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Biochar and Silicon for Sustainable Agriculture in Acid Soil-Nutrient Dynamics and Maize Production: A Review

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ABSTRACT

The central part of the country in the world classified Maize as their staple and essential crop, but this crop cannot cultivate appropriately in acidic soil. Thus, biochar, silicon and phosphorus observation can act as an agent to improve the growth of Maize in acidic soil. Additionally, biochar, well known for its alkaline properties, can reduce soil acidification and, at the same time, improve crop production. This low pH condition was caused by aluminium, manganese and low of phosphorus. Thus, silicon and Phosphorus can improve crop productivity. Using biochar as a soil amendment raises the pH value, alone or in combination. Maize (*Zea mays* L.) and the acidity of the soil are much related to the application of biochar combined with silicon and Phosphorus. Biochar simply can reduce exchangeable soil acidity, but when combined with silicon and Phosphorus, it can have a greater influence on reducing soil Al toxicity. The importance of biochar with different rates combined with silicon and Phosphorus to increase the pH of soil is still an inconsistent result by various studies. This review summarizes the properties of biochar, silicon and phosphorus and provides the scientific reference for its application to archive high yield of Maize and reduce the acidification effect on soil.

Key words: Maize, pH, Phosphorus, Rice husk biochar, Silicon, Yield.

Maize (*Zea mays* L.) is classified as one of the most significant cereal crops in the world, Sirisuntornlak *et al*. (2021) stated that the constantly increasing demand for Maize from various industries causes its production to meet the growing market demands. It also has high production and high export concentrations (Wang and Hu, 2021). Other than that, most of its part is beneficial, such as the use of a decoction of maize roots, leaves, cob and silk for urinary tract and stomach issues as well as nausea or vomiting (Rouf *et al*., 2016). Limited area for crop cultivation and the bad type of soil have become crucial issues in Malaysia and also some other countries. For example, Soil acidity will bring many problems to crop productivity (Shetty and Prakash., 2020; Mosharrof *et al*., 2022). Moreover, this problem stemmed mostly from a phosphorus shortfall and a high propensity for N_2O emissions (Phuong *et al*., 2020) and an increase in the solubilization of Al that inhibited root growth and affected the intake of nutrients (Shetty and Prakash, 2020).

Nowadays, biochar can be classified as an environmentally friendly amendment applied to a variety of soils for agriculture practices (Kamali *et al*., 2020; Ibrahim *et al*., 2016). Biochar is a rich content of carbon, high CEC, large specific surface area and stable structure that originated from various organic waste (Wang and Shizong, 2019). It can adjust the soil structure and soil physicochemical properties and enhance the uptake of soil nutrients for plant growth (Yuan *et al*., 2019). The incorporation of biochar into soils that are nutritionally deficient has the potential to enhance the availability of the soil's nutrient deficiencies and increase plant biomass (Shetty and Prakash, 2020). The acidity of the soil was caused by the availability of Al or Mn toxicity. Dinesh *et al*. (2020) reported that the Si application has the ability to reduce the Al. At the same time, increasing the phosphorus availability, control the Al toxicity and increase the pH of the soil (Chen and Liao, 2016).

According to some estimates, acidification will have a significant impact on 30% of global land and 50% of global arable land (Mosharrof *et al*., 2022). Soils with high concentrations of pyrite (FeS2), which cause high acidity when released into the environment owing to drainage and discharge of large levels of Al3+ and Fe2+ through into the environment, are found nearly exclusively in Malaysia's

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coastal plains (Manickam *et al*., 2015). In one study, soil treated just with biochar had the greatest pH (6.1), followed by soil treated with biochar plus compost, which had a pH of (5.7) and soil treated without additions had the lowest pH (4.8) (Mensah and Frimpong, 2018). Ullah *et al*. (2018) observed that the highest application of biochar at a rate of 5 t ha^{-1} and 10 t ha^{-1} showed the highest amount in the length of stem intermodal. In a different experiment for a height of leaf 6^{th} stage for 0, 5, 10 and 20 t ha^{-1}, Rice husk biochar dose showed a result of 39.36, 42.2, 42.80 and 44.83 cm (Shasi *et al*., 2018). On the other hand, Shetty and Prakash (2020) discovered that applying 10 and 20 t ha^{-1} of husk biochar to plants made them grow and make more biomass than other treatments. According to Rahman *et al*. (2021), biochar increases the nutrient content of C from 42 to 58%, P from 11 to 23%, K from 83 to 1.32% and S from 0.12 to 0.61% while decreasing the nutrient content of N from 2.03 to 1.17%. It was also found in other research that the Inorganic P soluble in $NaHCO_3$ increased by 16-30%, but inorganic P soluble in NaOH and organic P soluble in $NaHCO_3$ decreased (Phuong *et al*., 2020). All application doses of biochar show increasing in nitrogen % except for the control (Islam *et al*., 2018; Abukari, 2014). It was also observed in other experiments that 5% application of rice husk biochar showed 5.9 (cmol + kg/Soil) while 5.1 and 5.5 for control and 2% rice husk biochar application (Manickam *et al*., 2015). Biochar has the potential to improve nutrient retention supply and cause increasing in CEC by up to 50% (Abukari, 2014). Biochar combined with silicon and Phosphorus can benefit the Maize grown in acidic soil. Furthermore, silicon would decrease the carbon and increase oxygen content in the amendment (Zama *et al*., 2018). At the same time, Phosphorus can increase the diffusion of P in acidic soil caused by Al and Fe ions (Maru *et al*., 2020). The application of 3% biochar with Phosphorus shows the highest dry weight compared to the application of 0.5%, 1%, 2% and control (Ahmad *et al*., 2018). Tropic soils have long been regarded as a crucial and worrying constraint on the establishment of cereals because of their high concentrations of exchangeable $Al3+$ (Galindo *et al*., 2021) and decreasing the soil's exchangeable acidity and increasing the soil's exchangeable base cations and biochar could help reduce soil Al toxicity and enrich the soil (Shetty and Prakash, 2020). This study focuses on how biochar combined with silicon and Phosphorus could boost the production of Maize in acidic soil.

Importance of maize crop

Maize is the common crop in the world and will contribute a lot to humans and other living things source of food and for most households' livelihood, it becomes very necessary (Urassa, 2016). It contains a lot of vitamins such as vitamins B, C, A and K, high amounts of beta-carotene and a fair amount of selenium that can improve the thyroid gland and lead to the proper functioning of the immune system (Kumar and Jhariya, 2013). In Ghana, various types of Maize show in the range of 60.2% to 63.1% and 10.0%-12.0% of protein content in six different types of corn and less than 5% of moisture and ash observed (Krimmer *et al*., 2019). N, P, K, Mn and Zn nutrient content in the vegetative organs was 44%, 60%, 13%, 15% and 25%, respectively, in terms of the total nutrient content (Chen *et al*., 2016). Maize is also widely used as a feed mill and can be classified as the major supplier of energy for poultry (Dei, 2017).

Biochar properties

Biochar seemed to be having the highest content of Phosphorus compared to other nutrient content, which is 3098.40 mg kg^{-1} available P, while other nutrients observed less than 50.00 mg kg^{-1} (Mosharrof *et al*., 2021). This treatment also shows a good impact on soil carbon removal and avoiding global climate change (Xiao *et al*., 2020). Aoife *et al.* (2016) suggests that biochar also raises root growth and lowers some types of heavy metals. Different types of biochar would have different properties. For example, Rice straw, rice husk and rice bran biochar similarly showed alkaline Ph but different CEC (Zheng *et al*., 2013). Biochar is mostly produced by the waste product of the crop after harvest. In fact, some biochar can also have the ability to remove pollutants such as blue, tetracycline, pesticide and phosphate after going through the pyrolysis process (Li-Xiangping *et al*., 2020). High-temperature action destroyed Rice Hull's internal structure, but the surface of the biochar shaped a structure and properties with different pore sizes as well as the structure of the hole seemed to be round or oval, according to SEM analysis (Zhang *et al*., 2018). Fig 1 below state the other benefit of maize suggest by few researchers.

Biochar application

A total of 592,477 tonnes of rice husk and 32,000 tonnes of rice husk biochar were produced in Malaysia at the end of 2011 (Manickam *et al*., 2015). Before applying biochar to soils, it is important to know the target pollutant that can be immobilized by biochar (Oni *et al*., 2019). Other than that, applying more doses of biochar would bring a good impact on the crop (Shasi *et al*., 2018). As a result of using biochar, organic carbon, nitrogen and sulphur levels in the soil will rise and soil bulk density will fall to a desirable level (Islam *et al*., 2018). Different types of biochar would also affect nitrogen concentration. Ullah *et al*. (2018) analyze that biochar from the wood mixture, Maize and meadow grass has different Elemental composition (%, w/w), which is 50.43, 48.15 and 48.99 and also different in other nutrient content such as H, O, N and S. A low-cost method of controlling organic carbon and reducing greenhouse gas emissions, is by the implementation of biochar to soils (Mensah and Frimpong, 2018). With the implementation of these modern technologies, you may improve the health of the soil, keep the land alive and maintain its productive capacity (Islam *et al*., 2018). Through pyrolysis, biochar with carbon-rich is obtained and this biomass is normally in a high alkaline state. The higher the alkalinity of biochar, the more effective it treats the acidic soil problem (Shetty and Prakash, 2020).

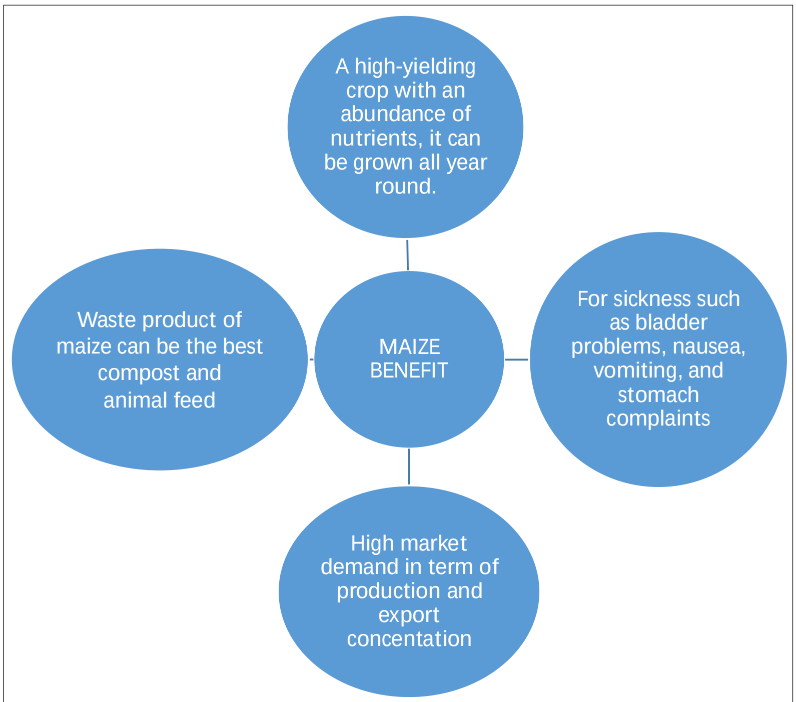


Fig 1: The Benefit of maize.

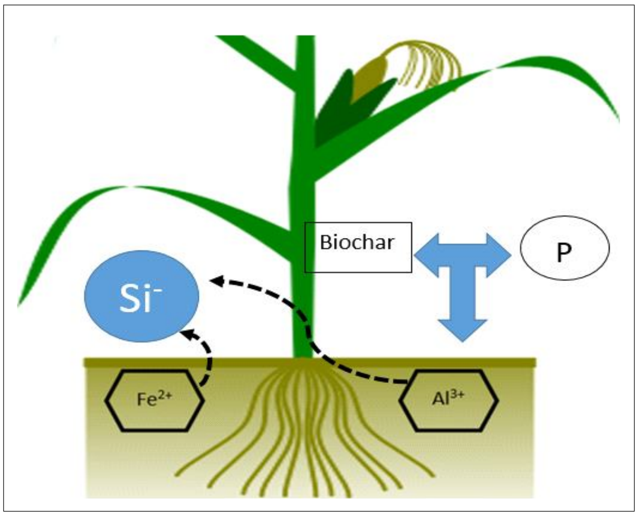


Fig 2: Mechanism of Ion reaction with the treatment.

Effect of biochar on the maize yield

The NPK application with the rate (130-80-40 kg ha^{-1}) applied alone gives less height 76.88 cm result compared with NPK application combined with 10t ha^{-1} biochar with the height of 84.16 cm (Gandahi *et al.*, 2015). Biochar treatments of 5, 3, 1.5 and 0 (controlled) t ha^{-1} produced the lowest crop morphological development in comparison to soil treated with rice husk biochar at a level of 7 t ha^{-1} (Islam *et al.*, 2018). The high dose of biochar combined with high nitrogen show more value for the maize girth and height development compared to low and sole biochar application (Abukari, 2014). Other than that, the seed per cob of Maize when 20 t/ha was 353.00 compared to the control, which was 163.00 seed per cob of Maize (Shasi *et al.*, 2018). The yield observation from different style of biochar application are shown in Table 1.

Mechanism of biochar combine with silicon and phosphorus in acid sulphate soil

Fig 2 illustrates the process of highly content of Fe^{2+} and Al^{3+} would affect nutrient uptake and inhibit root elongation (Manickam *et al.*, 2015; Galindo *et al.*, 2021). Thus, Si would reduce the effect of Fe and Al through the absorption by the silicate surface (Pontigo *et al.*, 2015; Haynes, 2014). Later, biochar was added to increase the cation and increase H+ consumption (Mosharrof *et al.*, 2021). While Phosphorus application would be more effectively applied after Al and Fe stress are reduced, make the ph increase and would improve the plant development (Chen *et al.*, 2016; Ahmad *et al.*, 2018).

Impact of silicon and phosphorus on maize yield

The application of Si to maize crops has the ability to improve the photosynthetic rate but lower the transpiration Rate (Amin *et al.*, 2018; Khan *et al.*, 2017). Si can control the biotic and abiotic stress of crops, at the same time raise nutrient availability and lower nutrient toxicity (Rao *et al.*, 2017) and seems to be an effective application to enhance

Table 1: The effect of biochar in different dose and practices in yield.

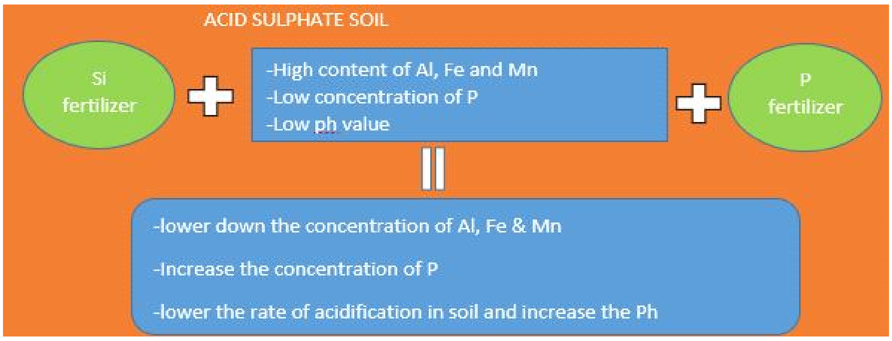
Subject	Condition	Different biochar applications giving different yield observation		Reference
		Treatment	Yield observation	
Maize	2013 at koont research farm Chakwalgrown in 4 m × 6 m sized plots.	5 and 10 tonnes of wheat straw and sugarcane biochar per hectares	Wheat straw biochar of 10 t/ha showed the highest increase in nutrient, biomass and grain yield and the second highest was 10 t/ha of sugar cane	(Ullah *et al*., 2018)
Maize	Bangladesh 2015 observe in 75 and 100 days after sowing	0, 1.5, 3, 5 and 7 (t ha^{-1}) Rice husk biochar	A higher dose would increase the grain yield but lower the net assimilation rate (NAR)	(Islam *et al*., 2018)
Maize	Bangabandhu SheikhMujibur Rahman Agricultural University (BSMRAU), Gazipur from November 2016 toMarch 2017.	0, 5, 10 and 20 (t ha^{-1})Rice husk biochar	Under 60% of FC, the plant height, leaf water content and yield were highest at 20 t/ha	(Shasi *et al*., 2018)
Maize	MARDI research station in Kubang Keranji for 75 days	2% and 5% rice mill biochar	Show yield 500 t/Ha for 2%, 550 t/Ha for 5% and 100 t/Ha for control	(Manickam *et al*., 2015)
Maize	glasshouse, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor	Co-application of RHB10 and 15 (t ha^{-1}) and lime (100% and 75%) was made with different rates of P (100%, 75% and 50%)	The T6 treatments (75% lime + 10 t^{-1} RHB + 100% triple superphosphate) yielded the highest grain production (15.50 t ha^{-1})	(Mosharrof *et al*., 2021)

plant growth and dry matter production mostly under stress-conditions (Younas *et al*., 2021; Kastori, 2015; Mihalicova *et al*., 2014). On the other hand, it found that the seminal root length of Maize applied single silicon in the form of 5 Mm SiO_2 is 24.838 cm, not varied too much from the control, which is 24.304 cm (Vaculikova *et al*., 2014). Besides, Si application improves the chlorophyll content in maize plants and can alleviate salinity without decreasing the growth attributes of the crop (Raza *et al*., 2019). Si would reduce N fertilization in corn from 185-180 kg N ha^{-1} to 100 kg N ha^{-1}, resulting in a 5.2% increase in maize grain production (Galindo *et al*., 2021).

One finding shows that compared to Maize, wheat is more responsive to P, while the responses of Maize and soybean were lower and somewhat equivalent (Sucunza *et al*., 2018). Besides, when it is added on, an amendment would increase the plant growth parameters and uptake of P (Ahmad *et al*., 2018) and yields much better than the control treatments in terms of P content and dry weight for Maize's leaves (Gorchiani *et al*., 2018). At the 8^{th} leaf stage, adding 8 kg ha^{-1} of Phosphorus to Maize increases water linkage, total chlorophyll and antioxidant content. This is true for both well-watered and stressed conditions (Ahmad *et al*., 2017). Biochar was added with lime and half the amount of required Phosphorus increased about 62.38% of the maize production compared to the control (Mosharrof *et al*., 2022) In the application of Phosphorus by using triple superphosphate with a few different rates of 0, 100, 200, 300 and 400 kg. It is observed that for better yield, 300 kg ha^{-1} could be the recommended rate (Aghaie *et al*., 2013). Phosphorus application with three doses of 0,30 and 100 kg P ha^{-1} gives various results in the height of maize 50.1, 72.7 and 82.6 cm that show that increase in height with the increase of P amount (Opala, 2017) P rates of 45-60 kg ha^{-1} and 90-120 kg ha^{-1}, as compared to the control, resulted in maize yields of 9450 kg ha^{-1} and 10, 262 kg ha^{-1} (Jiang *et al*., 2019). For most of the plant's vegetative and reproductive characteristics (Save for leaf dry weight and chlorophyll content), phosphorus fertilizer is beneficial (Gorchiani *et al*., 2018). When phosphorus uptake is optimized, leaf area expansion rates drop and a larger amount of the plant's total daily carbohydrate intake goes towards the plant root (Postma *et al*., 2014).

Effect of biochar on acidic soil

The low value of pH in soil was commonly faced by Asians. It was found that biochar can reduce the acidity of the soil (Islam *et al*., 2018). It also maintains the required pH through basic cation additions and H+ consumption (Mosharrof *et al*., 2021). Soil acidity can be reduced by using biochar that undergoes pyrolysis at a high temperature because of its high concentration of base cations (Mosharrof *et al*., 2022). Biochar alone or in combination with compost can improve soil quality and increase the production of Maize (Mensah and frimpong, 2018). It has been discovered that in pot trials conducted in acidic soil, biochar doses of 30 t/ha boosted crop productivity by 11% on average (Manickam *et al*., 2015). While in another



(Zama *et al*., 2018; Maru *et al*., 2020).

Fig 3: The summary for the application of Phosphorus and Silicon fertilizer.

finding shows that 0.5% biochar application shows the highest amount of Ph soil after treatment which is more than seven ph values compare to biochar treatment that more than 0.5% (Ahmad *et al*., 2018). However, soils with such a pH of 7 or above demonstrated no significant variation in the amount of plant P that could be available for plant growth when biochar was applied (Glaser and Lehr, 2019). There were no significant variations in soil P fractions between the treatments of biochar and Phosphorus combined with mineral P fertilizer, on the other hand (Li *et al*., 2020).

Acid sulphate soil and the nutrient availability

Soil acidity will bring many problems to crop productivity (Shetty and Prakash, 2020). This issue is caused by phosphorus deficiency, high potential for N_2O emissions and low ph value (Phuong *et al*., 2020) The acidity of the soil poses a significant challenge to agricultural production. (Mosharrof *et al*., 2021). The coastal regions of Malaysia are almost the only places in the country where these soils may be found and It is distinguished by significant concentrations of the mineral pyrite (FeS_2), when exposed to air as a result of drainage, generate a great deal of acidity and also liberate a great deal of the ions Al_3+ and Fe_2+ through into surrounding environment (Manickam *et al*., 2015). Soils in Sub-Saharan Africa (SSA) are also under this stress due to intensive agriculture and fast mineralization of organic materials (Mensah and Frimpong, 2018). Root elongation and nutrient uptake are inhibited by the solubilization of Al that occurs when the soil ph is low (Shetty and Prakash, 2020). High exchangeable Al3+ and Al_3+-related Al_3+ levels have long been recognized as substantial and worrying restrictions in tropical crop production when the soil pH value is low (Galindo *et al*., 2021).

Al and Mn will be more readily available to plants if the pH is lower than 5.5, but other important nutrients like Phosphorus, calcium and magnesium will be deleted. This will have a negative impact on plant growth (Potingo *et al*., 2015). The major factor of limitation for the crop in acid soils is Aluminum (Al) toxicity and at the same time would affect crop production (De Sousa *et al*., 2019). Ph below 5.5 shows that the soil is in an acidic state and also contains high solubility of aluminium that increases the toxic levels and leads to plant growth, reducing and severely restricting the root system (Opala, 2017).

Effect of silicon and phosphorus on acid sulphate soil

Silicon and phosphorus fertilizer can be applied to neutralize and lower the rate of acidification in soil. P deficit and metal toxicity from Mn and Al have a negative impact on the soil's ph value, resulting in an increase in the ph value of the soil (Potingo *et al*., 2015). Moreover, variable charged soil colloids such as Fe and Al hydrous oxides can be adsorbed through the surface by silicate and this process has the potential to increase the ph up to 9.8 (Hyanes, 2014) and Al toxic effects in maize plants cultivated on acidic soil can induce stressed-maize organs, which reduces the growth and photosynthetic rate of maize plants (De Sousa *et al*., 2019).

However, phosphorus application results in a fall in soil pH, which results in more acidic soil (Li *et al*., 2020). For Al-sensitive species, long-term Al-P alternating treatment may not always reduce Al toxicity and may only work after Al stress has been eliminated, according to this study (Chen and Liao, 2016). Moreover, the p application of P fertilizer (TSP) or in organic form (Farmyard manure) can cause $CaCl_2$-extractable aluminium to be reduced, whereas soil pH and the amount of P that can be extracted from $CaCl_2$ were both raised (De Bauw *et al*., 2021). Phosphorus applied with other nutrients such as nitrogen would enhance maize grain yield and nutrients (Zhihui *et al* ., 2016). Fig 3 is the summarization of the effect of adding Phosphorus and silicon fertilizer in acid sulphate soil.

Conclusion

The fast development of people population numbers in this world has become a limiting factor for natural resources. Biochar has been shown to be a useful tool for sustainable farming, improving soil health, keeping the land alive and keeping its ability to produce. Biochar has clear benefits that have been shown to increase the soil's organic carbon, nitrogen, sulphur, ph value and bulk density to a good level. Moreover, this application is still being under study and research continues to be done to observe more about this application. Many aspects of biochar combined with silicon and phosphorus fertilizer on maize yield and acid sulphate soil still need more study because the ready result is still inconsistent and unclear.

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