{-1},
iv. Average tuber weight plant^{-1} (g),
v. Weight of tubers plant^{-1} (g),
vi. Weight of marketable potato plant^{-1} (g),
vii. Weight of non-marketable potato plant^{-1} (g),
viii. Specific Gravity (g cm^{-3}),
ix. Potato firmness (%),
x. Total soluble solid content of potato,
xi. Tuber dry matter (%),
xii. Starch content (mg g^{-1} FW),
xiii. Reducing sugar (mg g^{-1} FW) and
xiv. Grading of potato (g plant^{-1}).

3.13 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

3.13.1 Days to emergence

After sowing the potato tuber keenly observed the first emergence in each pot twice in a day (morning and afternoon).

3.13.2 Plant height

Plant height refers to the length of the plant from ground level to the tip of the tallest stem. It was measured at an interval of 15 days starting from 35 DAP until 65 DAP.

3.13.3 Number of total tubers plant^{-1}

Number of total tubers plant^{-1} was counted at harvest. Tuber numbers plant^{-1} was recorded by counting all tubers from each plant.

3.13.4 Average tuber weight plant^{-1}

Average tuber weight was measured by using the following formula-

$$\text{Average tuber weight (g)} = \frac{\text{Yield of tuber pot}^{-1}}{\text{Number of tubers pot}^{-1}}$$

3.13.5 Weight of tubers plant^{-1}

Tubers of each pot were collected separately from which yield of tuber plant^{-1} was recorded in gram.

3.13.6 Marketable tuber and non-marketable tuber (by weight)

Based on weight, the tubers have been graded into marketable tuber (> 20 g) and non-marketable tuber (<20 g) and converted to percentages (Hussain, 1995).

3.13.7 Tuber dry matter

The samples of tuber were collected from each treatment. After peeling off the tubers, the samples were dried in an oven at 72˚C for 72 hours. Dry matter content was calculated as the ratio between dry and fresh weight and expressed as a percentage.

3.13.8 Starch

The residue remained after extraction for sugar, was washed for several times with water to ensure that there was no more soluble sugar in the residues. After that, using tap water and mark up to 250 ml beaker. Stir well on a magnetic stirrer. Then 0.5 mL solution was taken from the beaker into 3 test tubes. 0.5 mL was taken during the stirring. Then boiling the test tubes for 10 min at 100˚C. 1 mL AmyloglucosiDAPe solution was added and mix well and heat at 50–60˚C for 2 hrs in hot water. After cooling, a 0.5 mL Copper solution was added and mix well, heat at 100C for 10 min., cool in tap water again added 0.5 mL Nelson solution, mix well and added 7 mL distilled water, mix well (Final volume = 9.5 mL), and measure the absorbance at 660 nm (Abs4). Calculate starch content using the glucose standard curve.

3.13.9 Reducing sugar

3.13.9.1 Extraction of sugar

For the analysis of sugar content like glucose and sucrose potato flesh was extracted. For each extraction, 1.0 g fresh sample of chopped potato was taken from uniform tuber samples. Sugar was extracted using 5ml of 80% ethanol heat at 80°C for 30 min using a dry block heat bath and the extracts was centrifuged at 5000 rpm for 10 min and decanted the supernatant. 8mL 80% EtOH, was added and it was repeated 4 and 5 for 3 times in total. All the supernatants were mixed well and the final volume was made up to 25 mL using 80% EtOH. The residue is used for starch analysis.

3.13.9.2 Reducing sugar determination (glucose)

Reducing sugar was estimated by the photometric adaptation of the Somogyi method with some modification. Copper solution and Nelson reagent and standard glucose solution (0.5 mL) were used. 3 mL sample solution was put into a small glass container. Then it was completely dried up on an electric heater, 3 mL distilled water was added, and then mixed well. Then .5ml solution was taken from this, two times and was put in different test tubes. In one test tube, 0.5 mL Copper solution was added and was boiled (100°C) for 10 min. After boiling, immediately the test tube was cooled in tap water. 0.5 mL Nelson reagent in the test tube was added, and mixed them well. After 20 min, 8 mL distilled water was added and mixed well (Total volume = 9.5 mL). After that the absorbance at 660 nm (Abs1) was measured and the reducing sugar content was calculated.

3.13.10 Grading of tuber (g plant^{-1})

Tubers harvested from each treatment were graded by weight based on diameter into the 30–45 mm and 45-75 mm and converted to g plant^{-1} and percentages (Hussain, 1995). A special type of frame (potato riddle) was used to grading of tuber.

3.13.11 Specific Gravity (g cm^{-3})

Specific gravity was measured by using the following formula (Gould, 1995)-

$$\text{Specific gravity (g cm}^{-3}\text{)} = \frac{\text{Weight in air}}{\text{Weight in water at } 4^0 \text{ C}}$$

3.13.12 Potato firmness

Fries and crisp texture measurements were performed at room temperature by a puncture test performed in a Texture Analyzer (Sun Scientific Co. Ltd, Japan) equipped with a wedge probe imitating front teeth. Maximum Force (MF) was defined as the force at which the wedge penetrates the outer layer of the surface of the fried potato fries and crisps slices (Segnini *et al.*, 1999).

3.13.13 Total soluble solids (TSS)

TSS of harvested tubers was determined in a drop of potato juice by using Hand Sugar Refractometer "ERMA" Japan, Range: 0–32% according to (AOAC, 1990) and expressed as BRIX value.

3.14 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Least Significant Different (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of nitrogen form, source of potassium and biochar on yield and quality of potato. The results obtained from the study have been presented, discussed and compared in this chapter through tables and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix IV to IX. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings. The analytical results have been presented in Table 1 through Table 15 and Figure 1 through Figure 9.

4.1 Days to emergence (DAP)

4.1.1 Effect of urea form

Days to emergence was non-significantly influenced by the application of different urea form (Appendix IV and Table 1). The Urea Super Granule (USG) treatment (N_2) took the numerically maximum (13.93 days) for emergence whereas, the minimum (13.04 days) was taken by N_1 (Prilled urea) treatment.

Table 1. Effect of urea form on days to emergence of potato seedlings

Treatments	Days to emergence
N_1	13.04
N_2	13.93
LSD $_{(0.05)}$	**NS**
CV (%)	**15.30**

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
NS = Non-Significant

4.1.2 Effect of different source of potassium

Non-significant variation of days to emergence was found due to different source of potassium (Table 2 and Appendix IV).Numerically the minimum days to emergence (14.39 days) was required in K_3 (K_2SO_4) treatment and numerically the maximum (12.83 days) was recorded in K_1 (KCl) treatment.

Table 2. Effect of potassium source on days to emergence of potato seedlings

Treatments	Days to emergence
K_1	12.83
K_2	13.22
K_3	14.39
LSD $_{(0.05)}$	**NS**
CV (%)	**15.31**

Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
NS = Non-Significant

4.1.3 Effect of different source of biochar

Days to emergence was non-significantly influenced by the different source of biochar (Table 3 and Appendix IV). Results revealed that the Mahogany biochar (B_2) took numerically the maximum (13.94 days) for emergence whereas, the numerically minimum (13.22 days) was taken by Cowdung + Sawdust biochar (B_3) treatment.

Table 3. Effect of different biochar on days to emergence of potato seedlings

Treatments	Days to emergence
B_1	13.28
B_2	13.94
B_3	13.22
LSD $_{(0.05)}$	**NS**
CV (%)	**15.31**

Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant

4.1.4 Interaction effect of urea form, source of potassium and biochar

Interaction effect of nitrogen form, source of potassium and biochar significantly influenced the days taken to emergence of potato tubers (Table 4 and Appendix IV). The minimum duration for emergence (10.00 days) was recorded from the combination of $N_1K_1B_3$ (nitrogen: Prilled urea, Potassium: KCl and biochar: Cowdung + Sawdust biochar) treatment which was statistically similar to $N_1K_1B_2$ (11.67 days), $N_2K_2B_1$ (12.33 days), $N_1K_1B_1$ (12.67 days), $N_1K_2B_3$ (12.67 days), $N_1K_2B_1$ (13.00 days), $N_2K_3B_1$ (13.00 days) and $N_2K_2B_2$ (13.33 days) treatment. On the other hand, the maximum duration (15.33 days) was recorded from the combination of $N_2K_1B_1$ (nitrogen: Urea Super Granule (USG), potassium: KCl and biochar: Maize cob biochar) treatment which was statistically similar to $N_2K_1B_2$ (15.00 days), $N_1K_3B_1$ (14.67 days), $N_2K_3B_3$ (14.67 days), $N_1K_3B_2$ (14.33 days), $N_1K_3B_3$ (14.33 days), $N_1K_2B_2$ (14.00 days), $N_2K_2B_3$ (14.00 days), $N_2K_3B_2$ (14.00 days) and $N_2K_1B_3$ (13.67 days) treatment. Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Fertilizer affects the plant when plant had root. Roots are being developed 10-15 days after emergence. This trend was supported by the trends of Eugenia (2008).

Table 4. Combined effect of urea form, potassium source and different biochar on days to emergence of potato seedlings

Treatment combinations	Days to emergence
$N_1K_1B_1$	12.67 a-c
$N_1K_1B_2$	11.67 bc
$N_1K_1B_3$	10.00 c
$N_1K_2B_1$	13.00 a-c
$N_1K_2B_2$	14.00 ab
$N_1K_2B_3$	12.67 a-c
$N_1K_3B_1$	14.67 ab
$N_1K_3B_2$	14.33 ab
$N_1K_3B_3$	14.33 ab
$N_2K_1B_1$	15.33 a
$N_2K_1B_2$	15.00 ab
$N_2K_1B_3$	13.67 ab
$N_2K_2B_1$	12.33 a-c
$N_2K_2B_2$	13.33 a-c
$N_2K_2B_3$	14.00 ab
$N_2K_3B_1$	13.00 a-c
$N_2K_3B_2$	14.00 ab
$N_2K_3B_3$	14.67 ab
LSD $_{(0.05)}$	**3.42**
CV (%)	**15.31**
N × K	**NS**
N × B	**NS**
K × B	**NS**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar;
NS = Non-Significant

4.2 Plant height

4.2.1 Effect of urea form

The plant height of potato was measured at 35, 50 and 65 DAP. It was evident from Figure 1 and Appendix V that the height of plant was non-significantly influenced by urea form at all the sampling dates. At 35, 50 and 65 DAP, Urea Super Granule (USG) treatment showed numerically the highest plant (50.23,
60.02 and 62.33 cm, respectively) whereas, the numerically shortest plant (45.24, 54.99 and 57.96 cm, respectively) was found from Prilled urea treatment. Plant height of a crop depends on the plant vigor, cultural practices, growing environment and agronomic management. In the present experiment since potato was grown in the same environment and were given same cultural practices except nitrogen fertilization. So, the variation of plant height might be due to the effect different form of nitrogen fertilization.

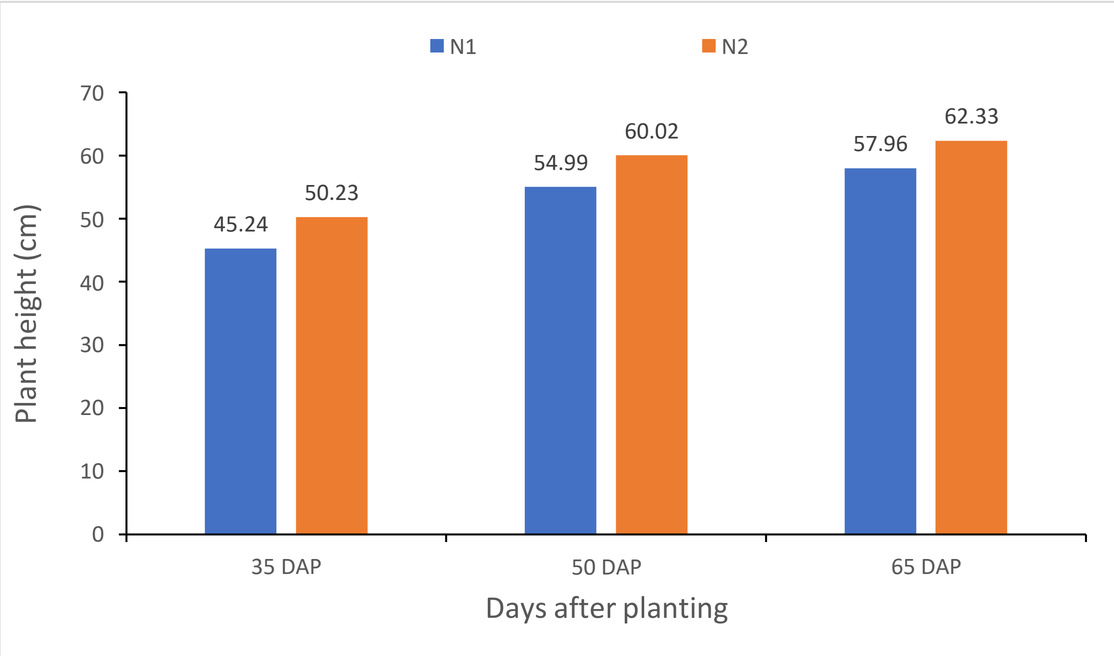

Figure 1. Effect of urea form on the plant height (cm) of potato at different days after planting (LSD value = NS, NS and NS at 35, 50 and 65 DAP, respectively)

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG); NS = Non-Significant

4.2.2 Effect of potassium sources

The plant height of potato was measured at 35, 50 and 65 DAP. It was evident from Figure 2 and Appendix V that the height of plant was non-significantly influenced by source of potassium at all the sampling dates. At 35, 50 and 65 DAP, KCl fertilizer (K_1) application showed numerically the longest plant (51.30, 60.97 and 64.17 cm, respectively) and numerically the shortest plant (43.83, 54.75 and 56.86 cm, respectively) was found from K_2SO_4 fertilizer (K_3) application. The result obtained from the present study was similar with Rahman *et al.* (2002) and Lu (2003).

4.2.3 Effect of different sources of biochar

Plant height due to different sources of biochar applications was non-significantly influenced at days after planting (DAP) except 65 DAP (Figure 3 and Appendix V). At 35 and 50 DAP,numerically the longest plant (53.51 and 62.83 cm, respectively) was recorded from B_1 (Maize cob biochar) treatment whereas, numerically the shortest plant (42.32 and 50.98 cm, respectively) was recorded from B_3 (Cowdung + Sawdust biochar) treatment. At 65 DAP, the longest plant (66.69 cm) was recorded from B_1 (Maize cob biochar) treatment which was statistically identical to B_2 (60.42 cm) whereas, the shortest plant (53.32 cm) was recorded from B_1 (Cowdung + Sawdust biochar) treatment. The results were conformity with the findings of Afrina (2017).

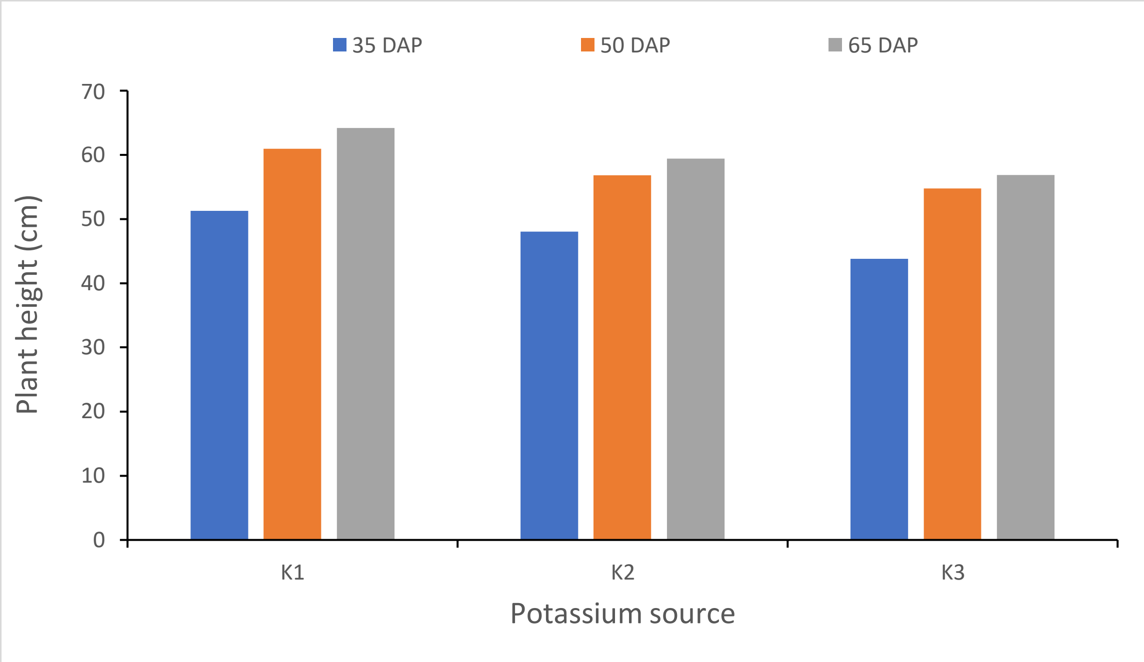

Figure 2. Effect of potassium source on the plant height (cm) of potato at different days after planting (LSD value = NS, NS and NS at 35, 50 and 65 DAP, respectively)

Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4; NS = Non-Significant

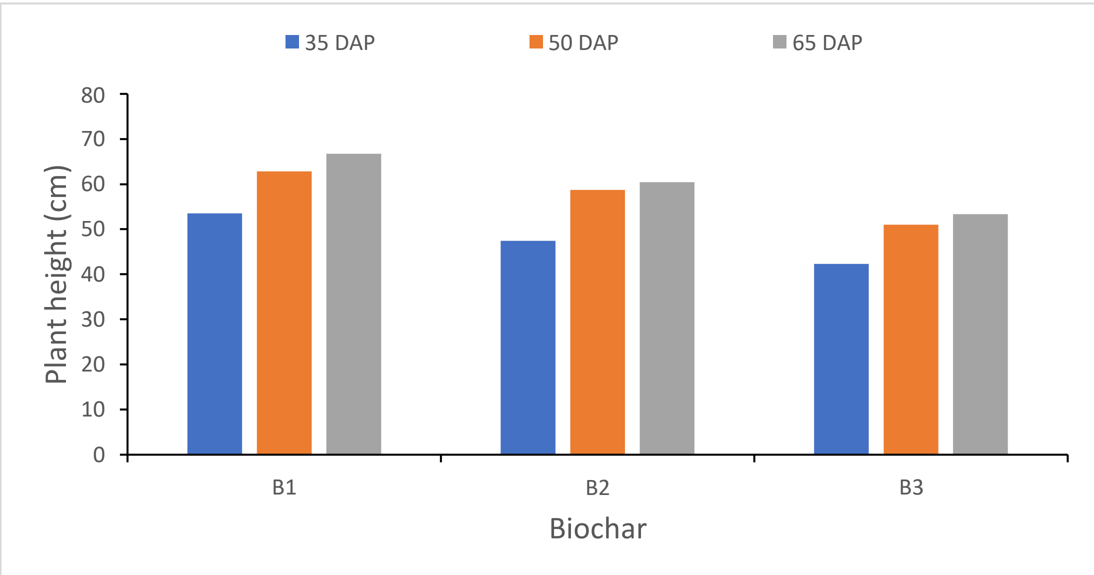

Figure 3. Effect of biochar on the plant height (cm) of potato at different days after planting (LSD value = NS, NS and 13.25 at 35, 50 and 65 DAP, respectively)

Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar; NS = Non-Significant

4.2.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of plant height was found due to interactional effect of urea form, potassium source and biochar source in all the studied durations (Table 5 and Appendix V). At 35 DAP, the tallest plant (59.27 cm) was measured from $N_2K_1B_1$ treatment combination which was statistically similar to $N_1K_1B_1$ (56.53 cm), $N_2K_2B_1$ (53.33 cm), $N_1K_2B_1$ (52.07 cm), $N_2K_3B_1$ (52.07 cm), $N_2K_2B_2$ (51.17 cm), $N_2K_2B_3$ (50.83 cm), $N_1K_1B_2$ (49.50 cm), $N_2K_3B_2$ (48.60 cm) and $N_1K_1B_3$ (48.37 cm) treatment and the shortest plant (26.63 cm) from $N_1K_3B_3$ treatment combination. At 50 DAP, the lattest plant (70.17 cm) was measured from $N_2K_1B_1$ treatment combination which was statistically similar to $N_2K_2B_1$ (65.17 cm), $N_2K_1B_2$ (64.83 cm), $N_1K_1B_1$ (62.33 cm), $N_2K_3B_1$ (61.83 cm), $N_1K_2B_1$ (61.00 cm) and $N_2K_2B_2$ (60.67 cm) treatment whereas, the shortest plant (45.67 cm) from $N_1K_3B_3$ treatment combination which was statistically similar to $N_1K_2B_3$ (45.90 cm), $N_2K_3B_3$ (52.00 cm), $N_2K_2B_3$ (51.83 cm), $N_2K_1B_3$ (54.33 cm), $N_1K_1B_3$ (56.17 cm), $N_1K_2B_2$ (56.17 cm), $N_1K_3B_1$ (56.50 cm), $N_1K_1B_2$ (58.00 cm) and $N_2K_3B_2$ (59.33 cm) treatment combination. At 65 DAP, the longest plant (72.17 cm) was measured from $N_2K_1B_1$ treatment combination which was statistically similar to $N_1K_1B_1$ (71.67 cm), $N_2K_2B_1$ (67.33 cm), $N_2K_1B_2$ (65.67 cm), $N_1K_2B_1$ (65.33 cm), $N_2K_3B_1$ (64.50 cm), $N_2K_2B_2$ (63.33 cm) and $N_1K_1B_2$ (62.20 cm) treatment whereas, the shortest plant (47.67 cm) from $N_1K_3B_3$ treatment combination which was statistically similar to $N_1K_2B_3$ (48.73 cm), $N_1K_3B_2$ (54.00 cm), $N_2K_3B_3$ (55.00 cm), $N_2K_2B_3$ (55.17 cm), $N_1K_1B_3$ (56.33 cm), $N_1K_2B_2$ (56.50 cm), $N_2K_1B_3$ (57.00 cm), $N_1K_3B_1$ (59.17 cm) and $N_2K_3B_2$ (60.83 cm) treatment combination.

Table 5. Combined effect of urea form, potassium source and different biochar on plant height of potato(cm) at different data recording intervals

Treatment combinations	35 DAP	50 DAP	65 DAP
$N_1K_1B_1$	56.53 ab	62.33 ab	71.67 a
$N_1K_1B_2$	49.50 a–d	58.00 a-c	62.20 a-c
$N_1K_1B_3$	48.37 a–d	56.17 a-c	56.33 b-d
$N_1K_2B_1$	52.07 a-c	61.00 ab	65.33 a-c
$N_1K_2B_2$	42.27 cd	56.17 a-c	56.50 b-d
$N_1K_2B_3$	38.77 d	45.90 c	48.73 d
$N_1K_3B_1$	47.80 b-d	56.50 a-c	59.17 a–d
$N_1K_3B_2$	45.20 b-d	53.17 bc	54.00 cd
$N_1K_3B_3$	26.63 e	45.67 c	47.67 d
$N_2K_1B_1$	59.27 a	70.17 a	72.17 a
$N_2K_1B_2$	47.53 b-d	64.83 ab	65.67 a-c
$N_2K_1B_3$	46.60 b-d	54.33 bc	57.00 b-d
$N_2K_2B_1$	53.33 a-c	65.17 ab	67.33 ab
$N_2K_2B_2$	51.17 a-c	60.67 ab	63.33 a-c
$N_2K_2B_3$	50.83 a-c	51.83 bc	55.17 b-d
$N_2K_3B_1$	52.07 a-c	61.83 ab	64.50 a-c
$N_2K_3B_2$	48.60 a–d	59.33 a-c	60.83 a–d
$N_2K_3B_3$	42.70 cd	52.00 bc	55.00 b-d
LSD ($_{0.05}$)	**11.33**	**14.49**	**13.25**
CV (%)	**14.34**	**15.22**	**13.30**
N × K	*	**NS**	**NS**
N × B	*	*	*
K × B	*	*	*

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant
* indicates significant at 5% level of probability

4.3 Number of tuber plant^{-1}

4.3.1 Effect of urea form

Number of tubers plant^{-1} non-significantly influenced by the urea form (Appendix VI and Table 6).Numerically the maximum number of tubers plant^{-1} (8.22) was recorded from Urea Super Granule (USG) (N_2) treatment and the minimum (8.04) was found from the Prilled urea (N_1) treatment. The result obtained from the present study was similar with Hossain (2017).

4.3.2 Effect of potassium sources

Number of tubers plant^{-1} significantly influenced by different potassium fertilizer (Appendix VI and Table 7). The maximum number of tubers plant^{-1} (8.61) was recorded from K_1 (KCl application) treatment. The minimum number of tubers plant^{-1} (7.67) was found from K_3 (K_2SO_4 application) treatment. The result obtained from the present study was similar with Qin (2003) and Rahman *et al.* (2002).

4.3.3 Effect of different sources of biochar

Number of tubers plant^{-1} significantly influenced by the different sources of biochar applications (Table 8 and Appendix VI). The maximum (8.95) number of tubers was produced from B_3 (Cowdung + Sawdust biochar) treatment whereas, the minimum (7.44) was produced from B_1 (Maize cob biochar) treatment. The results were in conformity with the findings of Afrina (2017).

4.3.4 Interaction effect of urea form, source of potassium and biochar

Interaction effect of urea form, source of potassium and biochar significantly influenced the days taken to number of tubers plant^{-1} (Table 9 and Appendix VI). The maximum tubers (9.67) was recorded from the combination of $N_2K_1B_3$ (nitrogen: Urea Super Granule (USG), Potassium: KCl fertilizer application and biochar: Cowdung + Sawdust biochar) treatment. On the other hand, the minimum tubers (6.33) was recorded from the combination of $N_1K_3B_1$ (nitrogen:

Prilled urea, potassium: K_2SO_4 fertilizer application and biochar: Maize cob biochar) treatment.

Table 6. Effect of urea form on yield attributes of potato

Treatments	Number of tubers plant^{-1}	Average weight of tuber plant^{-1}
N_1	8.04	37.40 a
N_2	8.22	36.34 b
LSD (0.05)	**NS**	**0.30**
CV (%)	**18.75**	**19.63**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
NS = Non-Significant

Table 7. Effect of potassium source on yield attributes of potato

Treatments	Number of tubers plant^{-1}	Average weight of tuber plant^{-1}
K_1	8.61 a	37.75 a
K_2	8.11 b	35.95 c
K_3	7.67 c	36.91 b
LSD (0.05)	**0.30**	**0.30**
CV (%)	**18.74**	**19.62**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4

Table 8. Effect of different biochar on yield attributes of potato

Treatments	Number of tubers plant^{-1}	Average weight of tuber plant^{-1}
B_1	7.44 c	39.77 a
B_2	8.00 b	35.93 b
B_3	8.95 a	34.92 c
LSD (0.05)	**0.30**	**0.30**
CV (%)	**18.75**	**19.62**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar

4.4 Average tuber weight plant^{-1}

4.4.1 Effect of urea form

The average tuber weight plant^{-1} varied significantly due to different urea form (Appendix VI and Table 6). The highest average tuber weight (37.40 g) was recorded from Prilled urea (N_1) treatment whereas, the lowest (36.34 g) was obtained from the Urea Super Granule (USG) (N_2) treatment. The results were supported by the findings of Azam *et al.* (2012).

4.4.2 Effect of potassium sources

The average weight of tuber varied significantly due to different potassium fertilizer application (Appendix VI and Table 7). The highest average weight of tuber (37.75 g) was recorded from KCl fertilizer application (K_1) treatment and the lowest (35.95 g) was obtained from KH_2PO_4 (K_2) fertilizer application treatment. The results were supported by the findings of Sobhani *et al.* (2002).

4.4.3 Effect of different sources of biochar

Average weight of tuber significantly varied among the different sources of biochar applications (Table 8 and Appendix VI). The highest average weight of tuber (39.77 g) was observed from B_1 (Maize cob biochar) while, the lowest average weight (34.92 g) was observed from B_3 (Cowdung + Sawdust biochar) treatment. The result obtained from the present study was dissimilar with Afrina (2017).

Table 9. Combined effect of urea form, potassium source and different biochar on yield attributes of potato

Treatment combinations	Number of tubers plant^{-1}	Average weight(g) of tuber plant^{-1}
$N_1K_1B_1$	7.33 h	40.99 b
$N_1K_1B_2$	8.67 d	36.92 f
$N_1K_1B_3$	9.00 c	34.78 ij
$N_1K_2B_1$	7.33 h	39.15 d
$N_1K_2B_2$	8.33 e	35.55 h
$N_1K_2B_3$	8.67 d	35.65 h
$N_1K_3B_1$	6.33 j	43.22 a
$N_1K_3B_2$	7.33 h	36.09 g
$N_1K_3B_3$	9.33 b	34.27 l
$N_2K_1B_1$	8.00 f	40.68 c
$N_2K_1B_2$	9.00 c	37.67 e
$N_2K_1B_3$	9.67 a	35.48 h
$N_2K_2B_1$	8.00 f	35.68 h
$N_2K_2B_2$	7.67 g	34.75 ij
$N_2K_2B_3$	8.67 d	34.93 i
$N_2K_3B_1$	7.67 g	38.88 d
$N_2K_3B_2$	7.00 i	34.61 jk
$N_2K_3B_3$	8.33 e	34.38 kl
LSD $_{(0.05)}$	**0.30**	**0.30**
CV (%)	**18.75**	**19.62**
N × K	*	**NS**
N × B	*	*
K × B	*	*

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant
* indicates significant at 5% level of probability

4.4.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of average weight of tuber was found due to interactional effect of urea form, potassium source and biochar source in all the studied durations (Table 9 and Appendix VI). The highest average weight (43.22 g) was measured from $N_1K_3B_1$ treatment (nitrogen: Prilled urea, Potassium: K_2SO_4 fertilizer application and biochar: Maize cob biochar) combination. On the other hand, the lowest average weight (34.27 g) from $N_1K_3B_3$ treatment (nitrogen: Prilled urea, Potassium: K_2SO_4 fertilizer application and biochar: Cowdung + Sawdust biochar) combination which was statistically similar to $N_2K_3B_3$ (34.38 g) treatment combination.

4.5 Weight of tubers pot^{-1} (g)

4.5.1 Effect of urea form

Urea form had significant effect on the weight of tubers pot^{-1} (Appendix VII and Figure 4). The highest weight of tuber (313.40 g pot^{-1}) was obtained from Urea Super Granule (USG) (N_2) treatment while, the minimum (276.17 g pot^{-1}) was found from the Prilled urea (N_1) treatment.

4.5.2 Effect of potassium sources

Source of potassium had significant effect on the weight of tubers pot^{-1} (Appendix VII and Figure 5). The maximum weight of tuber (317.89 g pot^{-1}) was obtained from KCl (K_1) treatment. On the other hand, the minimum weight of tuber (272.39 g pot^{-1}) was found from K_2SO_4 (K_3) treatment. Sobhani *et al.* (2002) supported these findings.

4.5.3 Effect of different sources of biochar

Different source of biochar had significant effect on the weight of tubers pot^{-1} (Appendix VII and Figure 6). Results revealed that, treatment B_1 (Maize cob biochar) produced highest weight of tuber hill^{-1} (31.61 g pot^{-1}) which was statistically identical to B_3 (299.93 g pot^{-1}) whereas, the lowest (272.84 g pot^{-1})

one was obtained from B_2 (Mahogany biochar) treatment. 21.56 % more weight of tuber was obtained from the plot treated with Maize cob biochar (B_1) than the plot treated with Mahogany biochar (B_2). The higher yield might be attributed to vigorous plant growth, more tuber plant^{-1} and large tuber size. Indawan *et al.* (2018) reported that tobacco biochar application increased storage root weight, storage root dry weight and storage root yield.

4.5.4 Interaction effect of urea form, source of potassium and biochar

Interaction effect of nitrogen form, source of potassium and biochar significantly influenced the days taken to weight of tubers pot^{-1} (Table 10 and Appendix VII). The highest weight of tubers (340.00 g pot^{-1}) was recorded from the combination of $N_2K_1B_1$ (nitrogen: Urea Super Granule (USG), Potassium: KCl fertilizer application and biochar: Maize cob biochar) treatment which was statistically identical to $N_2K_1B_3$ (339.00 g pot^{-1}) and similar to $N_2K_3B_1$ (332.67 g pot^{-1}) and $N_2K_2B_1$ (320.30 g pot^{-1}). On the other hand, the lowest weight of tubers (205.67 g pot^{-1}) was recorded from the combination of $N_1K_3B_2$ (nitrogen: Prilled urea, potassium: K_2SO_4 fertilizer application and biochar: Mahogany biochar) treatment.

4.6 Weight of marketable tuber

4.6.1 Effect of urea form

Weight of marketable potato pot^{-1} was significantly influenced by different urea form (Figure 4 and Appendix VII). The maximum (261.93 g pot^{-1}) marketable potato was found from N_2 (Urea Super Granule (USG)) treatment and the minimum (213.77 g pot^{-1}) was found from N_1 (Prilled urea) treatment. This variation might be due to change in tuber size under different urea form.

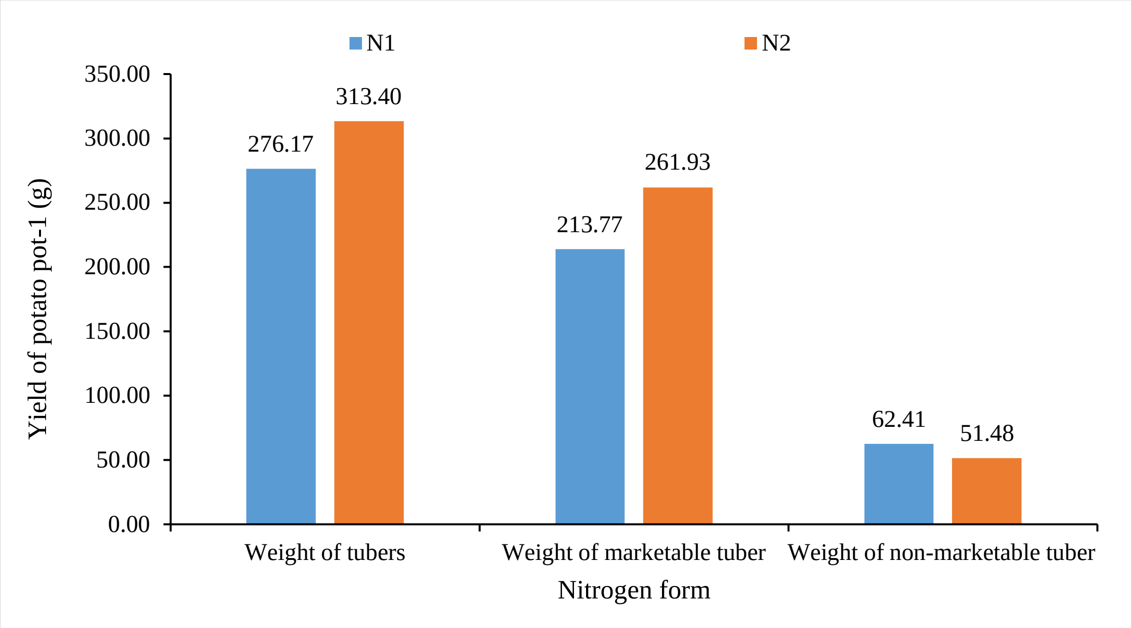

Figure 4. Effect of urea form on yield of potato pot^{-1} (LSD value = 21.53, 21.51 and NS, respectively)

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG); NS = Non-Significant

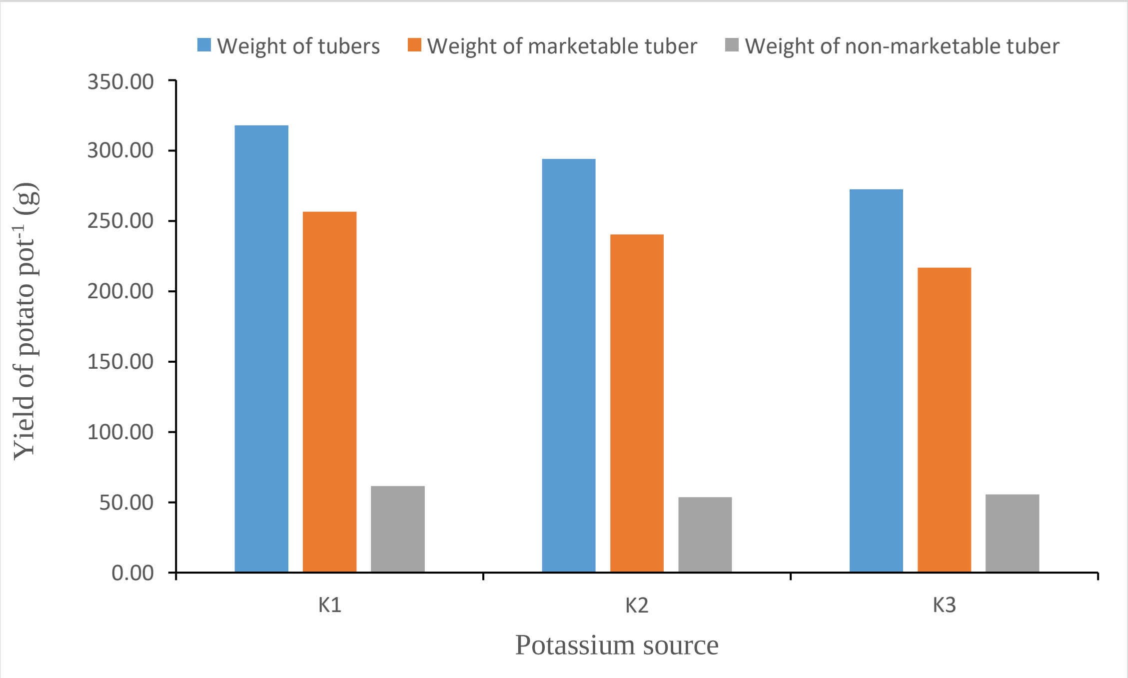

Figure 5. Effect of potassium source on yield of potato pot^{-1} (LSD value = 21.53, 21.54 and NS, respectively)

Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4; NS = Non-Significant

4.6.2 Effect of potassium sources

There was significant variation in marketable yield of potato pot^{-1} (Appendix VII and Figure 5). K_1 (KCl fertilizer application) treatment produced the maximum marketable yield (256.44 g pot^{-1}) of potato which was statistically similar to K_2 (240.44 g pot^{-1}) whereas, the minimum (216.69 g pot^{-1}) was produced by K_3 (K_2SO_4 fertilizer application) treatment.

4.6.3 Effect of different sources of biochar

Different sources of biochar had significant influenced on the marketable weight of potato (Figure 6 and Appendix VII). Results revealed that, treatment B_1 (Maize cob biochar) produced the highest marketable yield (250.44 g pot^{-1}) which was statistically similar to B_2 (235.89 g pot^{-1}) whereas, the lowest (227.22 g pot^{-1}) one was obtained from B_3 (Cowdung + Sawdust biochar). Gautam *et al.* (2017), Alburquerque *et al.* (2013) and Asai *et al.* (2009) reported that higher AP levels of the biochar amended soils could be due to improved availability ofphosphorous as a result of biochar addition which also could be the reason for better production of marketable potato. Timilsina *et al.* (2017) and Collins *et al.*(2013) also reported that increased biochar application had increased quality potato tuber. Youseef *et al.* (2017) reported that marketable yield was significantly increased with increasing biochar application rates up to 5 m^3 ha^{-1}.Ding *et al.* (2016) reported that organic matter and inorganic salt, such as humic-like and fluvic-like substances and available N, P, and K, can serve as fertilizer and be assimilated by plants and microorganisms. Chan *et al.* (2008) reported significant increase in radish yields from application of biochar and this increased yield was due to the biochar's ability to increase N availability to plants.

4.6.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of weight of marketable potato pot^{-1} was found due to interactional effect of nitrogen form, potassium source and biochar source in all the studied durations (Table 10 and Appendix VII). The highest marketable yield (290.67 g pot^{-1}) was measured from $N_2K_1B_1$ treatment combination which was statistically identical to $N_2K_2B_1$ (286.00 g pot^{-1}) and similar to $N_2K_1B_2$ (274.00 g pot^{-1}), $N_2K_2B_3$ (272.67 g pot^{-1}) treatment combination. On the other hand, the lowest marketable yield (155.00 g pot^{-1}) from $N_1K_3B_3$ treatment combination.

4.7 Weight of non-marketable tuber

4.7.1 Effect of urea form

Non-significant variation was found among different urea form to non-marketable potato $plant^{-1}$ (Figure 4 and Appendix VII).Numerically the maximum (62.41 g pot^{-1}) non-marketable potato was found from N_1 (Prilled urea) treatment whereas,Numerically the minimum (51.48 g pot^{-1}) was found from N_2 (Urea Super Granule (USG)) treatment. This variation might be due to change in tuber size under different nitrogen form.

4.7.2 Effect of potassium sources

There was non-significant variation in non-marketable yield of potato (Appendix VII and Figure 5). K_1 (KCl fertilizer application) treatment produced the numerically the highest non-marketable yield (61.44 g pot^{-1}). On the other hand, the numerically the lowest non-marketable yield (53.67 g pot^{-1}) was produced by K_2 (KH_2PO_4 fertilizer application) treatment.

4.7.3 Effect of different sources of biochar

Different sources of biochar had non-significant influenced on the non-marketable yield of potato (Figure 6 and Appendix VII). Results exposed that, treatment B_3 (Cowdung + Sawdust biochar) produced numerically highest non-marketable potato (72.72 g pot^{-1}). On the other hand, the numerically lowest non-marketable potato (36.94 g pot^{-1}) one was obtained from B_2 (Mahogany biochar) treatment.

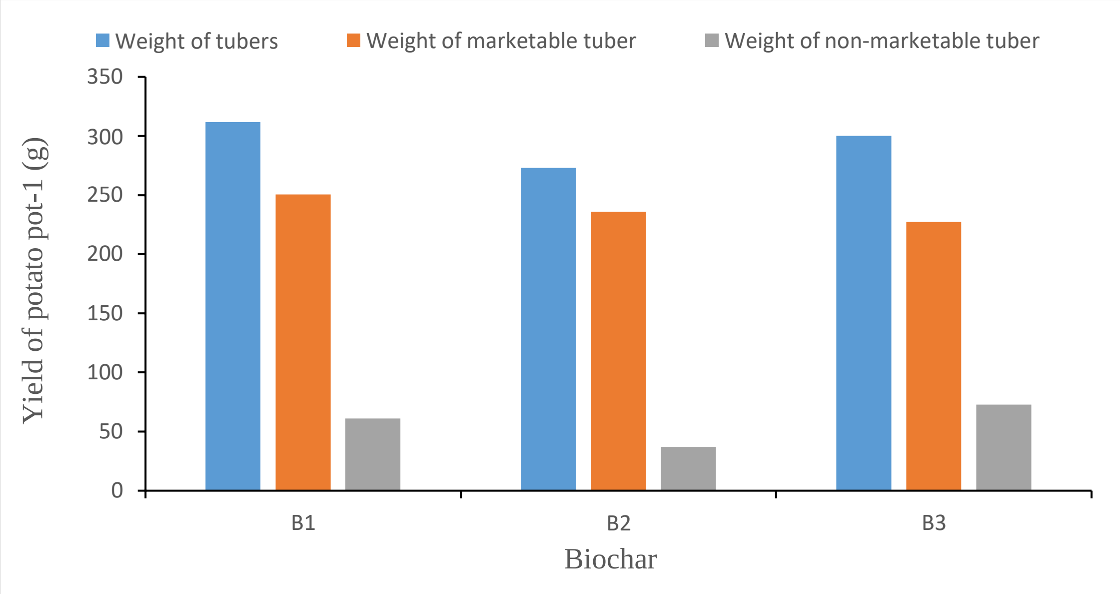

Figure 6. Effect of biochar on yield of potato pot^{-1} (LSD value = 21.53, 21.55 and NS, respectively)

Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar; NS = Non-Significant

4.7.4 Interaction effect of urea form, source of potassium and biochar

Interaction of different urea form, potassium sources and biochar source had significant effect on non-marketable yield of potato (Table 10 and Appendix VII). The highest non-marketable potato (102.00 g pot^{-1}) was recorded in $N_2K_1B_1$ combination treatment which was statistically similar to $N_1K_3B_3$ (99.33 g pot^{-1}), $N_1K_2B_3$ (87.33 g pot^{-1}), $N_1K_1B_3$ (82.33 g pot^{-1}), $N_2K_1B_3$ (81.00 g pot^{-1}) and $N_1K_1B_1$ (70.00 g pot^{-1}) treatment combination. On the other hand, the lowest non-marketable yield of potato (17.33 g pot^{-1}) was observed in $N_2K_3B_2$ combination treatment which was statistically identical to $N_1K_3B_2$ (21.00 g pot^{-1}) and similar to $N_2K_2B_1$ (34.33 g pot^{-1}), $N_2K_2B_3$ (38.33 g pot^{-1}) treatment combination.

Table 10. Combined effect of urea form, potassium source and different biochar on yield of potato pot^{-1}

Treatment combinations	Weight of tuber (g)	Weight of marketable tuber (g)	Weight of non-marketable tuber (g)
$N_1K_1B_1$	314.00 b-d	244.00 c-f	70.00 a-c
$N_1K_1B_2$	293.67 d-f	250.30 cd	43.33 a-c
$N_1K_1B_3$	304.00 c-f	221.67 g	82.33 a-c
$N_1K_2B_1$	292.00 e-g	227.30 e-g	64.67 a-c
$N_1K_2B_2$	266.00 hi	219.00 gh	47.00 a-c
$N_1K_2B_3$	285.30 f-h	198.00 hi	87.33 ab
$N_1K_3B_1$	270.67 g-i	224.00 fg	46.67 a-c
$N_1K_3B_2$	205.67 j	184.67 i	21.00 c
$N_1K_3B_3$	254.30 i	155.00 j	99.33 ab
$N_2K_1B_1$	340.00 a	290.67 a	102.00 a
$N_2K_1B_2$	316.67 bc	274.00 ab	42.67 a-c
$N_2K_1B_3$	339.00 a	258.00 bc	81.00 a-c
$N_2K_2B_1$	320.30 a-c	286.00 a	34.33 bc
$N_2K_2B_2$	290.00 e-g	239.67 c-g	50.33 a-c
$N_2K_2B_3$	311.00 c-e	272.67 ab	38.33 a-c
$N_2K_3B_1$	332.67 ab	230.67 d-g	49.33 a-c
$N_2K_3B_2$	265.00 hi	247.67 c-e	17.33 c
$N_2K_3B_3$	306.00 c-f	258.00 bc	48.00 a-c
LSD $_{(0.05)}$	**21.53**	**21.55**	**65.11**
CV (%)	**6.35**	**19.09**	**19.05**
N × K	*	**NS**	**NS**
N × B	**NS**	**NS**	**NS**
K × B	*	**NS**	**NS**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar;
NS = Non-Significant
* indicates significant at 5% level of probability

4.8 Yield of potato for flakes production (30–45 mm)

4.8.1 Effect of urea form

The yields of potato for flakes production (30-45 mm) was non-significantly affected by the different form of urea application (Figure 7 and Appendix VIII). Numerically the highest flakes production (146.44 g pot^{-1}) was obtained from N_1 (Prilled urea) treatment and numerically the lowest ones (130.30 g pot^{-1}) was obtained from N_2 (Urea Super Granule (USG)) treatment.

4.8.2 Effect of potassium sources

The yields of potato for flakes production (30–45 mm) was non-significantly influenced by the different potassium fertilizer application (Figure 8 and Appendix VIII). The numerically highest flakes production (151.61 g pot^{-1}) was obtained from K_1 (KCl fertilizer application) treatment whereas, the numerically lowest ones (121.83 g pot^{-1}) was obtained from K_3 (K_2SO_4 fertilizer application) treatment. Badrunnesa *et al.* (2021) showed similar results on influence of potassium fertilizer sources on flakes production.

4.8.3 Effect of different sources of biochar

The yields of potato for flakes production (30-45 mm) was non-significantly influenced by the different sources of biochar (Figure 9 and Appendix VIII). The numerically highest flakes production (158.50 g pot^{-1}) was obtained from B_3 (Cowdung + Sawdust biochar) treatment and the numerically lowest ones (118.39 g pot^{-1}) was obtained from B_2 (Mahogany biochar) treatment. This result had agreements with the findings of Youseef *et al.* (2017) who reported that potato yield for flakes production was significantly increased with increasing biochar application rates up to 5 m^3 ha^{-1}.

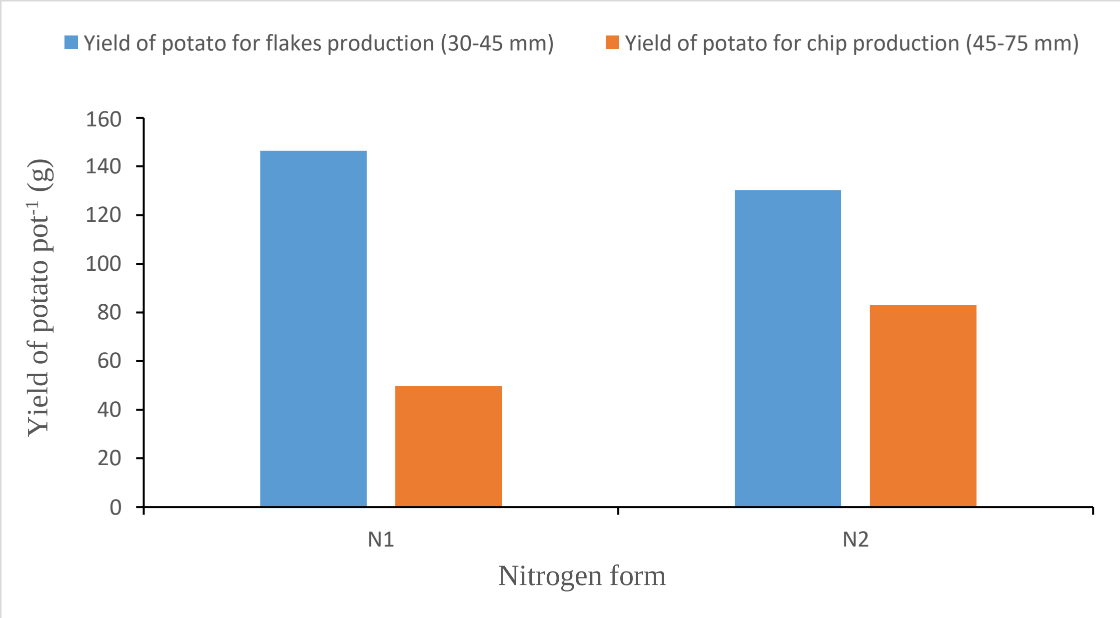

Figure 7. Effect of urea form on yield of potato pot^{-1} for different processing purpose (LSD value = NS and NS, respectively)

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG); NS = Non-Significant

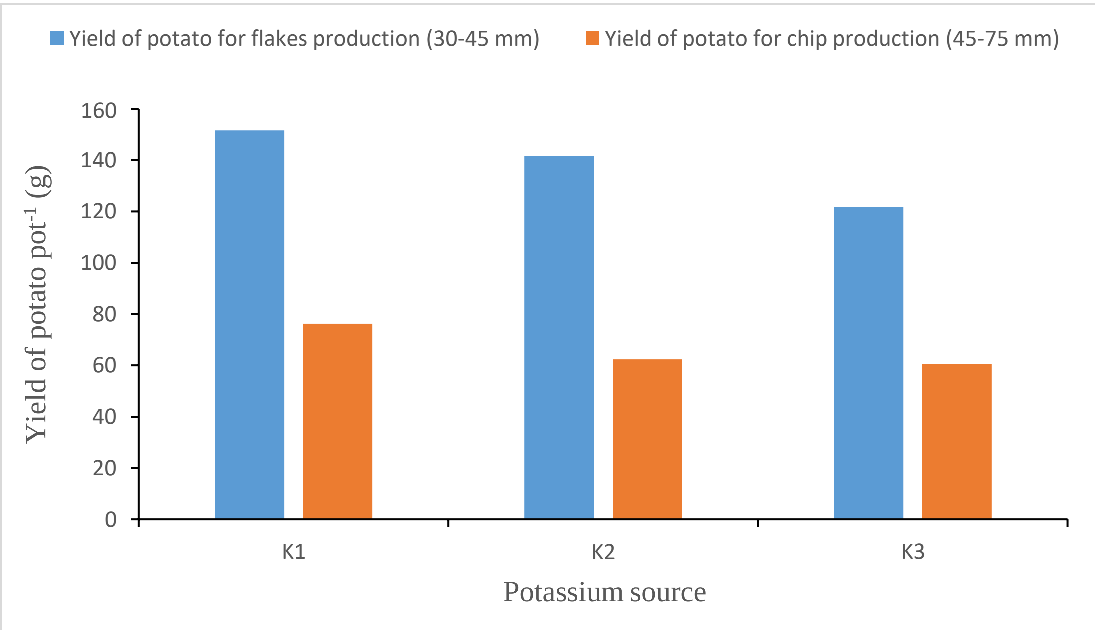

Figure 8. Effect of potassium source on yield of potato pot^{-1} for different processing purpose (LSD value = NS and NS, respectively)

Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4; NS = Non-Significant

4.8.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of the yields of potato for flakes production (30-45 mm) was found due to interactional effect of urea form, potassium source and biochar source in all the studied durations (Table 11 and Appendix VIII). The highest flakes production (201.33 g pot^{-1}) was measured from $N_2K_1B_1$ treatment (nitrogen: Urea Super Granule (USG), Potassium: KCl fertilizer application and biochar: Maize cob biochar) combination which was statistically similar to $N_1K_1B_1$ (168.67 g pot^{-1}), $N_1K_2B_1$ (167.33 g pot^{-1}), $N_1K_2B_3$ (165.67 g pot^{-1}), $N_2K_1B_3$ (164.67 g pot^{-1}) and $N_2K_3B_3$ (154.00 g pot^{-1}) treatment combination. On the other hand, the lowest flakes production (83.67 g pot^{-1}) from $N_2K_3B_2$ treatment (nitrogen: Urea Super Granule (USG), Potassium: K_2SO_4 fertilizer application and biochar: Mahogony biochar) combination which was statistically similar to $N_1K_3B_2$ (98.00 g pot^{-1}), $N_2K_2B_1$ (99.33 g pot^{-1}), $N_1K_1B_2$ (106.67 g pot^{-1}), $N_2K_3B_1$ (121.33 g pot^{-1}) and $N_1K_1B_3$ (128.67 g pot^{-1}) treatment combination.

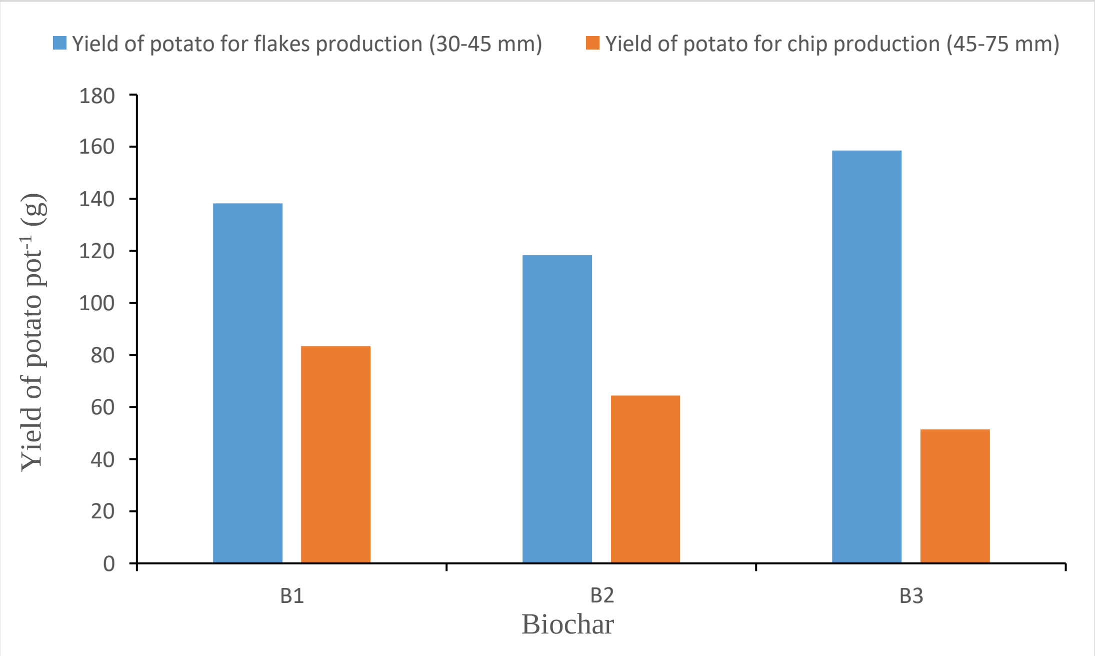

Figure 9. Effect of biochar on yield of potato pot^{-1} for different processing purpose (LSD value = NS and NS, respectively)

Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar; NS = Non-Significant

4.9 Yield of potato for chip production (45–75 mm)

4.9.1 Effect of urea form

The yields of potato for chips production (45-75 mm) was non-significantly affected by the different form of urea application (Figure 7 and Appendix VIII). The numerically maximum chips production (83.11 g pot^{-1}) was obtained from N_2 (Urea Super Granule (USG)) treatment and the numerically minimum ones (49.74 g pot^{-1}) was obtained from N_1 (Prilled urea) treatment.

4.9.2 Effect of potassium sources

The yields of potato for chips production (45–75 mm) was non-significantly affected by the different potassium fertilizer application (Figure 8 and Appendix VIII).Numerically the maximum chips production (76.28 g pot^{-1}) was obtained from K_1 (KCl fertilizer application) treatment. On the other hand, the numerically minimum chips production (60.56 g pot^{-1}) was obtained from K_3 (K_2SO_4 fertilizer application) treatment.

4.9.3 Effect of different sources of biochar

The yields of potato for chips production (45-75 mm) was non-significantly affected by the different sources of biochar (Figure 9 and Appendix VIII). The numerically maximum chips production (83.39 g pot^{-1}) was obtained from B_1 (Maize cob biochar) treatment whereas, the numerically minimum chips production (51.44 g pot^{-1}) was obtained from B_3 (Cowdung + Sawdust biochar) treatment. This result had agreements with the findings of Youseef *et al.* (2017) who reported that chips production was significantly increased with increasing biochar application rates up to 5 m^3 fed^{-1}.

Table 11. Combined effect of urea form, potassium source and different biochar on yield of potato pot^{-1} for different processing purpose

Treatment combinations	Yield of potato for flakes production (30–45 mm)	Yield of potato for chip production (45–75 mm)
$N_1K_1B_1$	168.67 ab	65.33 c-e
$N_1K_1B_2$	106.67 c-e	107.00 a-c
$N_1K_1B_3$	128.67 b–e	22.67 f
$N_1K_2B_1$	167.33 ab	44.67 d-f
$N_1K_2B_2$	136.33 b–e	49.67 d-f
$N_1K_2B_3$	165.67 ab	39.67 d-f
$N_1K_3B_1$	144.00 b-d	46.67 d-f
$N_1K_3B_2$	98.00 de	27.67 ef
$N_1K_3B_3$	130.00 b–e	44.33 d-f
$N_2K_1B_1$	201.33 a	121.00 a
$N_2K_1B_2$	139.67 b-d	77.00 b-d
$N_2K_1B_3$	164.67 ab	74.33 b-d
$N_2K_2B_1$	99.33 de	111.33 ab
$N_2K_2B_2$	146.00 b-d	44.00 d-f
$N_2K_2B_3$	135.33 b–e	75.67 b-d
$N_2K_3B_1$	121.33 b–e	111.33 ab
$N_2K_3B_2$	83.67 e	81.33 a–d
$N_2K_3B_3$	154.00 a-c	52.00 d-f
LSD $_{(0.05)}$	**54.34**	**42.53**
CV (%)	**13.72**	**14.67**
N × K	**NS**	*
N × B	**NS**	*
K × B	*	*

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant
* indicates significant at 5% level of probability

4.9.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of the yields of potato for chips production (45-75 mm) was found due to interactional effect of nitrogen form, potassium source and biochar source in all the studied durations (Table 11 and Appendix VIII). The maximum chips production (121.00 g pot^{-1}) was measured from $N_2K_1B_1$ treatment (nitrogen: Urea Super Granule (USG), Potassium: KCl fertilizer application and biochar: Maize cob biochar) combination which was statistically similar to $N_2K_2B_1$ (111.33 g pot^{-1}), $N_2K_3B_1$ (111.33 g pot^{-1}), $N_1K_1B_2$ (107.00 g pot^{-1}) and $N_2K_3B_2$ (81.33 g pot^{-1}) treatment combination. On the other hand, the minimum chips production (22.67 g pot^{-1}) from $N_1K_1B_3$ treatment (nitrogen: Prilled urea, Potassium: K_2SO_4 fertilizer application and biochar: Cowdung + Sawdust biochar) combination which was statistically similar to $N_1K_3B_2$ (27.67 g pot^{-1}), $N_1K_2B_3$ (39.67 g pot^{-1}), $N_1K_2B_1$ (44.67 g pot^{-1}), $N_1K_3B_1$ (46.67 g pot^{-1}) and $N_1K_2B_2$ (49.67 g pot^{-1}) treatment combination.

4.10 Specific gravity

4.10.1 Effect of urea form

In present study urea form had non-significant effect on specific gravity (Appendix IX and Table 12). Numerically, the highest specific gravity (1.05 g cm^{-3}) was obtained from Urea Super Granule (USG) (N_2) treatment whereas, the lowest (1.03 g cm^{-3}) specific gravity was found from the Prilled urea (N_1) treatment.

4.10.2 Effect of potassium sources

In present study potassium sources had not significant effect on specific gravity (Appendix IX and Table 13). Numerically, the highest specific gravity (1.09 g cm^{-3}) was obtained from KCl (K_1) treatment whereas, the lowest (1.07 g cm^{-3}) specific gravity was found from KH_2PO_4 (K_2) and K_2SO_4 (K_3) treatment. Similar findings were also reported by Parveen *et al.* (2004).

4.10.3 Effect of different sources of biochar

Specific gravity of tuber varied non-significantly with different sources of biochar application (Table 14 and Appendix IX). Numerically, the highest specific gravity of tuber was recorded (1.08 g cm^{-3}) from B_1 (Maize cob biochar) treatment while, the lowest (1.06 g c m^{-3}) was found from B_3 (Cowdung + Sawdust biochar) treatment. Similar findings were also reported by Bethee (2018) and Afrina (2017) who reported that biochar at 10.00 t ha^{-1} increased specific gravity in potato.

4.10.4 Interaction effect of urea form, source of potassium and biochar

The specific gravity of tuber due to different urea form, potassium source and sources of biochar application was found statistically non-significant of potato (Table 15 and Appendix IX). Numerically, the highest specific gravity of tuber (1.11 g cm^{-3}) exhibited by $N_2K_1B_1$ combined treatment which was statistically identical to $N_1K_3B_2$ (1.10 g cm^{-3}) and $N_2K_3B_2$ (1.10 g cm^{-3}). On the other hand, Numerically, the lowest specific gravity of tuber (1.06 g cm^{-3}) was exhibited by $N_1K_2B_1$ combined treatment which was statistically identical to $N_2K_2B_2$ (1.07 g cm^{-3}).

4.11 Firmness

4.11.1 Effect of urea form

Firmness of potato showed non-statistically significant variation for different urea form under the present study (Appendix XI and Table 12). Numerically, the maximum (35.62 %) firmness of potato was found from the Urea Super Granule (USG) treatment whereas, the minimum (35.43 %) was recorded from the Prilled urea treatment.

4.11.2 Effect of potassium sources

Firmness of potato showed non-statistically significant variation for different source of potassium under the present study (Appendix XI and Table 13). Numerically, the maximum (36.41 %) firmness of potato was found from the KCl fertilizer treatment whereas, the minimum (34.74%) was recorded from the KH_2PO_4 fertilizer treatment.

4.11.3 Effect of different sources of biochar

Firmness of potato showed non-statistically significant variation for different source of biochar under the present study (Appendix XI and Table 14). Numerically, the maximum (36.41 %) firmness of potato was found from the maize cob biochar treatment whereas, the minimum (34.07 %) was recorded from the Cowdung + Sawdust biochar treatment.

4.11.4 Interaction effect of urea form, source of potassium and biochar

Firmness of potato due to different urea form, potassium source and sources of biochar application was found statistically significant of potato (Table 15 and Appendix IX). The highest firmness of potato (38.15 %) exhibited by $N_2K_1B_1$ combined treatment which was statistically identical to $N_1K_1B_1$ (37.93 %) and similar to $N_1K_3B_2$ (37.70 %), $N_1K_1B_2$ (37.42 %), $N_2K_3B_2$ (37.35 %), $N_2K_1B_3$ (37.16 %), $N_2K_3B_1$ (35.76 %) and $N_2K_2B_1$ (35.73 %). On the other hand, the lowest firmness of potato (32.37 %) was exhibited by $N_1K_3B_3$ combined treatment which was statistically identical to $N_1K_1B_3$ (32.38 %) and similar to $N_2K_2B_2$ (33.39 %), $N_2K_3B_3$ (33.88 %), $N_2K_2B_3$ (33.96 %), $N_1K_2B_3$ (34.70 %).

Table 12. Effect of urea form on qualitative parameters of potato

Treatments	Specific gravity (g cm^{-}t)	Firmness (N)	Total soluble solid (˚brix)	Tuber dry matter (%)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
N_1	1.03	35.43	5.44	18.32	14.97 b	0.42 a
N_2	1.05	35.62	5.39	18.31	16.80 a	0.28 b
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**0.22**	**0.02**
CV (%)	**3.53**	**4.97**	**3.92**	**10.92**	**0.82**	**3.71**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
NS = Non-Significant

Table 13. Effect of potassium source on qualitative parameters of potato

Treatments	Specific gravity (g cm^{-}t)	Firmness (N)	Total soluble solid (˚brix)	Tuber dry matter (%)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
K_1	1.09	36.41	5.46	18.90	15.30 b	0.37 a
K_2	1.07	34.74	5.30	17.32	16.18 a	0.36 a
K_3	1.07	35.43	5.49	18.73	16.22 a	0.33 b
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**0.22**	**0.02**
CV (%)	**3.50**	**4.97**	**3.92**	**10.92**	**0.82**	**3.68**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
NS = Non-Significant

Table 14. Effect of different biochar on qualitative parameters of potato

Treatments	Specific gravity (g cm^{-}t)	Firmness (N)	Total soluble solid (˚brix)	Tuber dry matter (%)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
B_1	1.08	36.41	5.48	18.46	16.20 a	0.35
B_2	1.07	36.09	5.45	18.13	15.85 b	0.36
B_3	1.06	34.07	5.31	18.36	15.65 b	0.34
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**0.22**	**NS**
CV (%)	**3.53**	**4.97**	**3.92**	**10.92**	**0.82**	**3.71**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.
Here, B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant

4.12 Total soluble solid

4.12.1 Effect of urea form

Different urea form had insignificant between themselves regarding TSS (Appendix IX and Table 12).Numerically the maximum TSS (5.44 ° brix) was recorded from the N_1 treatment whereas,Numerically the minimum (5.39 ° brix) was obtained from the N_2 treatment. Study referred that the prilled urea expressed best result in terms of TSS.

4.12.2 Effect of potassium sources

Different potassium fertilizer had insignificant between themselves regarding TSS (Appendix IX and Table 13).Numerically the maximum TSS (5.49 ° brix) was recorded from K_2SO_4 (K_3) fertilizer application. On the other hand,Numerically the minimum TSS (5.30 ° brix) was obtained from the KH_2PO_4 (K_2) fertilizer application treatment.

4.12.3 Effect of different sources of biochar

Biochar sources had insignificant influenced on the total soluble solid (TSS) (Table 14 and Appendix IX). Results exposed that, treatment B_1 (Maize cob biochar) produced numerically the highest TSS (5.48 ° brix) followed by B_2 (5.45 ° brix) whereas,numerically the lowest one (5.31 ° brix) with B_3 (Cowdung + Sawdust biochar). Similar findings were reported by Youseef *et al.* (2017) who reported that biochar at 2.5 $m^3 fed^{-1}$ decreasedthe total soluble solid content in potato. Akhtar *et al*. (2014) found that biochar addition improved quality of tomato fruits.

4.12.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of the total soluble solid (TSS) was found due to interactional effect of urea form, potassium source and biochar source in all the studied durations (Table 15 and Appendix IX). The maximum TSS (5.80 ° brix) was measured from $N_2K_1B_1$ treatment (nitrogen: Urea Super Granule (USG), Potassium: KCl fertilizer application and biochar: Maize cob biochar) combination which was statistically similar to $N_1K_3B_2$ (5.61 ° brix), $N_2K_3B_2$ (5.61 ° brix), $N_1K_1B_1$ (5.58 ° brix), $N_2K_3B_1$ (5.56 ° brix), $N_1K_2B_2$ (5.51 ° brix), $N_2K_1B_3$ (5.50 ° brix) and $N_1K_3B_3$ (5.46 ° brix) treatment combination. On the other hand, the minimum TSS (5.01° brix) from $N_2K_2B_3$ treatment (nitrogen: Urea Super Granule (USG), Potassium: KH_2PO_4 fertilizer application and biochar: Cowdung + Sawdust biochar) combination which was statistically similar to $N_2K_1B_2$ (5.20 ° brix), $N_1K_2B_1$ (5.25 ° brix), $N_1K_1B_3$ (5.28 ° brix), $N_1K_2B_3$ (5.32 ° brix) and $N_2K_3B_3$ (5.32 ° brix) treatment combination.

4.13 Tuber dry matter

4.13.1 Effect of urea form

Tuber dry matter content showed insignificant variations among the different urea form (Appendix IX and Table 12). Numerically, the highest dry matter content of tuber (18.32 %) was recorded from N_1 treatment and numerically, the lowest ones (18.31 %) was recorded from N_2 treatment. The variation in dry matter content among the potato with nitrogen was also observed by Suyre *et al.* (1975), Lana *et al.* (1970) and Capezio (1987). Variation in tuber dry matter content may be attributed to nitrogen uptake difference in the production of total solids. Dry matter content is subjected to the influence of both the environment and cultural practice (Miller *et al.*, 1975; Tai and Coleman, 1999).

4.13.2 Effect of potassium sources

Tuber dry matter content showed insignificant variations among the different potassium fertilizer (Appendix IX and Table 13). Numerically, the highest dry matter content of tuber (18.90 %) was recorded from K_1 treatment whereas, numerically, the lowest ones (17.32 %) was recorded from K_2 treatment. Chettri and Thapa (2002) reported similar findings which are in conformity of these results.

4.13.3 Effect of different sources of biochar

Tuber dry matter content (%) of potato insignificantly influenced different sources of biochar application (Table 14 and Appendix IX). Numerically, the highest tuber dry matter (18.46 %) was recorded from B_1 treatment and numerically, the lowest tuber dry matter (18.13 %) was recorded from B_2 treatment. This result had agreements with the findings of Afrina (2017) and Youseef *et al.* (2017) who reported that the increases of potato dry matter may be attributed to that fertilizing with biochar positively increased number of main stems, leaves and tubers, as well as leaf area plant^{-1}.

4.13.4 Interaction effect of urea form, source of potassium and biochar

Tuber dry matter content due to different urea form, potassium source and sources of biochar application was found statistically significant of potato (Table 15 and Appendix IX). The highest tuber dry matter content (22.79 %) exhibited by $N_2K_1B_1$ combined treatment which was statistically similar to $N_1K_1B_1$ (22.44 %), $N_2K_1B_2$ (21.95 %), $N_2K_1B_3$ (21.76 %), $N_2K_3B_1$ (21.64 %), $N_1K_3B_3$ (21.38 %) and $N_1K_3B_2$ (21.11 %). On the other hand, the lowest tuber dry matter content (17.18 %) was exhibited by $N_2K_3B_3$ combined treatment which was statistically similar to $N_1K_1B_2$ (18.47 %), $N_2K_2B_1$ (18.63 %), $N_1K_3B_1$ (19.05 %) and $N_1K_2B_2$ (19.15 %).

4.14 Starch content

4.14.1 Effect of urea form

Starch content of potato showed statistically significant variation for different urea form under the present study (Appendix IX and Table 12). The maximum (16.80 mg g^{-1} FW) starch of potato was found from the N_2 treatment whereas, the minimum (14.97 mg g^{-1} FW) was recorded from the N_1 treatment.

4.14.2 Effect of potassium sources

Significant variation was found on starch content on potato due to different potassium fertilizer application (Table 13 and Appendix IX). The highest starch content on potato (16.22 mg g^{-1} FW) was attained by K_3 (K_2SO_4) treatment which was statistically identical to K_2 (16.18 mg g^{-1} FW). On the other hand, the lowest starch content on potato (15.30 mg g^{-1} FW) was attained by K_1 (KCl) treatment. Similar findings were also reported by Lu (2003) who stated that potassium fertilizer increased starch content in potato.

4.14.3 Effect of different sources of biochar

Significant variation was found on starch content on potato due to different biochar sources (Table 14 and Appendix IX). The maximum starch content on potato (16.20 mg g^{-1} FW) was attained by B_1 (Maize cob biochar) and the minimum starch content on potato (15.65 mg g^{-1} FW) was attained by B_3 (Cowdung + Sawdust biochar) which was statistically identical to B_2 (15.85 mg g^{-1} FW). Similar findings were also reported by Bethee (2018) and Youseef *et al.* (2017) who reported that biochar at 2.5 $m^3 fed^{-1}$ increased starch content in potato. Akhtar *et al.* (2014) found that biochar addition improved quality of tomato fruits.

4.14.4 Interaction effect of urea form, source of potassium and biochar

Starch content due to different urea form, potassium source and sources of biochar application was found statistically significant of potato (Table 15 and Appendix IX). The maximum starch content of potato (18.60 mg g^{-1} FW) exhibited by $N_2K_1B_1$ combined treatment. On the other hand, the minimum starch content of potato (13.70 mg g^{-1} FW) was exhibited by $N_1K_1B_1$ combined treatment which was statistically similar to $N_1K_1B_2$ (13.80 mg g^{-1} FW).

Table 15. Combined effect of urea form, potassium source and different biochar on qualitative parameters of potato

Treatment combinations	Specific gravity (g cm⁻t)	Firmness (N)	Total soluble solid (˚brix)	Tuber dry matter (%)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
$N_1K_1B_1$	1.08	37.93 a	5.58 a-c	22.44 ab	13.70 k	0.51 a
$N_1K_1B_2$	1.09	37.42 ab	5.41 b-d	18.47 de	13.80 k	0.49 a
$N_1K_1B_3$	1.08	32.38 d	5.28 b–e	19.38 b–e	14.10 j	0.42 b
$N_1K_2B_1$	1.06	35.39 a-c	5.25 c-e	19.61 a–e	16.30 ef	0.35 e
$N_1K_2B_2$	1.10	35.25 a–d	5.51 a–d	19.15 b–e	14.20 j	0.49 a
$N_1K_2B_3$	1.09	34.70 b-d	5.32 b–e	20.85 a–d	14.60 i	0.41 bc
$N_1K_3B_1$	1.08	35.53 a-c	5.36 b–e	19.05 c-e	16.40 ef	0.38 d
$N_1K_3B_2$	1.10	37.70 ab	5.61 ab	21.11 a–d	16.50 e	0.31 f
$N_1K_3B_3$	1.08	32.37 d	5.46 a–d	21.38 a–d	15.10 h	0.41 bc
$N_2K_1B_1$	1.11	38.15 a	5.80 a	22.79 a	18.60 a	0.32 f
$N_2K_1B_2$	1.09	35.43 a-c	5.20 de	21.95 a-c	16.90 d	0.25 g
$N_2K_1B_3$	1.08	37.16 ab	5.50 a–d	21.76 a–d	17.50 c	0.20 h
$N_2K_2B_1$	1.10	35.73 a-c	5.36 b–e	18.63 de	16.40 ef	0.39 cd
$N_2K_2B_2$	1.07	33.39 cd	5.34 b–e	20.50 a–d	17.50 c	0.30 f
$N_2K_2B_3$	1.10	33.96 cd	5.01 e	17.18 e	18.10 b	0.21 h
$N_2K_3B_1$	1.08	35.76 a-c	5.56 a-c	21.64 a–d	15.80 g	0.15 i
$N_2K_3B_2$	1.10	37.35 ab	5.61 ab	19.60 a–e	16.20 f	0.31 f
$N_2K_3B_3$	1.09	33.88 cd	5.32 b–e	20.19 a–e	14.50 i	0.41 bc
LSD (0.05)	**NS**	**2.92**	**0.35**	**3.31**	**0.22**	**0.02**
CV (%)	**3.51**	**4.97**	**3.92**	**10.92**	**0.82**	**3.71**
N × K	**NS**	**NS**	**NS**	**NS**	*	*
N × B	**NS**	*	**NS**	**NS**	*	*
K × B	*	*	*	**NS**	*	*

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability.

Here, N_1 = Prilled urea and N_2 = Urea Super Granule (USG);
K_1 = KCl, K_2 = KH_2PO_4 and K_3 = K_2SO_4;
B_1 = Maize cob biochar, B_2 = Mahogany biochar and B_3 = Cowdung + Sawdust biochar
NS = Non-Significant
* indicates significant at 5% level of probability

4.15 Reducing sugar

4.15.1 Effect of urea form

Reducing sugar (mg g^{-1} FW) showed statistically significant variation for different urea form under the present study (Appendix IX and Table 12). The highest (0.42 mg g^{-1} FW) reducing sugar of potato was found from the N_1 (Prilled urea) treatment whereas, the lowest ones (0.28 mg g^{-1} FW) was recorded from the N_2 (Urea Super Granule (USG)) treatment.

4.15.2 Effect of potassium sources

Reducing sugar (mg g^{-1} FW) was significantly influenced by different potassium fertilizer application (Table 13 and Appendix IX). The highest reducing sugar value (0.37 mg g^{-1} FW) was recorded from the "KCl application" (K_1) which was statistically identical with K_2 (0.36 mg g^{-1} FW) whereas, the lowest (0.33 mg g^{-1} FW) was found from the "K_2SO_4 application" (K_3).

4.15.3 Effect of different sources of biochar

Reducing sugar (mg g^{-1} FW) has insignificantly influenced different sources of biochar application (Table 14 and Appendix IX). Numerically, the highest reducing sugar value (0.36 mg g^{-1} FW) was recorded from the "Mahogany biochar" (B_2) treatment whereas, numerically, the lowest (0.34 mg g^{-1} FW) was found from the "Cowdung + sawdust biochar" (B_3) treatment.

4.15.4 Interaction effect of urea form, source of potassium and biochar

Significant variation of the reducing sugar (mg g^{-1} FW) was found due to interactional effect of urea form, potassium source and biochar source in all the studied durations (Table 15 and Appendix IX). The highest reducing sugar (0.51 mg g^{-1} FW) was measured from $N_1K_1B_1$ treatment (nitrogen: Prilled urea, Potassium: KCl fertilizer application and biochar: Maize cob biochar) combination which was statistically similar to $N_1K_1B_2$ (0.49 mg g^{-1} FW) and $N_1K_2B_2$ (0.49 mg g^{-1} FW) treatment combination. On the other hand, the lowest reducing sugar (0.15 mg g^{-1} FW) from $N_2K_3B_1$ treatment (nitrogen: Urea Super Granule (USG), Potassium: K_2SO_4 fertilizer application and biochar: Maize cob biochar) combination.

CHAPTER V

SUMMARY AND CONCLUSION

The pot experiment was conducted at Agronomy Research Field, Sher-e-Bangla Agricultural University during the period from 3rd November, 2020 to 28th February, 2021 to find out the effect of nitrogen form, source of potassium and biochar on yield and quality of potato. The experiment consisted of three factors. The factors were: factor A: Form of nitrogen (2); i. N_1: Prilled urea and ii. N_2: Urea Super Granule (USG); factor B: Source of potassium (3), i. P_1: KCl, ii. P_2: KH_2PO_4 and iii. P_3: K_2SO_4; factor C: Source of biochar (3), i. B_1: Maize cob biochar, ii. B_2: Mahogany biochar and iii. B_3: Cowdung + Sawdust biochar. The variety used in this experiment was BARI Alu-29 (Courage). The experiment was laid out in a RCBD factorial design with three (3) replications. Total 54 unit-pots were prepared for the experiment. Each pot was of equal size. Data on different growth, qualitative, yield contributing and yield parameter of potato were recorded and significant variation was recorded for different treatments.

It was observed that the plants treated with N_2 (Urea Super Granule or USG) out-yielded over N_1 (Prilled urea) by producing the highest weight of tubers (313.40 g pot^{-1}). The treatment N_2 (Urea Super Granule or USG) also showed significantly the highest weight of marketable tubers (261.93 g pot^{-1}), lowest weight of non-marketable tubers (51.48 g pot^{-1}), highest starch content (16.80 mg g^{-1} FW) and the lowest reducing sugar (0.32 mg g^{-1} FW) in compare to prilled urea treated plants.

Significant differences existed among different sources of potassium with respect to yield parameters in potato. The plants which were treated with K_1 (KCl) out-yielded over K_2 (KH_2PO_4) by producing the highest weight of tubers (317.89 g pot^{-1}). The treatment K_1 (KCl) also showed significantly the highest weight of marketable tubers (256.44 g pot^{-1}), highest number of tubers $plant^{-1}$ (8.61) and the highest average weight of tuber $plant^{-1}$ (37.75 g) in compare to K_2

(KH_2PO_4) treated plants. On the other hand, K_3 (K_2SO_4) treated plants showed significantly the lowest value in case of all the parameters mentioned above.

The result revealed that B_1 (Maize cob biochar) exhibited its superiority to other biochar sources B_2 (Mahogany biochar) and B_3 (Cowdung + Sawdust biochar) in terms of tuber yield of potato. It was observed that the plants treated with B_1 (Maize cob biochar) out-yielded over B_2 (Mahogany biochar) and B_3 (Cowdung + Sawdust biochar) by producing the highest weight of tubers (311.61 g pot^{-1}). The treatment B_1 (Maize cob biochar) also showed significantly the tallest plant at 65 DAP (66.69 cm), the highest average weight of tuber $plant^{-1}$ (39.77 g), the highest weight of marketable tubers (250.44 g pot^{-1}) and the highest starch content (16.20 mg g^{-1} FW) in compare to mahogany biochar and cowdung + sawdust biochar treated plants.

Interaction effects of urea form, source of potassium and biochar showed significant variation for most of the studied parameters. Among the interactions, $N_2K_1B_1$ was superior in producing the tallest plant at 65 DAP (72.17 cm), the highest weight of tuber (340.00 g pot^{-1}), highest weight of marketable tuber (290.67 g pot^{-1}), highest weight of non-marketable tuber (81.00 g pot^{-1}), highest yield of potato for flakes production (30–45 mm) (201.33 g pot^{-1}), highest yield of potato for chip production (45–75 mm) (121.00 g pot^{-1}), highest firmness (38.15%), total soluble solid (5.80 ˚brix), tuber dry matter (22.79%) and starch content (18.60 mg g^{-1} FW). $N_2K_1B_3$ and $N_2K_2B_1$ showed statistically the second and third best results among the other interaction.

CONCLUSION

From the above result it was revealed that N_2 (Urea Super Granule or USG), K_1 (KCl) and B_1 (Maize cob biochar) gave higher yield along with higher values in most of the yield attributing parameters in case of potato. Among the interactions; $N_2K_1B_1$, $N_2K_1B_3$ and $N_2K_2B_1$ were superior in most of the studied parameters along with tuber yield.

RECOMMENDATION

Considering the results of the present experiment, further studies in the following areas are suggested:

1. More urea form with different source of potassium and biochar may be used for getting the most suitable combination for potato cultivation.

2. Studies of similar nature could be carried out in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of zonal adaptability.

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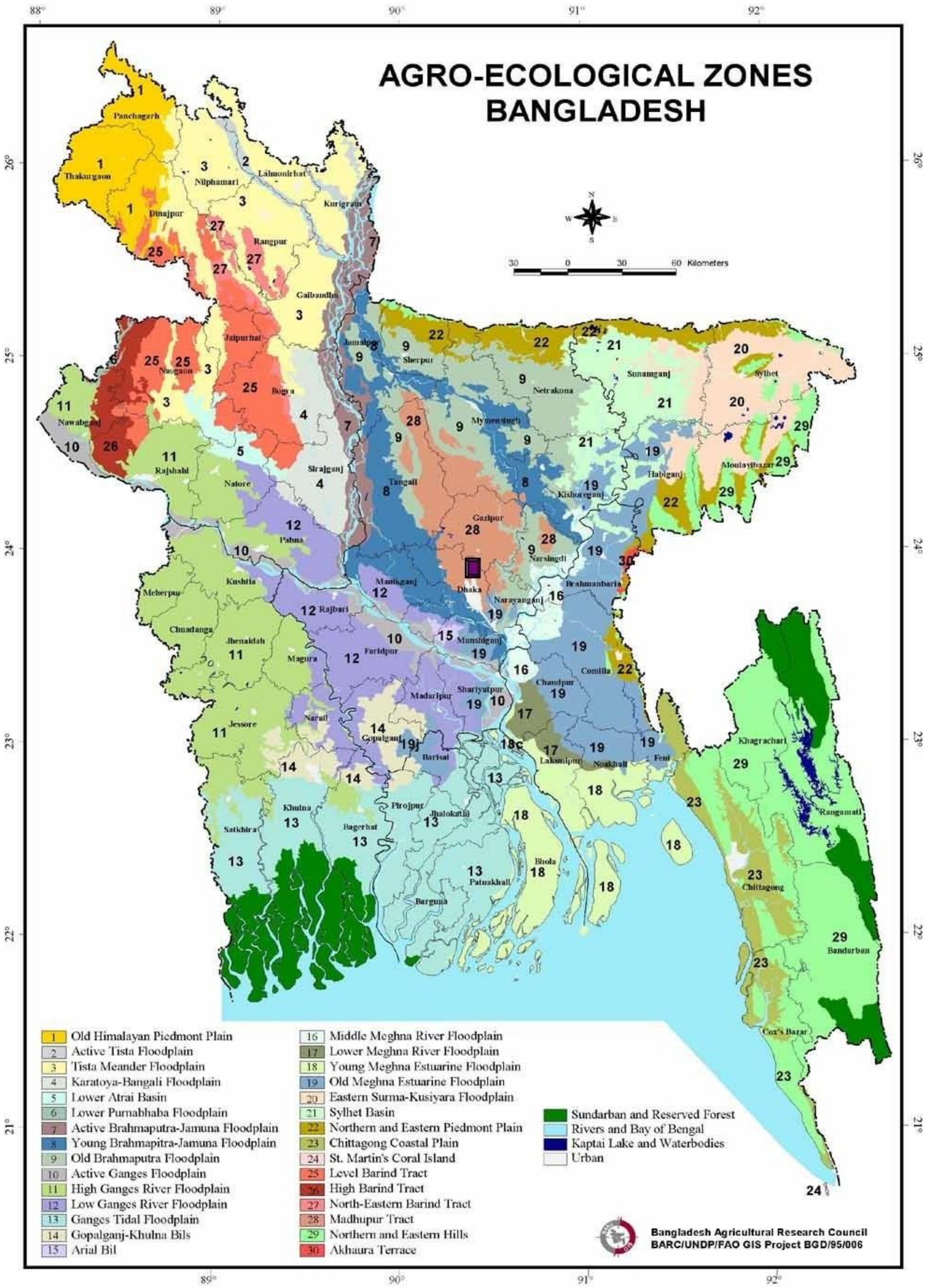
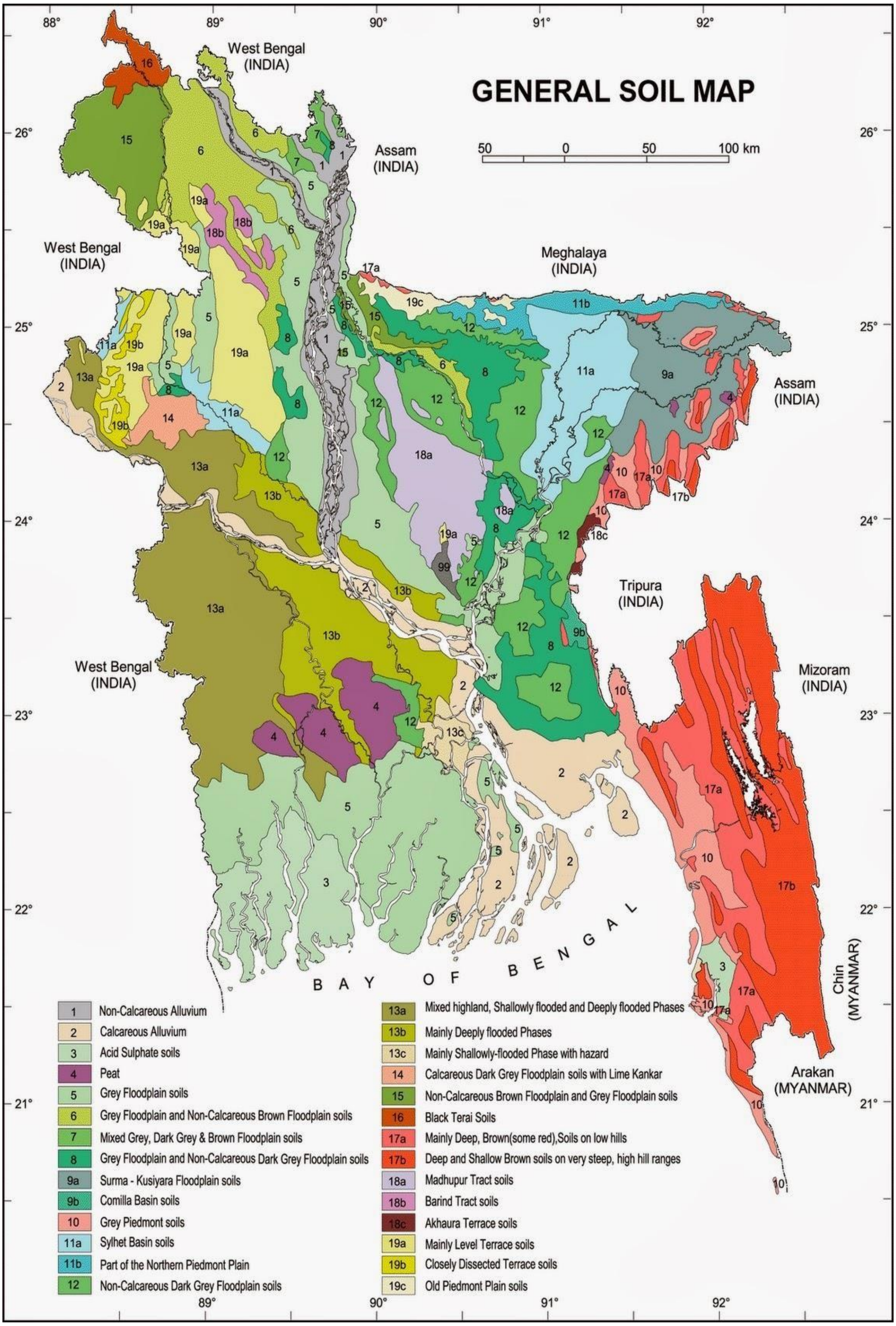
APPENDICES

Appendix I (A). Map showing the experimental sites under study



The experimental site under study

Appendix I(B). Map showing the general soil sites under study



Appendix II. Characteristics of soil of experimental site analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly levelled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	6.0
Organic carbon (%)	0.69
Organic matter (%)	1.10
Total N (%)	0.06
Available P (ppm)	20.00
Exchangeable K (meq/100 g soil)	0.10
Available S (ppm)	22

Source: SRDI, 2019

Appendix III. Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2020 to February 2021

Year	Month	Temperature			Relative Humidity (%)	Total Rainfall (mm)	Sunshine (Hour)
		Max (°C)	Min (°C)	Mean (°C)			
2020	November	32	24	29	65	42.8	349
	December	27	19	24	53	1.4	372
2021	January	25	14	23	50	3.9	364
	February	30	19	26	38	3.1	340

Appendix IV: Analysis of variance (mean square) of days to emergence of potato seedlings

Source of variation	Degrees of freedom	Mean Square value of
		Days to emergence
Nitrogen form	1	10.67
Potassium source	2	11.80
Biochar	2	2.91
Urea form × Potassium source	2	12.06
Urea form × Biochar	2	5.39
Potassium sources × Biochar	4	2.35
Urea form × Potassium source × Biochar	4	0.94
Error	36	4.26
Total	53	4.56

* indicates significant at 5% level of probability

Appendix V: Analysis of variance (mean square) of plant height of potato

Source of variation	Degrees of freedom	Mean Square value of		
		Plant height at 35 DAP	Plant height 50 DAP	Plant height 65 DAP
Nitrogen form	1	337.00	341.51	258.73
Potassium source	2	252.41	181.12	248.02
Biochar	2	565.64	651.04	806.38
Urea form × Potassium source	2	96.15	3.21	29.33
Urea form × Biochar	2	49.08	8.13	11.45
Potassium sources × Biochar	4	62.89	8.37	10.50
Urea form × Potassium source × Biochar	4	41.43	18.00	2.57
Error	36	46.85	76.58	64.00
Total	53	82.40	92.28	90.66

* indicates significant at 5% level of probability

Appendix VI: Analysis of variance (mean square) of yield attributes of potato

Source of variation	Degrees of freedom	Mean Square value of	
		Number of tuber/hill	Average weight of tuber/plant
Nitrogen form	1	52.02	176.89
Potassium source	2	7.46	25.94
Biochar	2	60.96	745.02
Urea form × Potassium source	2	8.69	32.39
Urea form × Biochar	2	1.41	47.59
Potassium sources × Biochar	4	5.74	63.34
Urea form × Potassium source × Biochar	4	3.24	17.91
Error	36	3.30	45.24
Total	53	6.86	72.31

* indicates significant at 5% level of probability

Appendix VII: Analysis of variance (mean square) of yields of potato

Source of variation	Degrees of freedom	Mean Square value of		
		Fresh weight/pot	Weight of marketable tuber	Weight of non-marketable tuber
Nitrogen form	1	4004.17	10696.30	1611.57
Potassium source	2	9322.46	7210.96	292.39
Biochar	2	7124.52	2478.74	6000.89
Urea form × Potassium source	2	1415.17	578.74	766.69
Urea form × Biochar	2	12.67	1816.96	1783.19
Potassium sources × Biochar	4	892.82	346.69	1324.61
Urea form × Potassium source × Biochar	4	48.08	1524.74	1874.13
Error	36	1419.20	1849.28	1545.89
Total	53	1785.07	2055.22	1655.56

* indicates significant at 5% level of probability

Appendix VIII: Analysis of variance (mean square) of tuber grade of potato

Source of variation	Degrees of freedom	Mean Square value of	
		Grade A (30–45 mm)	Grade B (45–75 mm)
Nitrogen form	1	3520.30	15033.35
Potassium source	2	4136.91	1326.35
Biochar	2	7240.35	4645.02
Urea form × Potassium source	2	724.24	441.46
Urea form × Biochar	2	3171.24	3578.69
Potassium sources × Biochar	4	1533.52	1242.57
Urea form × Potassium source × Biochar	4	1284.52	1716.96
Error	36	1076.96	659.69
Total	53	1586.95	1332.14

* indicates significant at 5% level of probability

Appendix IX: Analysis of variance (mean square) of qualitative parameters of potato

Source of variation	Degrees of freedom	Mean Square value of					
		Specific gravity	Firmness	Total soluble solid	Tuber dry matter	Starch content	Reducing sugar
Nitrogen form	1	0.005	0.477	0.046	0.000	47.040	0.252
Potassium source	2	0.002	12.708	0.187	13.507	4.865	0.007
Biochar	2	0.002	28.955	0.146	0.513	1.395	0.001
Urea form × Potassium source	2	0.003	3.176	0.022	9.067	7.295	0.023
Urea form × Biochar	2	0.006	11.937	0.029	6.611	0.545	0.000
Potassium sources × Biochar	4	0.005	9.717	0.138	4.030	5.893	0.030
Urea form × Potassium source × Biochar	4	0.003	4.894	0.091	11.243	4.578	0.027
Error	36	0.001	3.113	0.045	4.002	0.017	0.000
Total	53	0.002	5.369	0.063	4.992	2.221	0.010

* indicates significant at 5% level of probability

PLATES

Plate 1.Preparation of pot

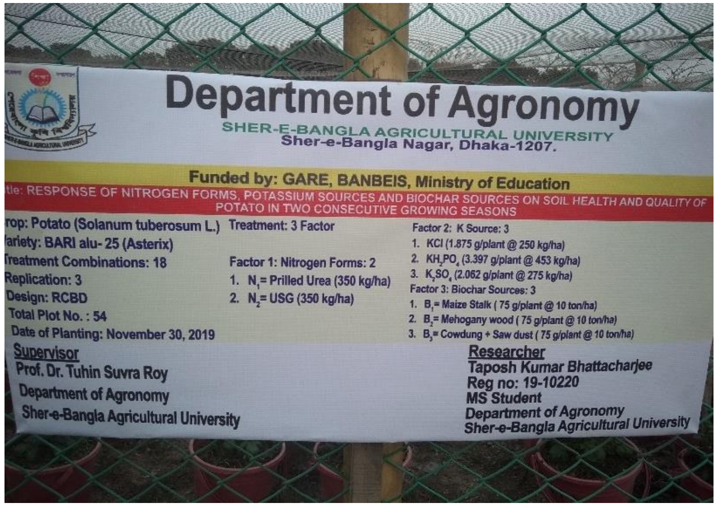


Plate 2.Tagging and signboard preparation

Plate 3. Watering

Plate 4. Vegetative stage of potato plant

Plate 5.Harvesting of potato