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INFLUENCE OF NITROGEN FERTILIZER AND RICE-HUSK BIOCHAR INTERACTION ON PHENOLOGY AND GROWTH PARAMETERS OF MAIZE GROWN IN THE VERTISOLS OF ACCRA PLAINS, GHANA

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ABSTRACT
The use of biochar is gaining international attention among researchers as amendment for fertility enhancement in recent years. This is because biochar has a vital carbon source which is essential for soil fertility improvement due to its physicochemical properties. The excessive sole application of inorganic fertilizers on vertisols of Accra plains in Ghana has led to the gradual degradation of the soil health. It is therefore important to consider nitrogen fertilizer and biochar combination as a sustainable soil fertility improvement strategy. It was hypothesized that the combined application of rice husk biochar (RHB) and Nitrogen (N) fertilizer to vertisols could improve growth parameters and phenology (number of days tasseling and maturity) of *Obatampa* maize cultivar. A 3 factorial (3 x 2 x 3) field experiment arranged in a RCBD was carried out to investigate the effects of biochar and Nitrogen fertilizer combinations on phenology and growth parameters of *Obatampa* maize cultivar. Three levels of Nitrogen fertilizer with and without RHB (10t ha^{-1}) were assessed on one maize (*Obatanpa*) variety. This was repeated on three different planting dates (1st sowing-S1, 2nd sowing-S2 and 3rd sowing-S3). The treatments (biochar only, 0N, 45N only, 45N + biochar, 90N only and 90N + biochar) were replicated thrice on a plot size of 6 m x 6.4 m. As basal application, a total of 45 kg ha^{-1} of P (Triple Super Phosphate) and K (Potassium Chloride) were applied respectively. The results showed significant differences among the growth parameters measured and phenology of *Obatanpa* maize cultivar. At the 50% flower stage, total leaf number (TLN) in all the three (3) sowing dates has significantly increased with the highest leaf number (17) obtained under 90 N kg ha^{-1} fertilizer applications and the least leaf number (13) under biochar alone. The combinations of RHB and Nitrogen fertilizer significantly ($P < 0.05$) increased leaf area index (LAI) of maize. Also, the number of days to maturity of *Obatanpa* maize cultivar was significantly ($P<0.05$) affected by Nitrogen fertilizer levels, RHB and planting date interaction.

1.0 Introduction

Maize (Zea mays L.) production plays a vital role in global food security, particularly in developing countries (Ali et al., 2017). Currently, maize is one of the most essential cereal crops grown and largely consumed by Ghanaians in one form or the other. The crop is high yielding, rich in nutrition with many uses. It is grown mainly under rain fed in all the agroecological zones in Ghana during the wet and dry seasons. With increasing population, there is the urgent need to meet the demand for food, freshwater, energy, feed, and fiber (Lindgren et al., 2018; Haider et al. 2017).

These situations, in recent years, have led to intensive production in the agriculture, resulting in increased inorganic fertilizers use in Ghana. The high dependence on chemical fertilizers, unfortunately, has caused many problems to the soil health. The decline in soil productivity in Ghana is largely attributed to continuous cultivation and increased inorganic fertilizer use. For instance, the over reliance on Nitrogen fertilizer for soil fertility improvement results in soil acidification (Sheng et al. 2016), poor nitrogen use efficiency and constant decline in the quality of agricultural soil (Arif et al. 2016) hampering food security.

To increase crop yield, serious attention must be paid to phenology of a crop since it plays very essential role towards crops yield. Generally, the phenology determines the growth, development and the time of assimilate partitioning in plant body (GonzalezNavarro *et al*., 2016). Nutrients management on environmentally friendly manner helps to ensure proper balance between vegetative and reproductive growth phases of crops (Shah, & Wu, 2019). It is therefore, important to adopt a modern soil management strategy that do not only improve the fertility of the soil, but also keep the land vigorously alive and sustains its productivity.

Biochar has been identified as amendment for soil improvement in recent years by the scientific community (Kraska et al., 2016). Biochar is mainly a stable organic material that is obtained by the pyrolysis of organic waste (plant residue) at higher temperature under low oxygen environment, particularly used for soil amendment (Qambrani et al., 2017). According to Zheng et al. (2013), the use of biochar as a soil amendment does not only improve the fertility of the soil but also promote sustainable agriculture promotion. This is because biochar is reported to act as a soil modifier to improve the crop yield, increase the NUE and for mitigation of soil acidification (Kuppusamy et al., 2016; Feng and Zhu 2017). The use of biochar as amendment also has the potential of reducing the adverse impacts of salt stress on crops and thereby enhancing the general production of crops (Akhtar et al., 2015, Saifullah et al., 2018).

In addition, biochar application to the soils helps change the physicochemical and biological properties of the soil (Sarfraz et al., 2017), increase cation exchange capacity (CEC), as well as contributing to an increase in water-holding capacity, and the mycorrhizal competence in the soil (Hagner et al., 2016). It was also observed that biochar could improve the nutrient retention of soil for nitrogen, phosphorus, potassium (Kameyama et al. 2014) as well as improving significantly the stability of soil organic carbon (Joseph et al., 2020). One of the major essential plant nutrients that affect crop morphology, phenology, growth and yield is Nitrogen (N) (Abid et al., 2016). However, its continuous use as a sole fertilizer causes fertility loss and decrease in farmland soil productive potential (Trupiano et al., 2017), whiles biochar in combination of N fertilizer improves the general quality of the soil. This is as a result of the positive synergistic effect on soil nutrient which result in efficient nutrient use, increased water holding capacity, improved plant growth, and general reduction in the amount of inorganic fertilizer application (Shi et al., 2020: Mensah and Frimpong, 2018). Despite numerous roles biochar plays in soil fertility improvement, it was observed that solitary application of biochar, in most cases, did not actually provide any significant amount of nutrients to the soil (Mensah and Frimpong, 2018: Sadaf et al., 2017), but very instrumental in promotion of soil health when used in combination with biochar (Sara et al., 2018).

Unfortunately, research into biochar in general, and rice husk biochar in particular, in Ghana is relatively new. Knowledge on biochar, its influence on soil properties, crop phenology, growth, and yield in various soil types in Ghana is limited. In view of the above discussion, the study was planned in a typic calcicustert (vertisol) soil with the following objectives: (1) to assess the impact of rice husk biochar and Nitrogen fertilizer on the phenology of *Obatampa* maize, and (2) to evaluate the impact of rice husk biochar and Nitrogen fertilizer on some growth parameters of *Obatampa* maize.

2.0 Materials and methods

2.1. Experimental site

The experiment was conducted at the University of Ghana, Soil and Irrigation Research Centre (SIREC) located in the Eastern Region of Ghana. The center is 80 km N.E from the capital city of Ghana, and 3km off Tema-Akosombo high way. The study site falls within the coastal savannah agro-ecological zone of Ghana which is on latitude 6° 09'N and longitude 00° 04'E at an altitude of 22 m above mean sea level. It is within the tropical climate with annual mean rainfall and temperature of 1200 mm and 27.5 °C respectively. The soil type of the study site is classified as a Typic Calcicustert, a Vertisol, based on FAO-UNESCO system of classification (FAO-UNESCO, 1990). It is tropical black clay locally belonging to the Akuse series (Amatekpor and Dowuona, 1995), covering about 0.163llion hectares of Accra plains (Brammer, 1967). Vertisol is a dark-coloured soil that is made up of about 35-40% of montmorillonite, an expansive clay mineral. The soil is prone to severe cracks particularly during the dry season. It however, swells and becomes very sticky when wet during the raining season.

2.2 Biochar Production

The RHB was prepared from the rice husk collected from the rice milling plant located within the research center. It was thoroughly dried under the ambient sunshine. The RHB was produced under partial oxygen supply, known as pyrolysis. A low -tech drum method as describe by Srinivasarao et al. (2013) was used in the production of biochar. Water was used to quench the hot biochar, and sun dried for few days before measurement and use. The chemical properties of the biochar were analyzed according to IBI (International Biochar Initiative's (1BI) 2011) standard protocol at the University of Ghana, Legon, Ecological laboratory (ECOLAB). The chemical characteristics of RHB biochar used in this study are showed in Table 2.

2.3 Properties of Soil and Biochar

The soil samples of the study site were collected at depths: 0–15, 15–30, 30–45, 45–60, 60–75, and 75–90 and 90–100 cm. prior to soil preparation They were open air dried, homogenized, ground to pass through a 2-mm sieve. The soil was analyzed for various physical and chemical properties (Table 1).

Table 1. Pre-planting soil chemical properties of the study site at SIREC, Kpong Ghana.

Soil depth (cm)	pH (1:2) Soil: H_2O	S.O.C	Total N	O.M	Avail. P (cmg kg^{-1})	CEC (cmol kg^{-1})	K (cmol kg^{-1})
		-----------------	%	----------------			
0-15	6.71	0.85	0.08	2.47	4.54	38.21	0.27
15-30	7.20	0.77	0.07	2.12	4.25	39.30	0.19
30-45	7.30	0.66	0.06	1.87	3.48	35.60	0.09
45-60	7.38	0.54	0.05	1.56	3.22	34.21	0.09
60-75	7.41	0.48	0.04	1.35	3.22	35.42	0.07
75-90	7.40	0.45	0.03	0.66	3.09	33.70	0.05
90-100	7.40	0.41	0.03	0.51	2.53	33.31	0.05
Lsd (<0.05)	0.034	0.011	0.006	0.008	0.007	0.071	0.007

S.O.C - Soil organic carbon; N - Nitrogen; O.M - organic matter, P - Phosphorus; CEC - cation exchange capacity, K - Potassium

Table 2. Chemical properties of rice husk biochar

Sample	pH (H_2O)	O.C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	CEC (cmol kg^{-1})
Bio-char	7.01	57	0.8	0.09	0.53	20.4

O.C - organic carbon; N - Nitrogen; P - Phosphorus; K - Potassium CEC - cation exchange capacity.

2. 4 Experimental design and treatments

The experiment was made up of three Nitrogen fertilizer levels of (0, 45 and 90 kg/ha) with and without RHB (10t ha^{-1}). The treatments were evaluated on *Obatanpa* maize cultivar on three different planting dates (26/06/14, 06/09/14 and 26/09/14). A 3 factorial (3 x 2 x 3) trials arranged in a RCBD was used. P and K in the form of Triple Super Phosphate (TSP) and Potassium Chloride

(KCl) were applied at the rate of 45 kg ha^{-1} as basal dose respectively. The individual plot sizes were 6 m x 6.4 m with three replications. The N was split applied at 50% rates at 14 days post emergence and 2 weeks prior to tasseling. The RHB was manually incorporated into the top 0.25 m of the soil 1 week before planting at the same rate except for the control. The planting material, *Obatanpa* maize cultivar, was secured from Crop Research Institute, Kumasi Ghana. The maize cultivar is an improved variety commonly grown in Ghana. Four (4) seeds were sown manually at a spacing of 0.8 m x 0.4 m and later thinned to two (2) plants per hill at 2 weeks after emergence. Weed emergence on the plots was controlled by hand weeding and the use of hoe to prevent competition with the maize plants. Supplemental irrigation was applied to avoid water stress on plants since there was insufficient rainfall toward the later part of the growing season.

2. 5 Sampling and measurements

Plants data on phenology were daily monitored and collected. These included: date of emergence, date of flag leaf stage, date of tasseling and date of physiological maturity. These stages were observed when at least 50% of the plant population attained that stage. Data on growth parameters collected during the field experiment for this study was the leaf number and leaf area index (LAI). For LAI, six plants were sampled and data taken on theme from the third week of planting to tasseling. The sampled plants were, tagged per plot and measured. The leaf length (from the tip of the leaf to the attachment to the collar) and width were measured using a tape. Thus, LA = Shape Factor (0.75) x Length x Width (LA = L × W × 0.75). Leaf area index was calculated as the total leaf area per plant divided by the soil surface available for each plant. For total leaf number, the same six plants that were sampled from each plot for LA were used. The number of leaves that are fully opened and senesced from first leaf to the flag leaf were counted and marked with a permanent maker. Total leaf number per plant was obtained as the average number of leaves counted.

2.6 Statistical analyses

Data collected were tested for main effects of rice husk biochar and Nitrogen fertilizer as well as the interactive effect using factorial analysis of variance (ANOVA). Where rice husk biochar and Nitrogen fertilizer interaction was significant ($P < 0.05$), the significant differences were assessed using Tukey's HSD test. All analyses were performed using GenStat (9th Edition).

3.0 Results

3.**1 Rainfall during the cropping seasons**

Rainfall during the first planting cycle (Jun-Oct 2014) was low compared to second planting (Sept-Dec 2014). The third planting (Sept-Jan. 2015) experienced the least rainfall (Figure 1). Rainfall during the growing period was highest (139.7 mm) in October, 2014 and decreased through November to December with January, 2015 recording the least (7.5 mm).

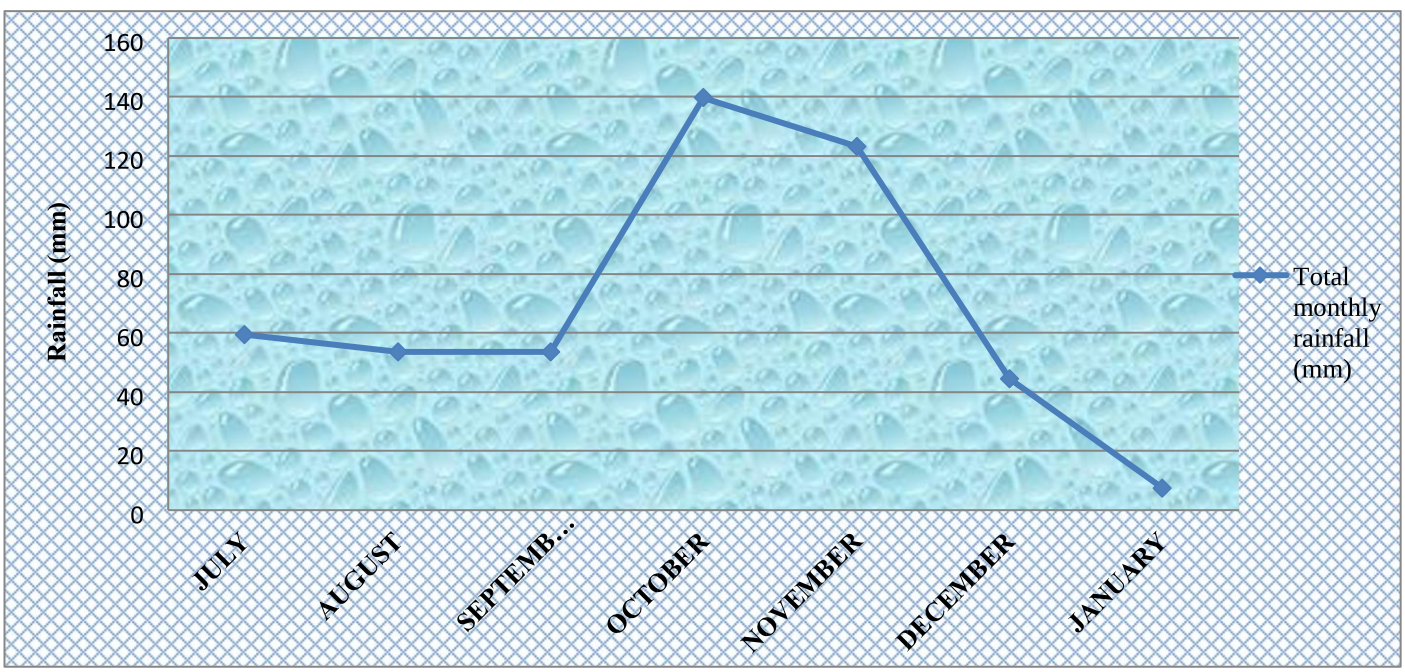

Figure 1. Total monthly rainfall for 2014-2015 cropping seasons at SIREC, Kpong Ghana.

3. 1 Soil and biochar properties

The soil pH values ranged from the topsoil (6.7) and increased down (7.4) the profile. The pH of the soil can be described as one that is neutral. On the top (0-15 cm) of the soil, organic carbon (OC) content was 0.85% and decreased to 0.41% at 90- 100cm soil depth. The topsoil has OC that is moderately high. The soil organic matter (2.47%) was moderate at the top soil (0-15 cm) but decreased to a very low 0.51% at soil depth of 90-100 cm. The N content of the soil was low at all depths, less than 0.1%. The RHB has CEC of 20.4cmol kg^{-1}. The percentage P and K in the RHB were 0.09 and 0.53 g kg^{-1} respectively. Nitrogen (0.8g kg^{-1}) content of RHB was low. The pH of the rice husk biochar (7.01) was neutral (Table 2).

3.2 Effect of biochar and N fertilizer on maize phenology

3.2.1 Germination

In all the 3 sowing dates, plant germination was not in any way affected by treatments. On the 5th day after planting, a 50% of emergence was observed in all the three sowing dates (S1, S2 & S3). Maize at a temperature of 20 ºC germinates within five to six days after planting; on the other hand, this may be faster or less variable at soil temperatures of 16 to 18 ºC (Bradáčová, Klara, et al., 2016).

3.2.2 Anthesis

The effects of Nitrogen levels on days to 50 % tasseling in all the 3 sowings were significant ($p < .001$). The control plots (0N) took more days (58) to tassel than 90N treated plots (55 days). This shows that Nitrogen stress has an effect of on days to tasseling on maize**.** The number of days to 50% tasseling of *Obatanpa* maize variety was significantly ($P<0.05$) affected by planting date, N levels and biochar interaction.

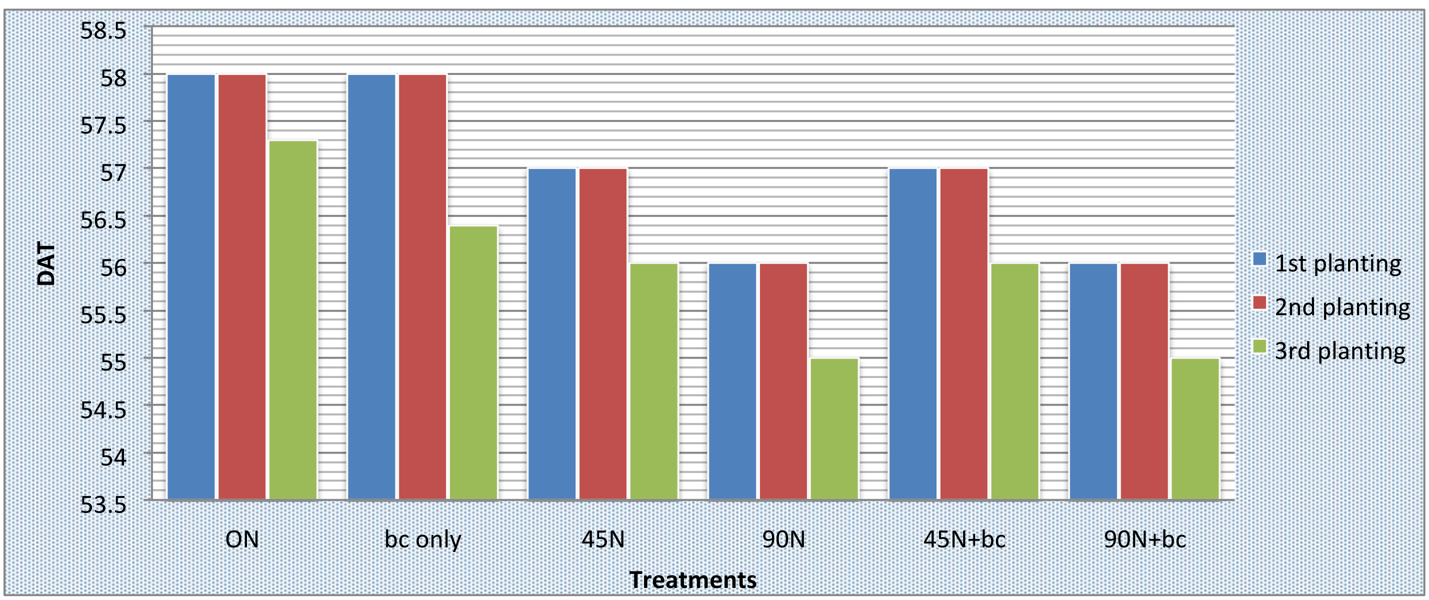

Figure 2. Effects of N fertilizer and biochar (bc) treatments on days to 50% anthesis (DAT) of *Obatanpa* maize cultivar at SIREC, Kpong Ghana.

3.2.3 Maturity

Treatments and different sowing dates greatly affected the number of days plants took to attain 50% maturity. Significant ($P< 0.05$) differences were noted in fertilizer treatments and planting dates (figure 3). The number of days to maturity (DMAT), in the 3 planting dates, ranged from 100 to107 days. The earliest DMAT was observed on highest fertilizer applications plots (90 N kg ha^{-1}). The number of days to maturity greatly decreased with increased nitrogen fertilizer rates for the *Obatanpa* maize variety. Furthermore, DMAT was significantly ($P<0.05$) affected by interaction between Nitrogen levels, RHB and planting date of *Obatanpa* maize cultivar.

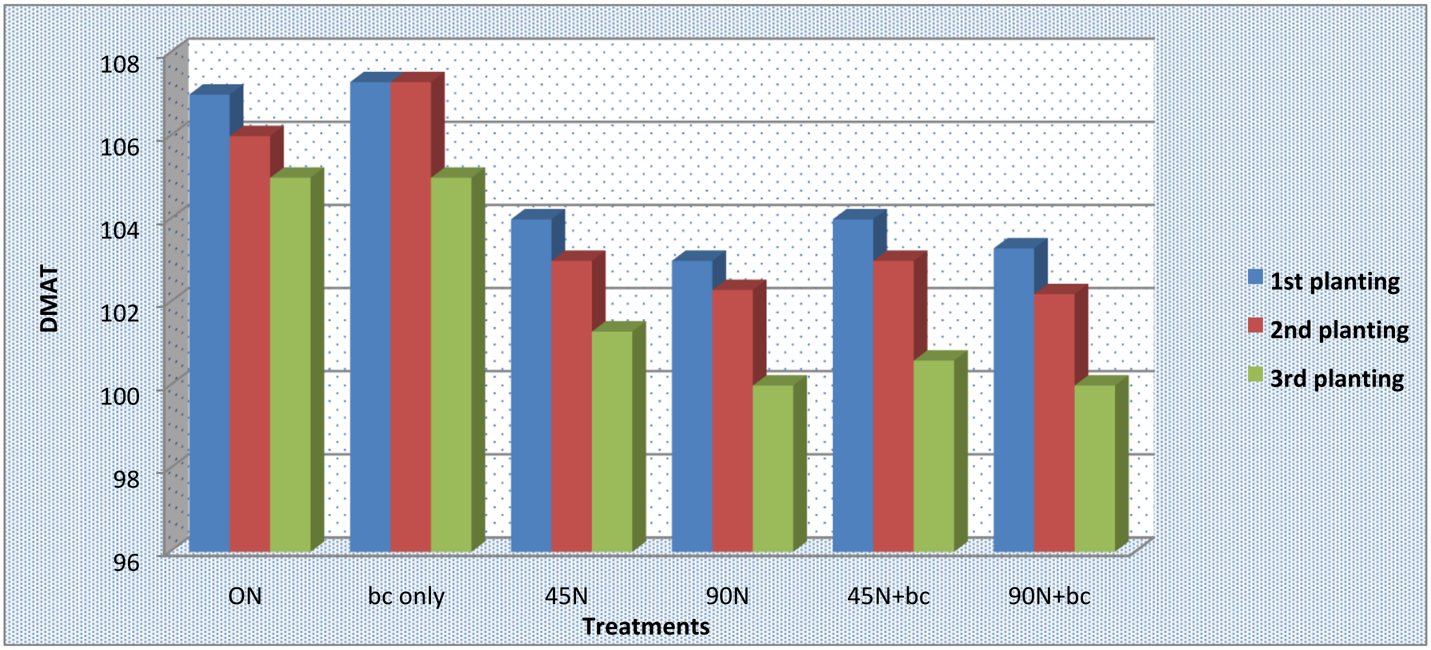

Figure 3. Effects of N fertilizer and biochar (bc) treatments on DMAT of *Obatanpa* maize cultivar at SIREC, Kpong Ghana.

3.3 The impacts of rice husk biochar (RHB) and nitrogen fertilizer rates on some growth parameters of maize *(Obatampa)*

3.3.1 Leaf number

The total leaf number (TLN) of *Obatampa* maize greatly increased with time and later peaked at 8 weeks post planting. At 50% flower stage, significant (P<0.05) differences were observed in the number of maize leaves produced among the various treatments (Table 1). At all the three (3) sowing dates (S1, S2 & S3), TLN at 50% flower stage were significant (P<0.05). Plots treated with 90 N kg ha^{-1} fertilizers produced the highest leaf number with the least number on plots with only RHB applications. The interactions between planting date, RHB and Nitrogen fertilizer has significantly (P<0.05) influenced the number of leaves produced by *Obatampa* maize.

Table 1. Effect of N fertilizer and rice husk biochar treatments on leaf number of maize (Obatanpa) during the 2014 cropping season at SIREC, Kpong Ghana.

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	14	15	17	15.3	
Date one	Biochar	14	16	17	15.7	15.5
Mean		14	16	17		
	No Biochar	14	16	17	15.6	
Date two	Biochar	14	16	17	15.7	15.7
Mean		14	16	17		
Date three	No Biochar	13	16	17	15.2	
	Biochar	14	16	17	15.5	15.4
Mean		13	16	17		
Mean		13.7	15.9	17.0		

LSD (P ≤ 0.05); Planting date = 0.28* Fertilizer = 0.28* Biochar = 0.23*
Planting date × Fert. = 0.49* Planting date × Biochar = 0.40*
Biochar × Fert. = 0.40* Planting date × Biochar × Fert. = 0.70*

* = significant at 5% probability level NS= not significant at 5% probability level

3.3.2 Leaf area index

The different Nitrogen fertilizer application levels significantly (P < 0.05) affected the leaf area index (LAI). The increase in Nitrogen fertilizer levels had a corresponding increase in the LAI of *Obatampa* maize. The highest LAI (2.7) was recorded for the high rate N + RHB with the least (1.0) for the control (Table 2). The interaction between the various Nitrogen fertilizer rates and RHB significantly (P < 0.05) affected LAI. However, planting date has no significant effect on leaf area index of *Obatanpa* maize cultivar (Table 2).

Table 2 Effects of Nitrogen fertilizer rates and biochar treatments on leaf area index (LAI) of *Obatanpa* maize cultivar during the 2014 cropping season at SIREC, Kpong Ghana.

		Fertilizer				
Planting date	**Biochar**	**No fertilizer**	**45 N**	**90 N**	**Mean**	**Mean**
	No Biochar	1.0	1.5	2.2	1.6	
Date one	Biochar	1.1	1.6	2.4	1.7	1.7
Mean		1.1	1.5	2.3		
	No Biochar	1.0	1.9	2.4	1.8	
Date two	Biochar	1.1	2.2	2.7	2.0	1.9
Mean		1.1	2.1	2.6		
	No Biochar	1.1	1.7	2.4	1.8	
Date three	Biochar	1.3	1.9	2.6	1.9	1.9
Mean		1.4	3.6	2.5		
Mean		1.7	2.4	2.5		

LSD (P ≤ 0.05); Planting date = **NS** Fertilizer = 0.38***** Biochar = 0.03*
Planting date × Fert. = 0.07* Planting date × Biochar = 0.05*
Biochar × Fert. =0.05***** Planting date × Biochar × Fert. = 0.09*****

* = significant at 5% probability level NS= not significant at 5% probability level

LSD (P ≤ 0.05); Planting date = **NS** Fertilizer = 0.38***** Biochar = 0.03*
Planting date × Fert. = 0.07* Planting date × Biochar = 0.05*
Biochar × Fert. =0.05***** Planting date × Biochar × Fert. = 0.09*****

* = significant at 5% probability level NS= not significant at 5% probability level

4. Discussion

4.1 Nitrogen fertilizer levels and rice husk biochar on phenology

Data on maize phenology as affected by RHB and N fertilizer management are presented in figure 2&3. Tasseling was delayed for treatments with decreasing N levels. The early tasseling of maize in 90N kg ha^{-1} treatment plots compared to 0N and 45N kg ha^{-1} plots indicate that the soil N level has influence on maize phenology. Golla and Chalchisa (2019) observed similar early tasseling of maize with higher level of N rate application in a field work conducted in the transition zone in Ghana.

On the other hand, N fertilizer and RHB interaction has no significant effect on the number of days to tasseling in *Obatanpa* maize cultivar. The differences that were observed between phenology and sowing dates could also be as a result to the differences in Nitrogen fertilizer levels, and other factors such as water and temperature differences in the 3 sowing dates. This is because the maximum temperatures going beyond 32 C increase the process of differentiation of the reproductive parts of maize most especially during tasseling and pollination periods, thereby resulting in an early completion of life circle (Wang et al., 2021)

The number of days to 50% maturity of maize decreased significantly (P < 0.001) with increased nitrogen fertilizer rates. This is due to the fact that, biochar as a soil amendment, played essential role in improving water holding capacity (WHC) of the soil, slowly release of nutrients, reduced nutrients leaching (Suo et al., 2021), enhancing nutrients concentration and nutrients use efficiency (Mierzwa-Hersztek *et al*., 2019), thereby making adequate nutrient readily available for the plants during the growing period resulting in early maturity.

5.4 Effects of Nitrogen fertilizer and rice husk biochar on growth parameters of the maize

Leaf number and leaf area index are indices of plant growth and have direct influence on crop yields. Therefore, where soil moisture and solar radiations are not limiting a larger leaf surface area is preferred to optimize photosynthetic activity of the plant. Results showed that treatment combinations (planting date, biochar and inorganic fertilizer) significantly influenced the number of maize leaves produced per plant during the growing season (Table 2). Wang et al. (2021) observed that the use of biochar with nitrogen fertilizer has a more positive impact on improving NUE of maize and promoting soil quality as a result increasing the total leaf number of maize.

Furthermore, the increase in LAI as the result of the combined effect of biochar and Nitrogen fertilizer application showed biochar as an effectiveness amendment for improving crop growth and development. This is because soils amended with biochar attract ammonium and nitrate ions, at the same time minimize their leaching and helps increase the vegetative growth of plants (Salim, 2016), such as the leaf area index The improved leaf area index could also be due to the delayed in the senescence of maize leaves because the physicochemical properties of biochar (Fidel et al., 2018). Ahmad et al. (2015) reported that biochar application as soil amendment does not only significantly enhance the fertility of the soil but also improve the leaf area index of crops (Singh et al., 2019), indicating a very strong fertilizer by biochar interaction. Also, the obtained results are consistent with those that were reported by (MacCarthy et al., 2020; Oladele et al., 2019; Batool et al., 2015).

Conclusion

Rice husk biochar greatly enhanced the soil physicochemical and biological properties thereby improving the Nitrogen fertilizer efficiency. Results obtained from the field experiment showed significant differences among the growth parameters measured and phenology due to different treatments imposed. The interaction between Nitrogen fertilizer levels, RHB and planting date greatly affected the number of days to maturity of *Obatanpa* maize cultivar. Additionally, Nitrogen fertilizer and RHB combination increased the total leaf number and LAI. Thus, nitrogen fertilizer in combination with biochar provides an ideal soil quality improvement strategy essential for growth and development of *Obatanpa* maize in vertisols of Accra plains, Ghana.

Reference

Abid, M., Schilling J., Scheffran J., Zulfiqar, F. (2016). Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. *Elsevier*. (584), 447-460.

Ahmad, M., Akbar, H., Jan, M.T., Khattak, M.J.K., Bari, A. (2015). Effect of seeding depth, nitrogen placement method and biochar on the growth, yield and its related parameters of sugar beet. *Sarhad Journal of Agriculture*, 31(4): 224-231.

Akhtar, S.S., Andersen, M.N., Liu, F.L. (2015). Residual effects of biochar on improving growth, physiology, and yield of wheat under salt stress. *Agricultural Water Management*, 158: 61–68.

Ali, K., M. Arif, F. Shah, A. Shehzad, F., Munsif, I.A., Mian, A.A. (2017). Improvement in maize (*Zea mays* L) growth and quality through integrated use of biochar. *Pakistan Journal of Botany*, 49(1): 85-94.

Amatekpor, J.K., & Dowuona, G.N.N. (1995). *Site Characterization. IBSRAM Vertisol Project*; Department of Soil Science, University of Ghana: Legon, Ghana, p. 42.

Arif, M., Ali, K., Jan, M.T., Shah, Z., Jones, D.L., Quilliam, R.S. (2016). Integration of biochar with animal manure and nitrogen for improving maize yields and soil properties in calcareous semi-arid agroecosystems. *Field Crops Research*, 195, 28–35.

Batool, A., Taj, S., Rashid, A., Khalid, A., Qadeer, S., Saleem A.R., Ghufran, M.A., (2015). Potential of soil amendments (Biochar and Gypsum) in increasing water use efficiency of *Abelmoschus esculentus* L. Moench. *Frontiers of Plant Science*, 733(6): 1-13.

Bradáčová, K., Weber, N. F., Morad-Talab, N., Asim, M., Imran, M., Weinmann, M., & Neumann, G. (2016). Micronutrients (Zn/Mn), seaweed extracts, and plant growth-promoting bacteria as cold-stress protectants in maize. *Chemical and Biological Technologies in Agriculture*, *3*(1), 1-10.

Brammer, H. (1967). Soils of the Accra Plains. Soil Science Research Institute (SRI) of Ghana, Memoir No.3. Kumasi, Ghana challenges and opportunities. In: Proceedings of the Sixth Eastern and Southern African Regional Maize Conference, CIMMYT and EARO, Addis Ababa, 21–25. FAO-UNESCO (1990). *Soil Map of the World*, Retrieved from. Food and Agriculture Organization (FAO), Rome.

Feng, Z., Zhu, L. (2017). Impact of biochar on soil N_2O emissions under different biochar-carbon/fertilizer-nitrogen ratios at a constant moisture condition on a silt loam soil. *Science Total Environment*, (584), 776–782.

Fidel, R.B., Laird, D.A., & Spokas, K.A., (2018). Sorption of ammonium and nitrate to biochars is electrostatic and pH-dependent. *Scientific Report*, 8(1), 17627.

Golla, B., & Chalchisa, D. (2019). Response of maize phenology and grain yield to various nitrogen rates and plant spacing at Bako, West Ethiopia. *Open Journal of Plant Science*. 4(1), 009-014.

Gonzalez-Navarro, O.E., Griffiths, S., Molero, G., Reynolds, M.P., Slafer, G.A. (2016). Variation in developmental patterns among elite wheat lines and relationships with yield, yield components and spike fertility. *Field Crop Research*, (196), 294-304.

Hagner, M., Kemppainen, R., Jauhiainen, L., Tiilikkala, K., Setälä, H. (2016). The effects of birch (Betula spp.) biochar and pyrolysis temperature on soil properties and plant growth. *Soil and Tillage Research*, (163), 224–234.

Haider, G., Steffens, D., Moser, G., Müller, C., Kammann, C.I. (2017). Biochar reduced nitrate leaching and improved soil moisture content without yield improvements in a four-year field study. *Agriculture Ecosystem and Environment*, (237) 80–94.

International Biochar Initiative (1BI), (2011). Standardized product definition and product testing guidelines for biochar that is used in soil. http://www.bioch ar-inter natio nal.org/chara cteri zatio n-standard. (Accessed Nov. 2021).

Joseph, U. E., Toluwase, A. O., Kehinde, E. O., Omasan, E. E., Tolulope, A. Y., George, O. O.,… Hongyan, W. (2020). Effect of biochar on soil structure and storage of soil organic carbon and nitrogen in the aggregate fractions of an Albic soil. *Archives of Agronomy and Soil Science*, 66(1), 1-12.

Kameyama, K., Miyamoto, T., Shiono, T. (2014). Influence of biochar incorporation on TDR-based soil water content measurements. *Europian Journal of Soil Science*, 65 (1). Kraska, P., Oleszczuk, P., Andruszczak, S., Kwiecińska-Poppe, E., Różyło, E., Pałys, E., Gierasimiuk, P., Michałojć, Z. (2016). Effect of various biochar rates on winter rye yield and the concentration of available nutrients in the soil. *Plant, Soil and Environment*, (11), 483–489.

Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., Naidu, R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: current knowledge and future research directions. *Environment International*, (87), 1–12.

Lindgren, E., Harris, F., Dangour, A. D., Gasparatos, A., Hiramatsu, M., Javadi, F.,… Haines, A. (2018). Sustainable food systems—a health perspective. *Sustainability Science*, *13*(6), 1505-1517.

MacCarthy, D.S., Darko, E., Nartey, E.K., Adiku, S.G.K., Tettey, A.(2020). Integrating Biochar and Inorganic Fertilizer Improves Productivity and Profitability of Irrigated Rice in Ghana, West Africa. *Agronomy*, (*10*), 904.

Mensah, A.K. & Frimpong, K.A. (2018). Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *Australian Journal of Crop Science*. 12(12):1813-1819.

Mierzwa-Hersztek, M., Wolny-Koładka, K., Gondek, K., Gałązka A., Gawryjołek, K. (2019). Effect of co-application of biochar and nutrients on microbiocenotic composition, dehydrogenase activity index and chemical properties of sandy soil. *Waste Biomass Valori*. 1-13.

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A., & Fasina, A. (2019). Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (Oryza sativa) yield grown on an Alfisol in Southwestern Nigeria. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(3), 295-308.

Qambrani, N. A., Rahman, M. M., Won, S., Shim, S., & Ra, C. (2017). Biochar properties and eco-friendly applications for climate change mitigation, waste management, and wastewater treatment: A review. *Renewable and Sustainable Energy Reviews*, (*79*), 255-273.

Sadaf, J., Shah, G. A., Shahzad, K., Ali, N., Shahid, M., Ali, S., Rashid, M. I. (2017). Improvements in wheat productivity and soil quality can accomplish by co-application of biochars and chemical fertilizers. *Science of the Total Environment*, (607), 715724.

Saifullah, Dahlawi S., Naeem A., Rengel Z., Naidu R. (2018). Biochar application for the remediation of salt-affected soils: Challenges and opportunities. *Science of the Total Environment*, (625), 320–335.

Salim, B.B.M., (2016). Influence of biochar and seaweed extract applications on growth, yield and mineral composition of wheat (*Triticum aestivum* L.) under sandy soil conditions. Annals of Agricultural Science. 61(2), 257-265.

Sara, Z.S., & Shah, T. (2018). Residual Effect of Biochar on Soil Properties and Yield of Maize (*Zea mays* L.) under Different Cropping Systems. *Open Journal of Soil Science*. 8(01): 16-35.

Sarfraz, R., Shakoor, A., Abdullah, M., Arooj, A., Hussain, A., & Xing, S. (2017). Impact of integrated application of biochar and nitrogen fertilizers on maize growth and nitrogen recovery in alkaline calcareous soil. *Soil science and plant nutrition*, 63(5), 488-498.

Shah, F., & Wu, W. (2019). Soil and crop management strategies to ensure higher crop productivity within sustainable environments. *Sustainability*, 11(5), 1485.

Sheng, Y., Zhan, Y., Zhu, L. (2016). Reduced carbon sequestration potential of biochar in acidic soil. *Science of the Total Environment*, (572), 129–137.

Shi, W., Ju, Y., Bian, R., Li, L., Joseph, S., Mitchell, D.R., and Pan, G. (2020). Biochar bound urea boosts plant growth and reduces nitrogen leaching. *Science of Total Environment*. (701), 134-424

Singh, P., Agrawal, V.K., and Singh, Y.V. (2019). Effect of potassium and FYM on growth parameters, yield and mineral composition of wheat (*Triticum aestivum* L.) in alluvial soil. *Journal Pharmacogn. Phytochem*, 8(3): 24-27.

Srinivasarao, C., Gopinath, K.A., Venkatesh, G., Dubey, A.K., Wakudkar, H., Purakayastha, T.J., Pathak, H., Jha, P., Lakaria, B.L., Rajkhowa, D.J., Mandal, S., Jeyaraman, S., Venkateswarlu, B., Sikka, A.K. (2013). Use of biochar for soil health enhancement and greenhouse gas mitigation in India. *NICRA Bulletin*, 1/2013

Suo, F., You, X., Yin, S., Wu, H., Zhang, C., Yu, X., ... Li, Y. (2021). Preparation and characterization of biochar derived from copyrolysis of Enteromorpha prolifera and corn straw and its potential as a soil amendment. *Science of the Total Environment*, (798), 149-167.

Trupiano, D., Cocozza, C., Baronti, S. (2017). Effects of biochar and its combination with compost on lettuce (*Lactuca sativa* L.) growth, soil properties, and soil microbial activity and abundance," *Hindawi International Journal of Agronomy*, (2017), 12.
Wang, y., Sheng, D., Zhang, P., Dong, X., Yan, Y., Hou, X., Wang, P., Huang, S. (2021). High temperature sensitivity of kernel formation in different short periods around silking in maize. *Environmental and Experimental Botany*, (138), 104-343
Zheng, R., Chen, Z., Cai, C., Wang, X., Huang, Y., Xiao, B., Sun, G. (2013). Effect of biochars from rice husk, bran, and straw on heavy metal uptake by pot-grown wheat seedling in a historically contaminated soil. *Bio Resources*. 8(4): 59655982.