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Research Article

Utilization of maize cob biochar and rice husk charcoal as soil amendments for improving acid soil fertility and productivity

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Abstract The decline in soil fertility in agricultural land is a major problem that causes a decrease in the production of food crops. One of the causes of the decline in soil fertility is declining soil pH that caused the decline in the availability of nutrients in the soil. This study aimed to assess the influence of alternative liming materials derived from maize cob biochar and rice husk charcoal compared to conventional lime to improve soil pH, soil nutrient availability and maize production. The experiment used a factorial complete randomized design which consisting of two factors. The first factor is the type of soil amendment which consists of three levels (calcite lime, rice husk charcoal and cob maize biochar). The second factor is the application rates of the soil amendment consisted of three levels (3, 6 and 9 t/ha) and one control treatment (without soil amendment). The results of this study showed that the application of various soil amendment increased soil pH, which the pH increase of the lime application was relatively more stable over time compared to biochar and husk charcoal. The average of the soil pH increased for each soil amendment by 23% (lime), 20% (rice husk charcoal) and 23% (biochar) as compared with control. The increase in soil pH can increase the availability of soil N, P and K. The greatest influence of soil pH on nutrient availability was shown by the relationship between soil pH and K nutrient availability with R^2 = 0.712, while for the N by R^2 = 0.462 and for the P by R^2 = 0.245. The relationship between the availability of N and maize yield showed a linear equation. While the relationship between the availability of P and K with the maize yield showed a quadratic equation. The highest maize yield was found in the application of biochar and rice husk charcoal with a dose of 6-9 t/ha. The results of this study suggested that biochar and husk charcoal could be used as an alternative liming material in improving acid soil fertility and productivity.

***Keywords:** calcite lime, maize cob biochar, soil pH, nutrient availability, acid soil, maize yield*

Introduction

In acid soil, nutrient availability becomes a major problem that causes decrease in crop productivity. Nutrient availability is closely related to soil pH. At low pH decreased availability of macronutrients cause deficiency of nutrients for plants. Therefore, soil acidity is often a critical issue in soil fertility, especially in tropical soils, because most crops are not tolerant to low soil pH. Soil acidity can be caused by the climatic conditions such as high rainfall and temperatures resulting in alkaline mineral weathering rapidly and accompanied leaching of bases cations. The soil acidification is also due to the application of acidic nitrogen fertilizer, N transformation (Nitrification) that produces H^+ ions, and the release process of H^+ ions into the soil of various reactions in the soil (Havlin et al., 2005; Tabitha et al., 2008).

The influence of soil acidification can be classified into three categories, namely: (1) the availability of nutrients, (2) toxic nutrients, and (3) the soil structure. Availability of essential nutrients for plant growth is affected by soil pH. In acid soils, nutrient deficiencies and toxicities (Al, Mn, and H) becomes a major problem. Plants Growth, especially root growth in acid soils is limited due to the toxicity of Al^{3+}, Mn^{2+}, and H^+. The degree of toxicity depends on the level of concentration and the dissolved Al and soil pH (Okalebo, 2009). The high concentration of Al^{3+}, Fe^{3+}, and H^+ in acid soil causes soil pH <5.5, high P fixation, and low organic matter content and activity of microorganisms (Fernández and Hoeft, 2012). The development of food crops in acid soil of dry land requires a great effort to recover the soil in order to the plants can produce optimally. According to Tarigan (2009), the plants will grow and produce optimally if planted in qualified growing medium especially environmental factors as climatic factors and soil properties such as soil pH, nutrient availability, CEC etc. One of the efforts to improve the soil fertility is the use of various soil amendment are easily available and are able to survive long in the soil or have the long-term effect and resistant to attack by microorganisms so that the process of decomposition is slow (Nurida and Rachman, 2010).

The soil amendments widely used farmers to increase soil pH is dolomite and calcite lime. Liming not only increase the pH, base saturation, exchangeable calcium and magnesium, but also increase soil microbial activity, improve the status of soil organic matter and improve soil nutrient availability (Johnson et al*.,* 1995).

The limestone material is relatively expensive and limited supply. To overcome it, recently have began to develop the use of agricultural wastes biochar (charcoal) as alternative soil amendment, because the waste is readily available and abundant supply and manufacture process is easier and cheaper than limestone. Maize biomass waste is one of the largest agricultural waste after the timber and rice waste. The maize biomass waste is usually used for animal feed and compost derived from stems and leaves of maize (Agustina, 2004). While many maize cobs are used as fuel, Rohaeni et al. (2005) reported that the potential of fresh maize straw waste is equal to 12.19 t/ha and maize cob by 1 t/ha. By considering the high C content of maize cobs (43.42%), waste of maize cob biomass has a great potential to be produced as charcoal (biochar) (Lachke, 2002).

Some research about applications of biochar as a soil amendment on degraded soil showed that application of biochar 23.2 t/ha increased the plant biomass by 189% that grown on degraded Oxisols (Major et al., 2010). Biochar can enhance the nutrient availability in the soil (Glaser et al., 2002; Lehmann et al., 2003; Rondon et al., 2007; Steiner et al., 2008). It is caused by the biochar can reduce nutrient leaching in soil (Schahczenski, 2010).

Increased nutrient availability in the soil due to the application of biochar can improve the productivity of degraded soil (Sinclair et al., 2010)

Based on the above information is necessary to study aimed to assess the effect of alternative liming materials in form of maize cob biochar and husk charcoal compared to conventional lime to improve soil pH, soil nutrient availability and maize production. This study is expected to provide information to farmers having problems with acidic soil that affected low nutrient availability in the soil.

Materials and Methods

Study Site and Soil Characteristics

This study is a pot experiment conducted at the field agriculture of Merjosari village in June-August 2013 with an altitude of 505 m above sea level, the average temperature of 20°-28°C and rainfall is 1750 mm/year. Soil samples used for this study were collected from the sugarcane monoculture land of more than 20 years with the type of soil is an Inceptisol. Soil samples were air dried and sieved to pass through a 2 mm sieve. The soil is well drained with the following characteristics; pH (H_20) 4.29, 1.85% organic C by Walkley and Black method; 0.13% total Kjeldahl N; 4.40 mg/kg P (Bray II), cation exchange capacity 17.22 me /100 g soil, and 14.1% sand, 85.5% silt and 0.4% clay.

Biochar and charcoal preparation

Maize cob biochar was made at the bioenergy laboratory of Tunggadewi Tribhuwana University. The biochar was made by pirolysis process (burning without oxygen). Maize cobs were put in a reactor to a slow burning process (carbonation) at a temperature of 300-400°C for about six hours with the absence of oxygen. After the combustion, cool charcoal was taken from the combustion reactor, then crushed and sieved using a 100 mesh sieve size. Husk charcoal was obtained from the farm shop. It was then crushed and sieved using a 100 mesh sieve size. The characteristics of husk charcoal and maize cob biochar are presented in the Table 1

Experimental procedures

Dry, ground (< 2 mm) of each of three soil amendments (b1 = calcite lime, b2 = husk charcoal, and b3 = maize cob biochar) with three application rates for each (d1 = 3 t/ha, d2 = 6 t/ha, and d3 = 9 t/ ha) was incorporated into 10 kg of soil in a 25-cm diameter plastic pot. A treatment receiving no added soil amendment was also included. The ten treatments (nine combinations of types and levels of soil amendment application, and one control soil alone without application of soil amendment) were replicated three times and arranged in a factorial randomized block design. One week after soil amendment application, two pre-germinated seeds of sweet maize, Bonanza variety, were planted in each pot at 5 cm depth, and thinned to one plant after 1 week. The experiment was conducted for 87 days. Water was supplied daily to each pot in order to keep the moisture content of the soil at the approximate water holding capacity.

Table 1. Some chemical properties of soil amendments

Soil Amendments	pH (H_2O)	Nutrient content (%)						C (%)	CEC me/100 g	Water content (%)
		N	P	K	Ca	Mg	Na			
Husk Charcoal	8.75	0.14	0.15	0.31	0.28	0.32	1.35	6.24	7.24	7.46
Maize cob biochar	8.85	0	0.12	0.22	0.46	0.42	1.44	18.73	18.52	5.42

Statistical Analysis

The collected data was statistically analyzed using analysis of variance (F-Test) at level ($P \leq 0.05$) and differences in each treatment were adjudged by Tukey test ($P \leq 0.05$) using Minitab Version 14.12. Dunnett test at 5% level was used to compare all treatments with control. The relationship between soil nutrient availability with crop yield was determined with regression and correlation analyses. For statistical analysis of data, Microsoft Excel was employed.

Results and Discussion

Soil pH

The results of this study showed that the treatments with application of soil amendments had higher soil pH compared with control (Figure 1). The average increase in soil pH of three kinds of soil amendment of calcite lime, rice husk, and biochar respectively were 23%, 20% and 23%. This indicates that the calcite lime and biochar has the same effectiveness in improving soil pH.

Increase of soil pH due to the application of these soil amendments was caused by the materials such as calcite lime, husk charcoal, and maize cob biochar having high base saturation and pH. If the basic compound is added (e.g. $CaCO_3$), H^+ will be neutralized. With the addition of a continuous base hydrolyzed Al^{3+} will produce H^+. In this way, the hydrolyzed Al^{3+} will buffer pH increase of solution. Soil pH will not rise until sufficient amount of basic compound is added to reduce soluble Al^{3+}. Finally, Al $(OH)_3$ will precipitate at pH 6.5, and the amount Al^{3+} in solution will be decrease and soil pH will increase (Plaster, 2004).

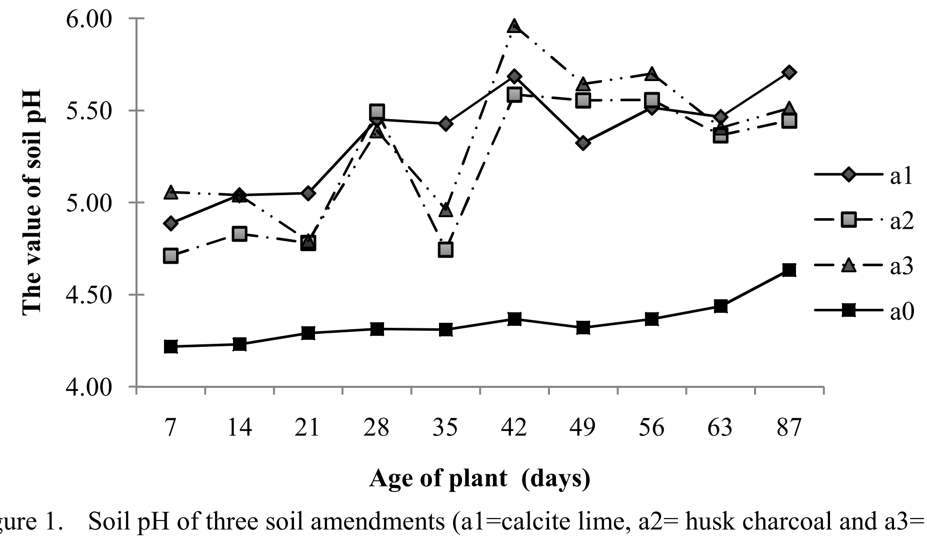

Figure 1. Soil pH of three soil amendments (a1=calcite lime, a2= husk charcoal and a3= maize cob biochar) at various plants age

Changes in soil pH during growth of sweet maize fluctuated since two weeks after application of soil amendment (sweet maize age of 7 days) until the sweet maize age of 87 days. The highest increase in soil pH occurred at the age of 42 days. Application of calcite lime (a1) caused an increase in the soil pH is relatively stable, compared with soil amendment derived from organic matter (a2, a3) (Figure 1).

Organic matters have variable charges. Functional group of organic matters can be positively and negatively charge depending on soil pH. Therefore, the ability to adsorb cations can also change, depending on the charge of soil complex (Havlin et al*.,* 2005). Sumarwoto (2004) reported that liming increased soil pH from 4.20 to 5.99, increased the availability of Ca and Mg, CEC, and decreased exchangeable Al 19.99 me/100g soil. Similarly, rice husk charcoal has high pH between 8.5 to 9 so it can be used to increase the pH of acid soils. The high soil pH gives the advantages because weeds and bacteria do not like the high pH. The use of rice husk charcoal as an organic fertilizer has a double advantage because it does not only supplying nutrients but also as soil amendment to improve soil properties. The results of this study showed that application of maize cob biochar was also able to increase the pH of acid soils equal to application of calcite lime. Masulili et al. (2010) reported that application rice husk biochar on acid sulfate soil increased the soil pH. The increase in soil pH occurred because the amount of exchangeable Al^{3+} decreased. Glaser et al. (2002) reported that the addition of soil amendment derived from organic matter in to the acid soil might have a positive effect that increase soil CEC and decrease toxicity of heavy metals present in the soil. This happens because the organic matters increase the soil negative charges derived from the carboxyl compounds, thereby reducing the solubility of heavy metals in the soil solution (Havlin et al., 2005; Shamshuddin et al., 2004). Hunt et al. (2010) pointed out that biochar is an organic material that is resistant to decomposition process. Therefore, biochar can survive for a long time in the soil. In addition, biochar also affects productivity through improved physical, chemical and biological soil properties (Chan et al., 2007). It has been widely reported that the use of biochar can increase soil pH and CEC (Liang et al., 2006; Yamato et al*.,* 2006).

Nutrient Availability

Results of analysis of variance showed that the interaction of soil amendment and doses significantly affected the availability of soil N, P and K. Application of 6-9 t maize cob biochar /ha gave the highest soil N and K contents, while the highest soil P content was found on treatment using 9 t rice husk charcoal /ha. All treatments were significantly different from control except for the soil N content with application of 3 t calcite lime /ha (Table 2).

Table 2. The Average of total soil N content, available P, and exchangeable K in the treatments of various soil amendments (a) and dose of application (d).

Treatment	Total soil N (%)	Available P (mg/kg)	Exchangeable K (me/100 g soil)
a_0d_0 (control)	0.10	20.010	0.147
a_1d_1	0.105^{ns} a	21.757^{*} a	0.200^{*} a
a_1d_2	0.108^{*} a	23.083^{*} a	0.217^{*} a
a_1d_3	0.123^{*} b	24.667^{*} b	0.257^{*} ab
a_2d_1	0.128^{*} bc	26.050^{*} b	0.250^{*} ab
a_2d_2	0.133^{*} c	29.433^{*} c	0.273^{*} bc
a_2d_3	0.141^{*} d	33.477^{*} d	0.287^{*} bc
a_3d_1	0.143^{*} d	21.873^{*} a	0.233^{*} a
a_3d_2	0.152^{*} e	22.107^{*} a	0.297^{*} bc
a_3d_3	0.156^{*} e	24.690^{*} b	0.327^{*} c
LSD 5%	0.005	1.759	0.057
Dunnet 5 %	0.004	1.560	0.050

Means followed by the same letters at each column are not significantly different (P=0.05)
ns = not significant at Dunnet test 5 % * = significant at Dunnet test 5 %

The results of this study showed that the application of biochar improved nutrient availability in the soil. Biochar does not only increase soil pH but also hold nutrients in the soil directly through the negative charge on the surface area of the charcoal.

The negative charge can act as a buffer so that the application of biochar can improve the use efficiency of N fertilizer (Chan et al., 2007). Thus, rice husk charcoal and biochar can serve as soil conditioners that can retain nutrients, so reducing the loss of nutrients due to leaching processes in the soil. Biochar derived from crop residues can also act as a nutrient source.

The relationship between soil pH and soil nutrient availability

Soil nutrient availability is affected by several factors such as total nutrient supply, soil moisture and aeration, soil temperature, and soil physical and chemical properties. One of the soil chemical properties influencing soil nutrient availability is soil pH. According to Siringoringo and Siregar (2011), the increase in the pH of acid soils can increase availability of nutrients for plant growth. Figure 2 shows the relationship between the pH of the soil with nutrient availability due to the application of three kinds of soil amendment. In general, the relationship between soil pH and soil nutrient availability follows a linear pattern. This means that the higher the pH of the soil, the higher is the availability of soil nutrients. The pattern of this relationship occurs because the increase in pH due to application of soil amendment has not reached a pH of 6.5, so the availability of nutrients is continuously expanding. The largest amount of essential nutrients is available in the range of pH between 5.2 and 6.5. Above and below this range, most nutrients are strongly bound by soil particles such as Fe and Mn oxides and they become unavailable to plants (Plaster, 2004). The greatest effect of soil pH on nutrient availability was indicated by the relationship between soil pH and soil K content (Figure 2). The availability of potassium (K) including base cations will increase with increasing pH of the soil. Brady and Weil (2004) stated that largest increase of soil K occurred at pH 6.5, whereas the optimum N availability occurred at pH 5.5.

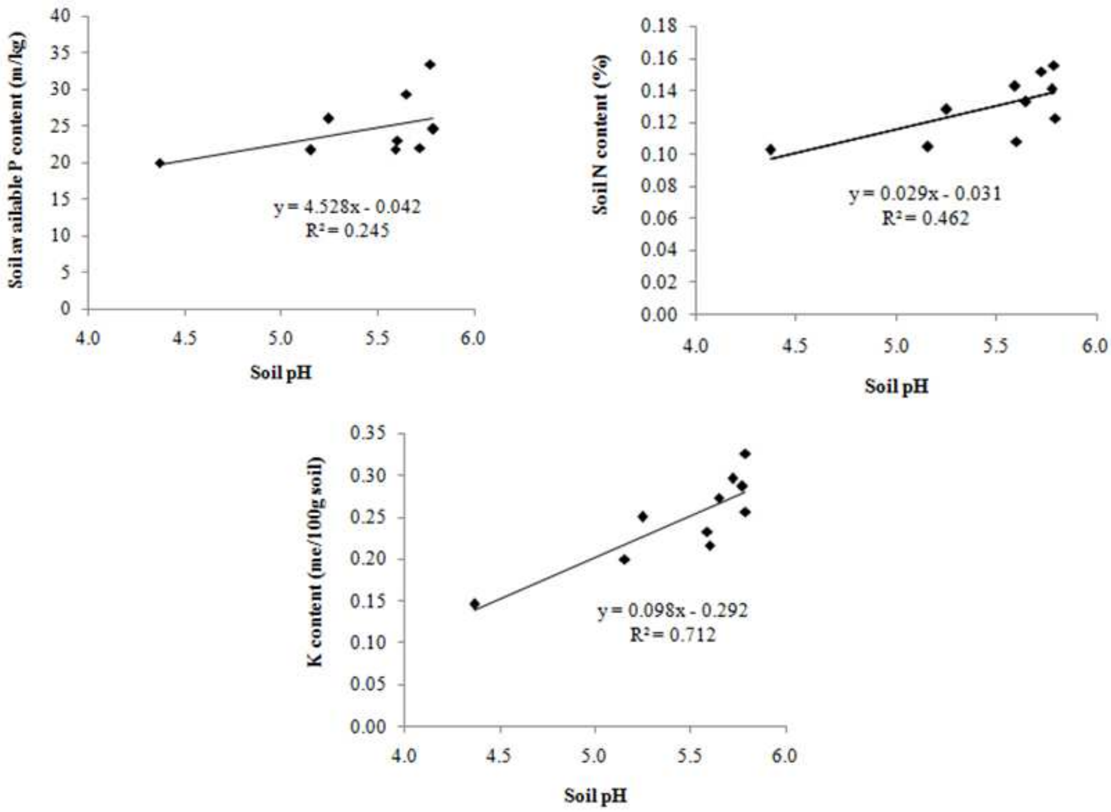

Figure 2. Relationship between soil pH and availability of soil nutrients.

Effect of soil pH on soil P content was not significant and provide a low R^2 value (R^2 = 0.245). This is because the increase in soil pH that was caused by the application of soil amendment only reached pH 5.5, where at the pH value; P availability was still relatively low due to the high availability micronutrients resulting in P fixation by Al, Mn and Fe. Optimum nutrient availability for plants is in the range of pH 5.0 - 7.5, but each plant has a specified optimum pH range. If the soil pH is above or below this range, the amount of nutrients will be imbalanced. The availability of essential nutrients is too high at a low pH such as Al and Mn, may be toxic for the plants, but if the nutrient availability is too low can causes nutrient deficiency in plants (Fernández and Hoeft, 2012). Thus, the pH value of the soil can be used as an indicator of soil chemical fertility, because it can reflect the availability of nutrients in the soil.

Maize Yields

The results of this study showed that the application soil amendments application significantly affected the yields of sweet maize. When compared with the control, the average increase of yield was 30% for all treatments. The high yields of sweet maize cobs between 59.5-63.1 g/plant was found in the rice husk charcoal and maize cob biochar treatment at a dose of 6-9 t/ha (Figure 3).

The positive impact of biochar applications include: retain nutrients in the soil, increasing the cation exchange capacity and soil pH, decreasing the absorption of soil toxic materials, improve soil structure, increase nutrient use efficiency, water holding capacity, reduce emissions of CO_2 and other greenhouse gases (CH_4, N_2O), and increase the population of beneficial soil microbes (Krishnakumar et al., 2013). Siringoringo and Siregar (2011) reported that biochar is able to hold nutrients in the soil directly through the negative charge on the surface area of the charcoal. With the increase in soil pH and soil nutrient availability due to the soil amendment application, the plants will be able to produce optimally, because the plant-growing medium can provide better conditions.

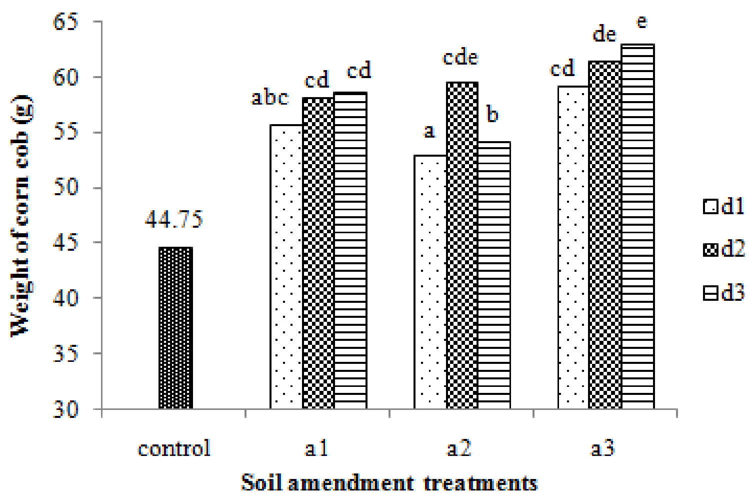

Figure 3. Effect of the soil amendment and dose of application doses on weight of maize cob (LSD 5% = 3.99)

The relationship between the nutrient availability and sweet maize yield

Compared to the control, application of calcite lime, rice husk charcoal, and maize cob biochar increased N availability by 9%, 30%, and 46%, P availability by 16%, 48%, and 14%, and K availability by 53% , 84%, and 94%, respectively. The increased nutrient availability was followed by the increase in yield of sweet maize. The relationship between soil N content and maize cob yield followed a linear pattern. It means that the higher N content of the soil, the higher is the weight of maize cobs, while the relationship between P and K content and maize cob yield followed a quadratic pattern (Figure 4). Based on the regression equation relationship between soil P and K with maize cob yields, the soil content of P and K gave a maximum maize cob yields was at soil P content by 27.2 mg/kg and soil K content by 12.27 me/100 g soil. Plants obtain nutrients and water from the soil through the roots system. However, increased soil nutrient availability does not always increase crop yields because there are many factors affecting the growth and activity of plant roots to absorb nutrients that can limit the uptake of plant nutrients. Understanding of other factors that cause nutrient deficiency in plants is important to avoid excess nutrients due to fertilizer application.

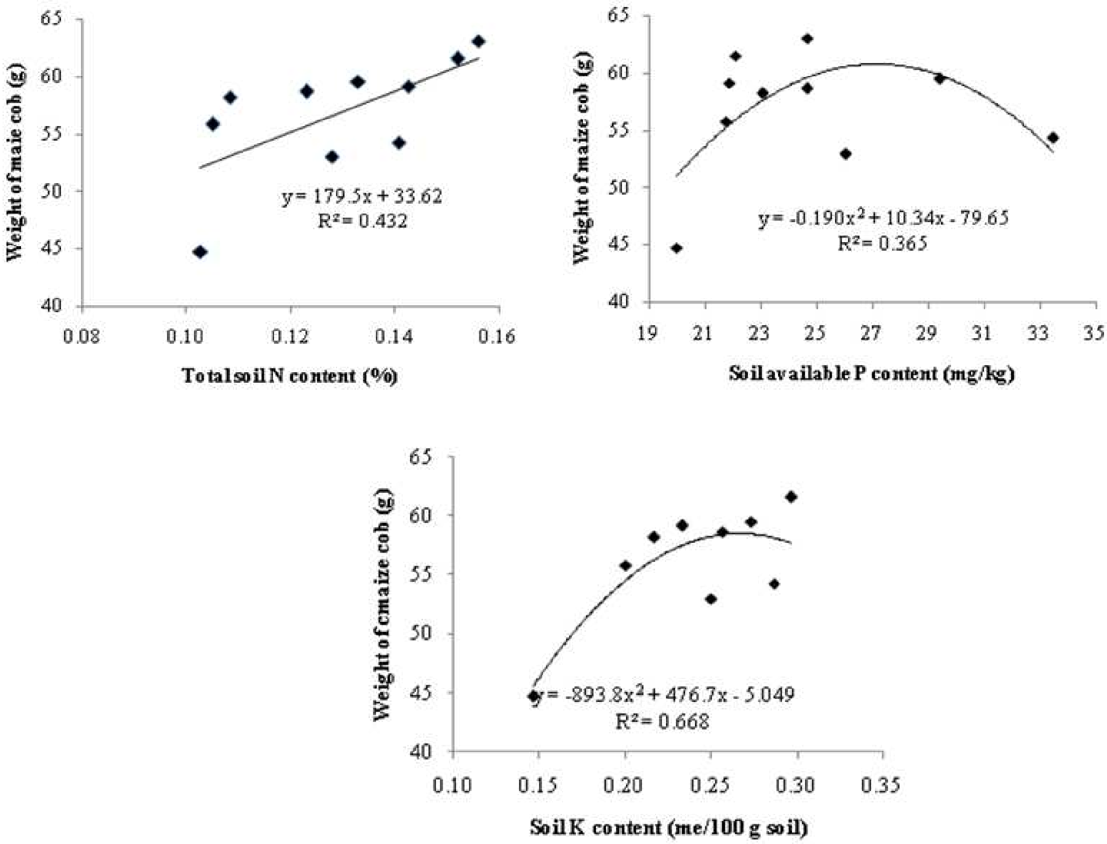

Figure 4. Relationship between availability of soil nutrients and yield of maize cob.

Conclusions

Application of various soil amendments on acid soils can improve soil fertility due to the increase in soil pH, which in turn increases nutrient availability in the soil. The increase of soil pH due to the application of biochar is able to be equally the beneficial effects caused by liming. The average of the increase in the soil pH for each soil amendment treatment was 23% (calcite lime), 20% (rice husk charcoal), and 23% (maize cob biochar) as compared to controls. The increase in soil pH increased the availability of N, P and K. The relationship between the N availability and maize cob yield followed a linear equation, while the relationship between the availability of P and K with the maize cobs yield followed a quadratic equation. The highest sweet maize cobs yield was found in the application of biochar and rice husk charcoal with a dose of 6-9 t/ha. The results of this study suggested that biochar and rice husk charcoals could be used as alternative lime materials for acid soils to improve soil fertility and productivity.

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