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Slow Pyrolyzed Banana Leaf Waste Biochar Amended Calcareous Soil Properties and Maize Growth

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Abstract

Background/objectives: Biochar has gained tremendous potential for mitigation of climate change and improving soil quality and productivity. This study aimed to develop biochar from banana leaves and evaluate its effect on soil properties and maize yield. **Methods:** Banana leaf-based biochar, prepared through slow pyrolysis (300-400 °C), was tested on maize crop in pot experiment using three biochar rates (B_0 = 0 t ha^{-1}, B_1 = 20 t ha^{-1} and B_2 = 40 t ha^{-1}) along with a compost control (B_c = 5 t compost ha^{-1}) and three chemical fertilizer (CF) rates (F_0 = 0–Control, F_1 = 120 kg N ha^{-1} and F_2 = 120-90 kg NP ha^{-1}) based on completely randomized design with three replications. **Findings:** The addition of banana leaf based amendments (BLBA) significantly improved soil properties except soil pH and EC. The application of higher biochar rate (40 t ha^{-1}) revealed maximum soil CEC (23.65 cmol$_c$ kg^{-1}), TOC (1.48%), TN (0.12%) and K (89.31 mg kg^{-1}) while maximum P concentration (4.26 and 4.04 mg kg^{-1}) was noted in NP and compost applied treatments. Likewise, higher biological (231.00 g pot^{-1}) and grain yield (104.81 g pot^{-1}) as noted in compost treatment, were at par with biochar rates of 20 and 40 t ha^{-1} which were due to improvement in nutrient uptake. Overall, higher rate of biochar (40 t ha^{-1}) performed better over lower rate (20 t ha^{-1}) and compost (5 t ha^{-1}) in buildup of nutrients and improvement in soil properties. **Applications/improvements:** Therefore, lower biochar rate and compost of banana leaf origin with chemical fertilizers can serve as an alternate for maize nutrition and improvement in soil fertility and quality So, it is suggested that BLBA may be tested under long term field experiments on different crops.

Keywords: Banana leaves; biochar; calcareous soil; maize; nutrients; slow pyrolysis; yield

1 Introduction

Biochar has gained tremendous momentum in agriculture sustainability and environment safety in the present era [1]. It is produced from variety of feedstocks through process of pyrolysis with limited or no oxygen supply [2].

According to IBI (International biochar initiative), biochar is solid material attained from thermo chemical conversion of biomass in the absence or limited oxygen environment. In recent years, the use of biochar in agriculture has been amplified in order to the valuable properties of this recalcitrant material for reducing greenhouse gas emission, carbon sequestration and enhancing the sustainability of agriculture ecosystem[3].

Economically efficient biochar production depends on the availability of feedstock and its nature of composition. The major feedstock generating from agriculture, forest, aquatic, animal, urban, industry and household are included crop residues, wood biomass, aquatic biomass, manures from poultry and dairy farms, municipal wastes, paper wastes, and kitchen wastes[4]. The agriculture operations across the world are generating huge quantities of agro-wastes with higher contribution from developing countries which evidenced that out of the world total land area (13 Gha), 1.5 Gha are under agriculture practices[5]. In case of Pakistan, out of total land area (79.61 million ha), 22.51 million ha are under agriculture generating millions of ton waste materials. The primary constituents of agriculture wastes are cellulose, hemicellulose and lignin[6] where cellulose is contributing as major organic materials in the world and it is estimated that plants annually produce $4x10^{10}$ ton cellulose[7]. Cellulose degradation through microbes and chemical process is difficult because of its highly resistant nature and further its binding with lignin and hemicellulose by ether and hydrogen bonds make it more resistant to biological and chemical degradation[8,9]. Some fraction of the agricultural waste materials has alternate utilization such as livestock feeding, fuel purposes, compost making and biogas generation[10]. Nevertheless, most of agriculture wastes are directly burnt in the field or land filled as an easy way of disposing that lead to pollution of air, water and soil. Consequently, the conversion of agro-wastes into compost is recommended by many researchers as a tool of waste management[10–13]. But it is an unattractive choice due to its slow decomposition process and laborious nature[14]. Thus, in comparison to composting, the use of waste materials for biochar production could be a best option.

Biochar is produced by various methods which is reflected in traditional and modern approaches. These are included pyrolysis techniques, gasification, torrefactions, hydrothermal carbonization, electro-modified technique and magnetic biochar production. The traditional pyrolysis approaches are slow and fast pyrolysis while modern pyrolysis approaches are flash pyrolysis, vacuum pyrolysis and microwave pyrolysis. In slow pyrolysis, biomass is pyrolyzed at 300-600 ^{o}C for several hours[15] with heating rate of 5-7 ^{o}C min^{-1}, producing 35-40% yield of biochar, 25-35% bio-oil and 20-30%syngas[15–17]. Fast pyrolysis is quick method used for large scale of biochar production where pyrolysis of biomass is conducted above 500 ^{o}C using 300^{o}C min^{-1} as heating rate. In this method the yield of biochar and syngas is 20% but bio-oil is 60%[18,19]. It is fast technique in which biochar production completed in few seconds. Gasification is actually a thermochemical process used for syngas production from biomass and generating biochar as a by product[20]. Gasification process is carried out at higher temperature of >700 ^{o}C in which steam and oxygen are supplied under controlled condition[21]. Whereas, torrefaction is biochar production technique through microwave and conventional slow pyrolysis at temperature of 230-300° C[22,23], which improve the properties of biomass. Wet feedstocks like sewage sludge, animal waste and composts that contain higher moisture contents are pyrolyzed through hydrothermal carbonizationusing high pressure reactor at 2-10 MPa for several hours at temperature of 220-240 ^{o}C[24,25]. The biochar prepared through hydrothermal process shows important traits that help in nutrient retention particularly nitrogen and phosphorus essential for enhancing soil fertility.

The calcareous soil in arid environment has low fertility and productivity due to lack of organic matter and high pH that resulting in unavailability of nutrients particularly phosphorus and micronutrients[26–30]. This low organic matter status in soil also leads to reduction in microbial activities which affect soil health and quality[31]. The addition of organic matter in calcareous soil is indispensable to improve its physical, chemical and biological properties[32]. In agriculture production system, compost and/or undecomposed animal manures have been utilized so far as a soil amendment which have marked influence on soil pH, nutrient availability, improvement in soil structure and better crop performance. But it is unstable and quickly decompose due to high temperature and intensive agriculture practices leading to low soil organic matter in the arid environment. Instead of compost, the use of biochar seems a better choice due to its recalcitrant nature and an excellent soil amendment. In acidic soil the addition of biochar shown a liming effect by raising the soil pH[33] but in calcareous soil it decreased the soil pH[34,35]. In both types of soil the fixation of phosphorus is high and not available to plants. According to Ferrell et al.[36] that the addition of biochar as a soil amendment significantly enhanced phosphorus availability. Negis et al.[37] reported that the application of compost and biochar exhibited improvement in soil quality. Low nitrogen use efficiency is common in calcareous soil, the literature indicated that the application of biochar increased the uptake and use efficiency of nitrogen by reducing N_2O emission and adsorption of NH_4^+ and NO_3^- on its surface through acidic and basic functional groups resulting in enhanced plant available nitrogen[38]. Like compost, biochar also work as a source of nutrients when added to soil. It supplies plant essential nutrients such as N, P, K, and micronutrients[39]; enhanced soil organic carbon as noted 0.93% in fertilizer application and 1.25% in biochar application, increased soil water contents by >23%, increased soil cation exchange capacity as noted 8.9 $cmol_c$ kg^{-1} in fertilizer application and 10.3 $cmol_c$ kg^{-1} in biochar application[40]. The adsorbed NH_4^+ on biochar surface can be used by the crop through slow release mechanism that ultimately augment N uptake and yield of crop[38].

Maize plays an important role in world food security[41]. In developing countries, maize is cultivated in both summer and spring season for fodder and grain purpose. In Pakistan maize ranks third after rice and wheat and grown in 1.087 million ha with total production of 4.34 million ha having average yield of 3.99 t ha^{-1} [42]. This per hectare average yield is quite low as compared to the developed countries which is due to low soil fertility and productivity having intrinsic alkaline and calcareous nature with low organic matter status. Augmentation of soil organic matter level play vital role for improving soil fertility on sustainable basis[43]. In a greenhouse study conducted by Sarfraz et al.[44] at University of Agriculture Faisalabad Pakistan, biochar from grape vines pruning's was prepared by slow pyrolysis (400 °C) and tested on maize crop integrated with different nitrogen doses in factorial arrangements and found significant increase in maize shoot biomass (375.33 g) when 1% (w/w) biochar was integrated with 50% of recommended dose of N. In comparison to control, the biochar application recorded 78.8% increase in maize dry weight. In china a field experiment was conducted by Zhang et al.[45] on maize crop grown in alkaline and calcareous soil using wheat straw based biochar @ 0, 20 and 40 t biochar per hectare with and without 300 kg N ha^{-1} and recorded 7.3% yield increase without N fertilizer and 15.8% increase with N applied fertilizer. Further, increase in crop production is might be due to improvement in nitrogen use efficiency in soil having more organic carbon[46]. Another group of researchers reported that biochar added soil increased maize yield because of availability of nutrients[47–49]. Several researchers have revealed that the biochar amendment in soil affect maize grain yield both positively and negatively because of variation in feed stock and its pyrolysis temperature along with crop and soil type[50–52].

A huge quantity of waste material annually produced in Pakistan and banana waste is one the them with Sindh contribution of 3.79 million tons. But unfortunately, they are not utilized properly, instead directly burned in the open air resulting in emission of CO_2 and smoke. So, it hypothesized that the development and use of banana leaf based amendments i.e. biochar and compost can help in improving soil properties and crop yield under alkaline calcareous soil and is environment friendly. The objective of the study was to develop biochar from banana leaves through low pyrolysis and evaluate its effect on soil properties and maize growth and yield.

2 Materials and methods

2.1 Biochar and compost production

Banana leaves were used as a feed stock for making biochar. The leaves of banana were collected from the local growers, surrounding Hyderabad, Sindh. The sun-dried banana leaves were pyrolyzed at low temperature range (300-400 °C) using Barrel Kiln Technology as proposed by Mok and Antal[53]. The Kiln was constructed from locally available iron made barrel with volume capacity of 200 dm^3 and one small barrel of stainless steel with 78 dm^3 capacity. The pyrolytic process was initiated by heating the Kiln through natural gas. While, the system was also provided from syngas produced during pyrolysis. The temperature range of Kiln was determined by Temperature Data Logger with Thermocouple Probe[54].

For compost, banana leaves were chopped to 2 cm pieces and mixed with farmyard manure in 3:1 ratio on weight basis, following the windrow composting procedure (Fleming, 2001)[55]. During composting, moisture content was maintained to 60% and temperature was monitored with the help of temperature data logger, which would not let the temperature exceed above 75 °C. This was done due to the reason that beyond that temperature most of the beneficial microbes would be killed. For releasing heat from compost, turning of compost was performed after each 10 days, so that it mixes well, uniformly composted and keep the temperature maintained. The entire composting process completed in four months' time.

2.2 Experimental design

A pot experiment was conducted in the net house at Agriculture Research Institute (ARI), Sariab Quetta, Pakistan during 2016 to examine the effect of banana leaf-based amendments on the growth, yield of maize and properties of the soil. The experiment was laid down in complete randomized design (CRD) in two factorial arrangement which were replicated thrice. Factor (A) was comprised of banana leaf based amendments (0, 5 t compost, 20 and 40 t biochar ha^{-1}) while factor (B) was consisted of three fertilizer rates (0-0, 120-0, and 120-90 N-P kg ha^{-1}). Bulk surface soil (0-15 cm) was collected from experimental field of ARI, air-dried and passed through 2 mm sieve before its use for pot study or of soil properties. Each pot was filled 20 kg with air-dried soil, after mixing the biochar, compost or chemical fertilizer as per treatment requirement. All the P and half of N in the form of NP and urea were applied at the time of sowing to meet the initial crop requirement. The remaining N was applied at silk stage. Five seeds of Golden maize (MMRI-Yellow) were sown, which were later thinned to one. Pots were regularly irrigated or as per water requirement of maize using tap water.

2.3 Plant growth parameters

Growth and yield parameters of maize crop recorded were: plant height, chlorophyll content, leaf area plant^{-1}, cob weight, seed index, biological yield and grain yield. Plant height was measured from the surface of soil to the top of tassels in centimetre (cm) with help of measuring tape. While, chlorophyll contents were recorded using Chlorophyll meter (SPAD 502 Plus) and leaf area was determine by measuring leaf width at three places converting them into average width multiply by the length of leaf and multiply by constant 0.75. In this way leaf area of all leaves in plant were measured and then through summation converted into leaf area (cm^2) plant^{-1}. Similarly, seed index was calculated by weighing 1000 grains. At maturity, maize plant was harvested and dried and then weight it along with cobs. The total yield per pot was noted as biological yield. For grain yield, cobs were separated from the plants, manually shredded the seeds from cobs and weighted per pot per treatment.

Nutrient uptake (g pot^{-1}) for N, P and K was calculated using concentration and yield data as given below:

$$\text{N uptake } \left(\text{g pot}^{-1}\right) = \frac{\text{Straw yield x\% N concentration}}{100} + \frac{\text{grain yield x\% N concentration}}{100}$$

2.4 Analytical methods

2.4.1 Biochar and compost analysis

Biochar and compost products were analysed for EC, pH, ash contents, total organic carbon, total N, P and K contents. Electrical conductivity and pH were determined in 1:10 biochar to deionized water ratio[56]. Total N, organic carbon and C:N ratio of the biochar and compost were analysed on CHNS Analyzer (FLASH EA 1112 Series). The ash contents of biochar were determined by ignition method[57]. The compost (prepared from banana leaves and farmyard manure) was analysed for P and K contents as given by Wilde et al.[58]. While, P and K contents in biochar was determined by AB-DTPA extraction method as adopted in soil.

2.4.2 Soil analysis

Soil were analysed for texture, organic matter, pH, EC, CEC and macro nutrients (N, P and K) concentration. Soil texture of pre-soil samples was carried out by Bouyoucos hydrometer method[59]. The percent sand, silt and clay were calculated from hydrometer readings and textural class was allocated by using the textural triangle[60]. The organic matter content of soil was determined by oxidizing method[61]. Electrical conductivity and pH were determined in 1:2 soil to deionized water ratio[62] using pH meter (Model WTW pH 720) and EC meter (Model HI 8033) while, cation exchange capacity (CEC) was determined by ammonium acetate method as described by Rhoades[63]. Available P and K by AB-DTPA extraction method[64]. Theses extracts were used to determine the quantity of P and K. Phosphorus in the samples was determined by spectrophotometry as detailed under Olsen et al.[65] for blue colour development using spectrophotometer (Model ANA 75). While, K in the extracts was quantified by emission spectroscopy using Flame photometer (JENWAY PFP 7). Total nitrogen by Kjeldahl's method[66]. Soil bulk density was measured by an intact core method (McKenzie et al., 2004)[67].

2.4.3 Leaf and grain tissue analysis

For maize leaf and grain tissue sampling, standard procedure was followed. At tasselling to pollination growth stage, leaf below and opposite from ear was sampled. The sampled leaves were decontaminated with tap water and washed with distilled water, followed by drying at room temperature under shade. While, grain samples were collected at maturity. Both the dried leaves and grains were oven dried at 80°C for 24 hours, ground to 20 mesh and stored in plastic vials for further analysis[68].

The banana leaf tissue and grains of maize were used to determine N, P, K, Ca and Mg. Nitrogen in the samples was determined by Kjeldahl's method[66] as already detailed for soil N. The remaining nutrients were wet digested using nitric acid and perchloric acid mixture[69]. The digests were used for the determination of total P, K, Ca and Mg. Phosphorus in the digests was quantified by yellow colour method[70] using spectrophotometer. While, K in the digests was directly quantified by flame photometer using emission spectroscopy[71,72]. As for Ca and Mg, the digests were quantified on atomic absorption spectrophotometer (AA-6300 SHIMADZU with GFA-EX7i Graphite Furnace Atomizer) at Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi.

2.5 Data analysis

The data from pot experiments under CRD design were subjected to two way analysis of variance (Steel et al. 1997)[73] using software Statistix 8.1 (Analytical Software, 2005). The significant parameters were further subjected to comparison of means using HSD test ($p<0.05$).

3 Results

Biochar prepared from banana leaf wastes showed highly alkaline pH (9.8) and high electrical conductivity (4.63 dSm^{-1}) as compared to banana based compost having pH 7.04 and EC (1.88 dSm^{-1}). The other nutrient characterization of both biochar and compost revealed that total organic carbon and nitrogen were 53.8% and 1.31% in biochar, 40.12% and 2.33% in compost with C:N ratio of 40.06 in biochar and 17.21 in compost. Because this huge difference in C:N ratio is due to higher total organic carbon with low nitrogen contents in biochar but compost comparatively have lower total organic carbon with more total nitrogen level. In case of P and K concentration, P content (1.31%) in compost was higher over biochar (0.48%) but K contents (1.53 and 1.58%) were equal in both biochar and compost. In addition, biochar manifested 5.42% ash contents as well.

Soil used for pot experiments was sandy clay loam having sand, clay and silt fraction of 48.20%, 30.50% and 21.30%, respectively. The soil was non-saline (0.61 dS m^{-1}) with alkaline pH (8.23). Soil organic matter, total N and AB-DTPA extractable P were observed in low status with 0.57% organic matter, 0.039% N and 2.31 mg kg^{-1} P, respectively. Whereas, K was in medium range with 63.3 mg kg^{-1}. Further, cation exchange capacity was the main soil chemical property influencing water and nutrient retention capacity of the soil. The pre soil analysis showed cation exchange capacity of 15.12 $cmol_c$ kg^{-1}.

3.1 Maize growth traits

Maize growth and yield parameters studied under the influence of banana leaf based amendments (BLBA) were included plant height, chlorophyll content, leaf area $plant^{-1}$, cob weight, seed index, biological yield and grain yield (Tables 1 and 2). Analysis of variance pertaining to plant height expressed statistically significant differences ($p<0.05$) for chemical fertilizer application that recorded increase in plant height from 116.09 in control to 136.40 cm, where 120 kg N and 90 kg P was applied. However, there were no differences in plant height (128.40 cm), when P was not applied with N (i.e. 12 kg N ha^{-1}). Same is the case with chlorophyll contents that showed highly significant ($p<0.01$) influence of chemical fertilizer (CF) on chlorophyll content that depicted increase from 41.88 mg g^{-1} in control to 44.99 mg g^{-1} on N and NP applied fertilizer. Further, the interactive effect of BLBA and CF did not exhibit significant differences on chlorophyll content (Table 1).

In contrast to plant height and chlorophyll content, the statistical data of leaf area recorded highly significant ($p<0.01$) differences for CF, BLBA and even the interaction between them as evidenced from Table 1. Leaf area is the base of light interception for photosynthetic activity and works as food preparing factory for plant growth and development. The $HSD_{0.05}$ test for mean comparison revealed leaf area of 2018.1 cm^2 in control, which increase to 3478.5 cm^2 in NP applied fertilizer. While, the same comparison for BLBA showed an increase in leaf area from 1652.7 cm^2 in control to 3467.0 cm^2 in compost applied treatments. The treatment having leaf area of 3467 cm^2 under 5 t ha^{-1} compost, and 3360.0 cm^2 under 20 t ha^{-1} biochar were statistically at par, and therefore, behaved equally with respective increase of 14.64% and 11.92% over higher biochar rate of 40 t ha^{-1}. But higher biochar rate reduced leaf area. Similarly, the interaction of BLBA and CF increased leaf area from 1397.8 cm^2 in control to 4581.6 cm^2 under compost treatment integrated with NP fertilizer (Table 2).

The cob weight is one of yield contributing factors and compost application produced non-significantly higher cob weight of 88.27 g that was equally at par with the biochar applied treatments. Without BLBA application only CF application also expressed statistically significant ($p<0.05$) differences for cob weight and the maximum cob weigh (100.55 g) was noted in NP applied treatment. The combined effect of BLBA and CF increased the cob weight from 47.95 g in control to 111.65 g in compost applied treatments. Seed index is an important component of yield contribution. The use of BLBA ($p<0.05$) and CF ($p<0.01$) showed significant effect on seed index. Among BLBA, the application of compost had the highest seed index of 237.16 g, which was followed by both biochar rate with non-significant differences while in case of fertilizer means, the minimum seed index of 206.20 g in control significantly increased to seed index of 243.12 g where NP fertilizer was applied (Table 2). But the interactive effect of BLBA and CF on seed index was non-significant (Table 1).

Both biological and grain yield were significantly affected by BLBA and CF but their interaction produced at par variation (Table 1). Higher biological (231.00 g pot^{-1}) and grain yield (104.81 g pot^{-1}) were obtained in compost applied treatment which were statistically at par with biochar rates of 20 and 40 t ha^{-1} and significant over control. While, in sole CF treatment, the NP application resulted in higher biological (229.48 g $plant^{-1}$) and grain yield (110.25 g pot^{-1}).

Table 1. Analysis of variance showing F-value of studied parameters of maize crop and post soil properties under the influence of banana leaf-based amendments (BLBA), chemical fertilizer (CF) and their interaction (BLBA x FC)

Particulars	F value		
	BLBA	CF	BLBA x CF
Maize plant traits			
Plant height	0.47^{NS}	5.19*	0.825^{NS}
Chlorophyll contents	2.24^{NS}	37.56**	1.00^{NS}
Leaf area	152.24**	166.55**	12.56**
Cob weight	31.06**	134.73**	2.78*
Seed index	4.23*	9.01**	0.33^{NS}
Biological yield	5.91**	7.39**	0.93^{NS}
Grain yield	24.78**	70.24**	1.86^{NS}
Leaf tissue nutrient contents			
N	36.56**	116.26**	12.36**
P	4.33*	61.08**	2.62*
K	22.27**	4.51*	2.23^{NS}
Ca	25.91**	72.89**	1.22^{NS}
Mg	6.95**	9.43**	4.17**
Grain tissue nutrient contents			
N	84.01**	3.32^{NS}	4.32**
P	52.89**	79.42**	4.58**
K	46.39**	225.24**	3.38*
Ca	23.18**	51.90**	0.99^{NS}
Mg	8.98**	35.29**	1.87^{NS}
Nutrient uptake			
N uptake	128.34**	90.06**	0.0006**
P uptake	94.75**	206.43**	0.049*
K uptake	60.51**	164.65**	6.70**
Soil properties			
pH	1.79^{NS}	0.26^{NS}	1.66^{NS}
EC	1.79^{NS}	2.23^{NS}	0.43^{NS}
CEC	143.21**	0.01^{NS}	0.00^{NS}
TOC	74.76**	0.44^{NS}	0.06^{NS}
TN	62.10**	1.08^{NS}	0.05^{NS}
AB-DTPA P	25.74**	42.30**	0.45^{NS}
AB-DTPA K	7.70**	1.04^{NS}	0.45^{NS}

** highly significant at P <0.01, * significant at P<0.05, NS non-significant
BLBA: Banana leaf based amendments
CF: Chemical fertilizer
BLBA x CF: interaction between bananan leaf based amendments and chemical fertilizer

Table 2. Maize growth and yield contributing components as affected by banana leaf based amendments, chemical fertilizer and their interaction

Treatments	Plant height (cm)	Chlorophyll content (mg g^{-1})	Leaf area $plant^{-1}$ (cm^2)	Cob weight (g)	Seed index (g)	Biological yield (g pot^{-1})	Grain yield (g pot^{-1})
Banana leaf based amendments-BLBA (t ha-1)							
Control (0 tons)	#122.44 a	43.30 a	1652.7 c	62.00 b	202.29 b	190.48 b	74.16 b
Compost (5 tons)	126.43 a	44.11 a	3467.0 a	88.27 a	237.16 a	231.00 a	104.81 a
Biochar (20 tons)	128.04 a	43.97 a	3360.0 a	85.42 a	224.15 ab	216.20 a	95.76 a
Biochar (40 tons)	130.93 a	43.22 a	2959.5 b	83.48 a	229.79 ab	225.33 a	95.00 a
S.E.±	7.34	0.43	95.58	3.05	10.32	10.42	3.68
HSD (0.05)	-	-	265.44	8.47	28.67	28.95	10.23
Chemical fertilizer (CF)							
0-0 (No NP)	116.09 b	41.88 b	2018.1 c	57.27 c	206.20 b	196.25 b	72.58 c
120 kg (N)	128.40 ab	44.10 a	3082.8 b	81.56 b	220.12 b	221.52 a	92.47 b

Continued on next page

Table 2 continued

120 + 90 (NP)		136.40 a	44.99 a	3478.5 a	100.55 a	243.73 a	229.48 a	110.25 a
S.E.±		6.35	0.37	82.77	2.64	8.94	9.03	3.19
HSD (0.05)		15.96	0.93	207.98	6.64	22.46	22.68	8.02
BLBA x CF								
1	1	117.16	42.03	1397.8	47.95	180.41	183.53	63.80
1	2	122.18	43.81	1633.5	56.59	192.53	190.64	72.56
1	3	127.97	44.07	1926.9	81.45	233.94	197.27	86.11
2	1	115.71	42.20	2248.8	64.27	225.95	221.85	84.05
2	2	129.11	44.98	3570.8	88.90	232.83	231.25	104.09
2	3	134.49	45.13	4581.6	111.65	252.69	239.88	126.30
3	1	119.90	41.78	2457.7	57.37	204.22	179.75	69.92
3	2	123.43	44.25	3709.6	89.86	225.10	232.92	101.47
3	3	140.80	45.86	3912.7	109.04	243.14	235.93	115.61
4	1	111.59	41.49	1968.2	59.50	214.21	199.86	72.56
4	2	138.89	43.28	3417.4	91.00	230.01	231.29	99.47
4	3	142.32	44.89	3493.0	100.04	245.15	244.84	112.96
S.E.±		12.71	0.74	165.54	5.28	17.88	18.03	6.38
HSD (0.05)		-	-	601.95	19.22	-	-	-

[#]Mean bearing the same letters are statistically alike.

3.2 Leaf and grain tissue nutrient concentration

Leaf tissue nutrient concentration of maize were significantly affected by BLBA, CF and their interaction (Tables 1 and 3). All BLBA products depicted statistically higher but non-significant leaf N and Ca concentration and grain tissue N, K, Ca and Mg concentration over control. But higher leaf and grain tissue P concentration were noted in compost and low biochar rate applied treatments which were statistically at par from each other. In case of leaf K concentration, both biochar levels expressed non-significant values along with control and the compost treatment manifested higher K concentration (1.62%). Whereas, higher leaf tissue Mg concentration was noted in the treatment when lower biochar rate (20 t ha^{-1}) was applied. $HSD_{0.05}$ test of CF for mean comparison showed higher but non-significant values for both leaf and grain tissue nutrient concentration on N applied treatments with and without P fertilizer (Table 3).

The interactive effect of BLBA and CF on leaf tissue N concentration showed minimum values under control (1.01%) and maximum of 2.20% under biochar (20 t ha^{-1}) treated with NP. However, the same biochar rate integrated with only N (1.96%) also gave similar results. In the same manner, 2.01% and 1.96% of N was statistically at par when compost application of 5 t ha^{-1} was respectively integrated either with N or NP. When amendments were combined with chemical fertilizer, higher N concentration in grain (2.24%) was recorded when compost was combined with NP fertilizer. The lowest N was under control with N, however, the complete control also had N concentration which was statistically similar.

Interactive effect BLBA and CF (N or NP) on leaf tissue P concentration was non-significant except that over control (Tables 1 and 3). While, in grain tissue P concentration, the interactive effect recorded higher P concentrations of 0.125% that was equivalent to the treatments (0.110%, 0.107% and 0.118%) receiving compost or biochar at 20 t ha^{-1} along with N or NP. But leaf and grain tissue K concentration were found non-significant in the interaction BLBA and CF. However, the K concentration of grain under compost (1.21% and 1.24%) or biochar, regardless of rate (1.19% and 1.26%) in conjunction with N or NP treatments was not any different and these treatments behaved equally in supplying K to the grain parts.

Table 3. Maize leaf and grain tissue nutrient concentration (%) as affected by banana leaf based amendments, chemical fertilizer and their interaction

Treatments	Leaf tissue nutrient concentration (%)					Grain tissue nutrient concentration (%)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Banana leaf based amendments-BLBA (t ha-1)										
Control (0 tons)	#1.45 b	0.13 b	1.03 b	0.38 b	0.39 b	1.26 b	0.07 c	0.62 b	0.25 b	0.16 b
Compost (5 tons)	1.81 a	0.14 a	1.62 a	0.47 a	0.45 ab	2.12 a	0.11 a	1.00 a	0.35 a	0.22 a
Biochar (20 tons)	1.85 a	0.14 a	1.14 b	0.45 a	0.48 a	2.03 a	0.10 a	0.99a	0.36 a	0.22 a
Biochar (40 tons)	1.78 a	0.13 ab	1.07 b	0.46 a	0.40 b	1.97 a	0.08 b	0.93 a	0.36 a	0.21 a
S.E.±	0.04	0.003	0.08	0.01	0.02	0.06	0.003	0.037	0.015	0.014
HSD (0.05)	0.12	0.01	0.22	0.03	0.06	0.17	0.009	0.104	0.042	0.040

Continued on next page

Table 3 continued

Chemical fertilizer (CF)											
0-0 (No NP)		1.39 b	0.12 b	1.10 b	0.38 b	0.36 b	1.74 a	0.07 c	0.49 b	0.25 b	0.15 b
120 kg (N)		1.85 a	0.15 a	1.22 ab	0.46 a	0.46 a	1.92 a	0.09 b	1.05 a	0.36 a	0.22 a
120 + 90 (NP)		1.92 a	0.15 a	1.32 a	0.48 a	0.45 a	1.82 a	0.11 a	1.12 a	0.38 a	0.25 a
S.E.±		0.04	0.003	0.70	0.01	0.02	0.05	0.003	0.032	0.013	0.013
HSD (0.05)		0.09	0.01	0.14	0.02	0.05	-	0.007	0.082	0.033	0.032
BLW x CF											
1	1	1.01	0.11	1.02	0.34	0.40	1.23	0.036	0.36	0.20	0.126
1	2	1.64	0.14	1.04	0.40	0.41	1.20	0.066	0.70	0.27	0.168
1	3	1.71	0.15	1.04	0.42	0.38	1.36	0.100	0.79	0.27	0.186
2	1	1.45	0.13	1.27	0.38	0.37	1.96	0.092	0.55	0.25	0.135
2	2	2.01	0.14	1.67	0.50	0.53	2.16	0.110	1.21	0.38	0.268
2	3	1.96	0.16	1.91	0.52	0.44	2.24	0.125	1.24	0.41	0.270
3	1	1.38	0.13	1.12	0.38	0.42	1.94	0.083	0.52	0.28	0.151
3	2	1.96	0.15	1.16	0.47	0.45	2.20	0.107	1.19	0.39	0.242
3	3	2.20	0.15	1.16	0.49	0.56	1.94	0.118	1.26	0.41	0.271
4	1	1.75	0.12	1.02	0.41	0.35	2.04	0.076	0.53	0.28	0.176
4	2	1.81	0.15	1.02	0.48	0.43	2.13	0.088	1.08	0.38	0.215
4	3	1.79	0.14	1.16	0.50	0.42	1.74	0.098	1.18	0.41	0.263
S.E.±		0.07	0.01	0.14	0.018	0.04	0.11	0.01	0.064	0.026	0.021
HSD(0.05)		0.27	0.02	-	-	0.13	0.38	0.2	0.236	-	-

[#]Mean bearing the same letters are statistically alike.

3.3 Nutrient uptake

The application of banana leaf based amendments (i.e. compost and biochar) and chemical fertilizers (N and NP) alone or in combination, resulted in significant ($p<0.01$) increase in nutrient uptake (i.e. N, P and K), except for the interactive effect of P ($p<0.05$).

Compost and biochar treatments significantly increased N uptake from 1.33 g plant^{-1} as obtained in control to 2.79 g plant^{-1} in compost, 2.48 g plant^{-1} and 2.41 g plant^{-1} under biochar amended at 20 and 40 t ha^{-1}, respectively. Statistically, both biochar rates were at par (Figure 1a). Application of N (2.43 g plant^{-1}) or NP (2.60 g plant^{-1}) significantly enhanced the N uptake over control. However, application of P was not beneficial in increasing the N concentration further than that obtained under N alone treatment. Therefore, both chemical fertilizer rates behaved equally with regard to N concentration. The interaction of BLBA and CF (Figure 1b) revealed significant increase in N uptake with higher N uptake of 3.37 g plant^{-1} when compost was applied with NP fertilizer. Both the compost and biochar (20 t ha^{-1}) applied treatments behaved equally in raising the N uptake of maize plant. While, raising the biochar rate to 40 t ha^{-1} did not prove to be beneficial in increasing the N uptake.

The $HSD_{0.05}$ test of BLBA for the comparison of means (Figure 1c) indicated higher P uptake of 0.12 g plant^{-1} in treatment when compost was applied. This was followed by P uptake of 0.101 and 0.084 g plant^{-1}, respectively at 20 and 40 t ha^{-1} with lowest values under control (0.051 g plant^{-1}). The CF particularly the NP treatment contributed significantly in enhancing the P uptake from 0.053 g plant^{-1} in control to 0.123 g plant^{-1}. The efficiency of chemical fertilizer increased (Figure 1d) when it was integrated with compost and biochar as evidenced from the interaction between compost and NP (0.157 g P plant^{-1}), and biochar (20 t ha^{-1}) and NP (0.136 g plant^{-1}).

In case of K uptake, application of BLBA significantly ($p<0.05$) increased the values from 0.72 g plant^{-1} in control to 1.58 g plant^{-1} in compost applied treatment (Figure 1e). This was followed by 1.41 and 1.26 g plant^{-1}, respectively under biochar at 20 and 40 t ha^{-1}. The uptake of 1.58 g plant^{-1} under compost and that under biochar (1.41 g plant^{-1}) at 20 t ha^{-1} were statistically at par (Figure 1e). Chemical fertilizers significantly ($p<0.05$) increased the K uptake from 0.69 g plant^{-1} in control to 1.67 g plant^{-1} in NP. When CF were integrated with BLBA, the uptake of K was much prominent as given in Figure 1f. The figure illustrated an increase in K uptake from 0.52 g plant^{-1} in control to 2.09 g plant^{-1} under compost coupled with NP fertilizer. Treatments receiving N or NP coupled with compost (1.78 and 2.09 g plant-1) or NP coupled with biochar at 20 or 40 to ha^{-1} (1.93 and 1.69 g plant^{-1}) also registered equivalent K uptake.

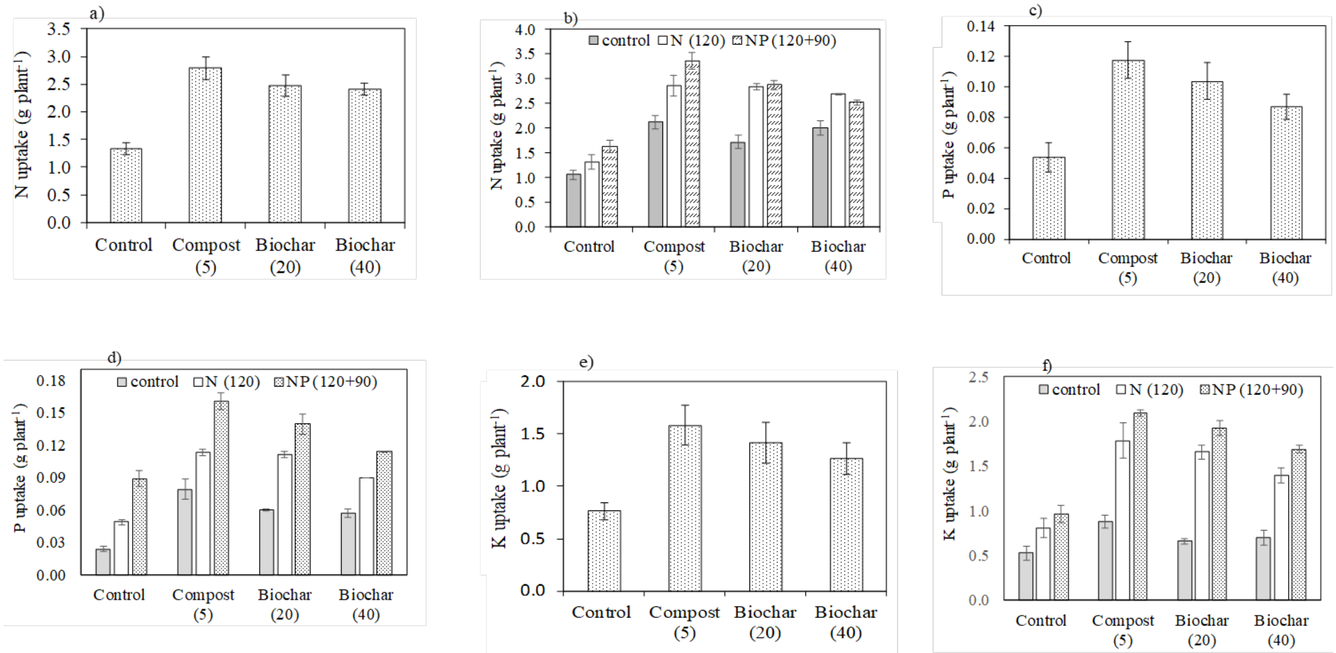

Fig 1. The effect of banana leaf based amendments (BLBA) on Uptake of N (a), P (c) and K (e), the interactive effect of BLBA and chemical fertilizer on uptake of N (b), P (d) and K (f) of maizeError bars represent standard error of means

3.4 Soil properties

There was no significant effect of banana leaf based amendments, fertilizer rates and their interaction on soil pH and EC after the completion of maize production cycle. The amendments slightly decreased soil pH from 8.22 in control to 8.16 in compost and 8.17 and 8.20 under biochar at lower and higher rate of application (Figure 2a). However, the application of higher biochar rate caused slight increase in electrical conductivity value of 0.57 dSm^{-1} (Figure 2b). Overall, the electrical scenario moved within a narrow range.

Soil cation exchange capacity determined after completion of production cycle of maize was significantly affected by BLBA application. For the treatments not receiving any organic amendments, the mean cation exchange capacity value was 14.75 $cmol_c$ kg^{-1}, which increased to 18.68 $cmol_c$ kg^{-1} with compost, 21.63 $cmol_c$ kg^{-1} with lower biochar rate of 20 t ha^{-1} and to 23.65 $cmol_c$ kg^{-1} with application of higher biochar rate of 40 t ha^{-1} (Figure 2c). Further, the results showed that neither chemical fertilizer nor the interaction between amendments and chemical fertilizer was effective in increasing the soil cation exchange capacity after the completion of maize production cycle. Similarly, BLBA addition significantly increased total organic carbon content from 0.51% in control to 0.79% in compost, 1.16%, and 1.48% in lower and higher biochar rates applied (Figure 2d). However, the effect of chemical fertilizer and the interaction with amendments did not give any fruitful results regarding the increase in organic carbon. Likewise, soil total N after completion of production cycle of maize also increased from 0.04% in control to 0.07% in compost, followed by 0.10% and 0.12% respectively under lower and higher biochar rates application (Figure 2e). The increase in total N is very clear from control to higher biochar treatment. However, the integration of BLBA with CF did not affect the soil total N content after the completion of production cycle of maize.

The separate application of banana leaf based amendment and chemical fertilizer highly significantly ($p<0.01$) affected availability of P after maize harvest. Maximum P concentration (4.26 mg kg^{-1}) was recorded in NP applied treatment and lower P concentration in control. While, the application of compost exclusively recorded available P of 4.04 mg kg^{-1} that were at par with lower and higher biochar rates. This indicates that the use of chemical fertilizer (NP) comparatively contributed higher AB-DTPA extractable P over banana leaf based amendment (Figure 2f). However, the interactive effect of BLBA and CF on available P was statistically non-significant. In addition to that the AB-DTPA extractable K of soil after the completion of production cycle of maize (Figure 2c) was also affected by BLBA. Nevertheless, either chemical fertilizer alone or its integration with BLBA produced non-significant differences towards post soil K concentration. Among the amendments, higher K concentration (89.31 mg kg^{-1}) was noted under higher biochar, followed by 71.62 mg kg^{-1} in lower biochar rate. It means that both higher and lower biochar rates equally performed in supply of K. Even though, the lower biochar rate outperformed the compost treatments (Figure 2g).

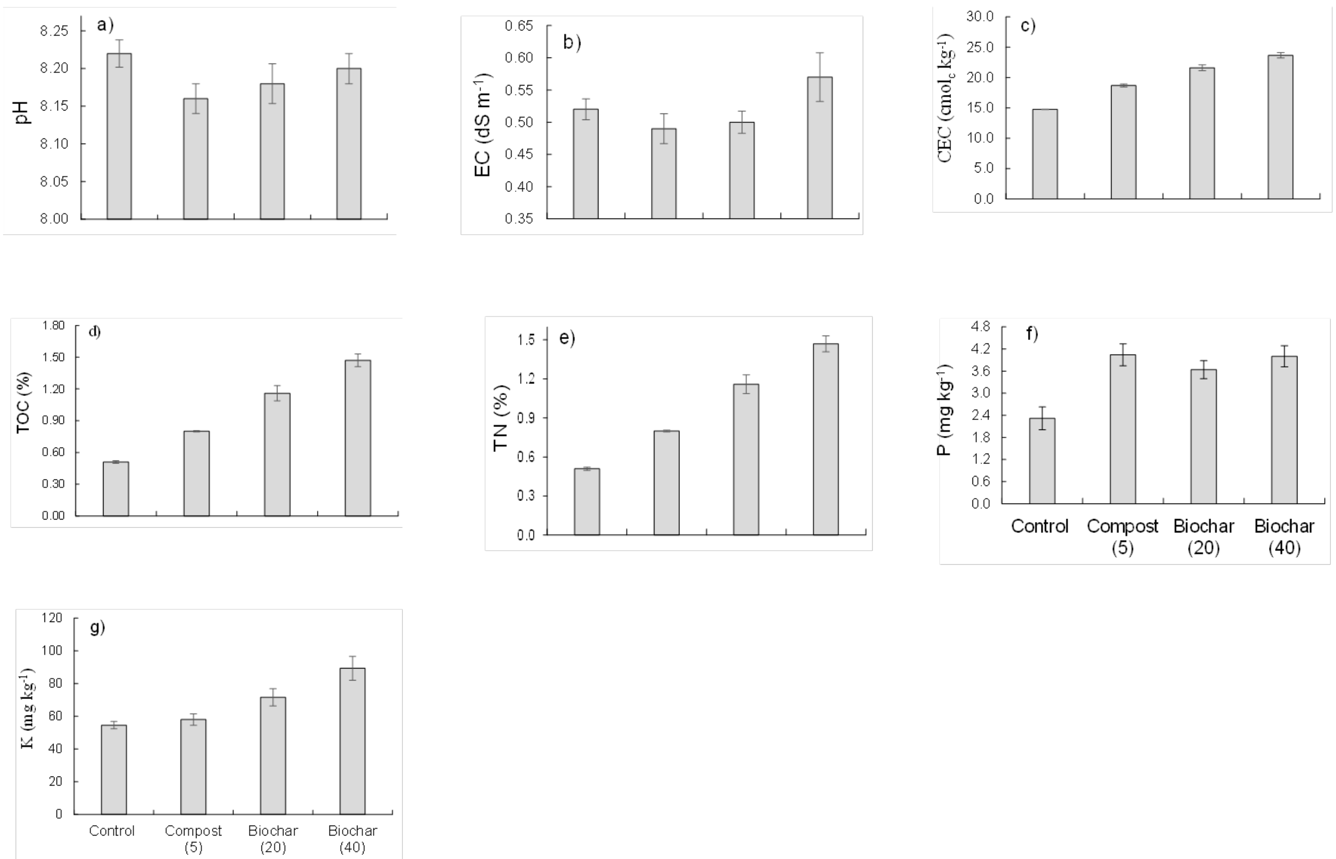

Fig 2. Changes in pH (a), EC_e (b), CEC (c), TOC, (d), TN (e), AB-DTPA extractable P (f) and K (g) of the soil added with banana leaf based amendments after maize harvest. Error bars represent standard error of means

3.5 Pearson correlation among soil properties, plant growth and yield traits

Correlation analysis between the soil properties, growth and yield traits as presented in Table 4 showed that soil total N, AB-DTPA extractable P and K, cation exchange capacity were significantly and positively correlated with soil total organic carbon while soil pH expressed negative but non-significant correlation with organic carbon and correlation coefficient (r) were 0.92, 0.46, 0.60, 0.96 and -0.29 respectively. Similarly, soil total N, AB-DTPA extractable P, nutrient uptake (N, P and K), HI and biological yield expressed positive and significant correlation with grain yield and correlation coefficients were 0.48, 0.78, 0.89, 0.93, 0.94, 0.85 and 0.84, respectively.

Table 4. Pearson correlation among soil properties, growth, yield and yield related parameters and nutrition of maize under pot condition

Parameters	pH	CEC	OC	TN	Soil P	Soil K	N uptake	P uptake	K uptake	HI	BY	GY
pH	1											
CEC	-0.30^{NS}	1										
OC	-0.29^{NS}	0.96**	1									
TN	-0.32*	0.88**	0.92**	1								
Soil P	-0.32*	0.50**	0.46**	0.59**	1							
Soil K	-0.11^{NS}	0.54**	0.60**	0.54**	0.21^{NS}	1						
N uptake	-0.23^{NS}	0.49**	0.42*	0.58**	0.82**	0.27^{NS}	1					

Continued on next page

Table 4 continued

P uptake	-0.20^{NS}	0.31*	0.24^{NS}	0.42*	0.82**	0.11^{NS}	0.89**	1				
K uptake	-0.17^{NS}	0.29^{NS}	0.24^{NS}	0.47**	0.81**	0.21^{NS}	0.91**	0.928*	1			
HI	-0.12^{NS}	0.23^{NS}	0.19^{NS}	0.34*	0.67**	0.09^{NS}	0.73**	0.89**	0.81**	1		
BY	-0.18^{NS}	0.34*	0.31*	0.48**	0.65**	0.15^{NS}	0.77**	0.69**	0.77**	0.43**	1	
GY	-0.16^{NS}	0.33*	0.30^{NS}	0.48**	0.78**	0.14^{NS}	0.89**	0.93**	0.94**	0.85**	0.84**	1

CEC – Cation exchange capacity, OC – Organic carbon, Soil P and K – AB-DTPA extractable P and K, HI –Harvest index, BY – Biological yield and GY – Grain yield

** Significant at 1% level, * Significant at 5% level, NS Non-significant

4 Discussion

The results regarding plant growth traits of maize exhibited the significant influence of banana leaf based amendment (BLBA) which were statistically differed to great extent. As the two parameters such as plant height and chlorophyll contents did not differ statistically and expressed at par values across BLBA treatments. But chemical fertilizer treatments expressed variations for both of plant height and chlorophyll contents. This variation might be due to the amount of nitrogen contents supplied by BLBA products and that by CF to crop. However, Sarfraz et al.[44] recorded significant variation in plant height when biochar rates were integrated with nitrogen fertilizers and found 73.4% increase in plant height over control. Maize grain yield was improved by BLBA addition along with improvement in yield contributing factors like leaf area, cob weight, seed and biological yield. The improvement in yield could be attributed to more leaf nutrient accumulation and nutrient uptake along with improvement in overall soil physical and chemical condition after BLBA addition. Similar results were reported by Omara et al.[74,75] who recorded 17 and 13% increase in maize grain yield when nitrogen-biochar combination (NBC) integrated with 50 and 100 kg N ha^{-1}. In literature, different reports are available that have shown both positive as well negative impacts on maize yield under added biochar[76,77] planted in either acid or calcareous soil environment. It is evidenced that the contradicting results about maize grain yield under biochar amendments are pertaining to the production of biochar from different feedstocks using varying pyrolysis temperature and also due to different soil types and above all the rates of biochar applied matters to great extent. As one group of researchers reported 150% increase in maize grain yield when added 15 t ha^{-1} cow manure based biochar under acidic sandy soil[78].

The leaf and grain tissue nutrient concentration of maize in this study were significantly influenced by the application of banana leaf based amendments. Among the BLBA treatments, compost (5 t ha^{-1}) and low biochar rate (20 t ha^{-1}) application improved nutrients accumulation of N, P, K, Ca and Mg in both leaf and grain tissue but the higher biochar rate (40 t ha^{-1}) resulted in reducing all these nutrients in leaf tissue and only P reduction in maize grain. However, in comparison to control all BLBA seemed to enhance nutrient accumulation over control where neither BLBA nor chemical fertilizer (CF) was applied. These positive effect of BLBA on leaf and grain tissue nutrient status clearly demonstrate that both compost and biochar addition improved soil nutrient availability. Further, the N, P and K uptake of maize were significantly increased both by sole BLBA amendments as well as its integration with chemical fertilizer (CF) of N and/or NP applied. These results are consistent with those reported by Sarfaraz et al.[44] who prepared biochar from vineyard's pruning at 400°C pyrolysis temperature and tested on maize crop under calcareous soil. They observed increase in leaf tissue N, P and K concentration and higher N uptake when biochar (1% w/w) was applied with nitrogen (50% of recommended urea) fertilizer, higher P uptake when biochar rate was increased without nitrogen fertilizer and maximum K uptake was recorded in the treatment when biochar (2% w/w) was combined with 50 and 100% of recommended N fertilizer. The biochar amendment maneuvers the soil N dynamics on the basis of higher CEC of biochar itself by retaining and releasing of ammonium nitrogen in the soil that consequently influence the availability and uptake of N in crop[79]. Another group of researchers[80] also noted improvement in N uptake in biochar treated crop. One of the biochar co-founders Lehman and Gaunt[81] stated that the biochar application enhanced soil fertility and nutrient availability.

The chemical properties of soil are tremendously influenced by biochar amendments. In this study the effect of BLBA on soil pH and EC were non-significant with marginal decrease in pH by compost applied treatment followed by the biochar rates. In acidic soil the addition of biochar shown a liming effect by raising the soil pH[33] but in calcareous soil it decreased the soil pH[34,35]. But other soil properties particularly the CEC was highly significantly affected by the addition of BLBA and highest CEC was recorded in biochar applied treatments. The surface of biochar work as platform for occurrence of oxidation that results in the formation of both acid basic functional groups. The former one helps in retention of NH_4^+ ion on biochar surface while the latter group facilitate for adsorption of NO_3^- nitrogen and in this way the added biochar in soil provide the available N to crop[82]. Basically the higher CEC of biochar and soil is responsible for the availability of nutrients along with positive factors of biochar addition. The scientific literature evidenced that CEC of biochar decreased when pyrolyzed at high temperature due to conversion of acidic function groups particularly carboxyl into basic functional group which aromatically bond but instead the slow pyrolyzed biochar has showed high CEC[83,84]. In this study biochar produced from banana leaf through slow pyrolysis increased soil CEC due to high CEC of the biochar. In arid agro-ecological condition, the calcareous soil has low organic matter, total N and P. The soil analysis after the completion of production cycle of maize further revealed that BLBA addition enhanced soil TOC, TN, AB-DTPA extractable P and K. Because in both acidic and calcareous soils the fixation of phosphorus is high and not available to plants. Several researchers have reported that biochar amendments augmented TOC (1.25%) leading to increasing crop production by 25%[85]. In acid and calcareous soil phosphorus fixation is high and not available to plants. According to Ferrell et al.[36] that the addition of biochar as a soil amendment significantly enhanced phosphorus availability. Negis et al.[37]reported that the application of compost and biochar exhibited improvement in soil quality. Many studies have shown that biochar can be a source of plant essential nutrient including both micro and macro nutrients that could be one of the reasons i.e. why the addition of biochar in soil enhance nutrient availability[39,40]. It is well established concept that appreciable amount of Phosphorus exists in biochar which have been recognized for long time that P releases from biochar when added to the soil[86]. Furthermore, the conserved amount of N in poultry and pine chip based biochar was reported to be from 27.4 to 89.6% but some other group of researches revealed that the total P, K, Ca and Mg contents conserved in biochar were ranged from 60 to 100% and their bioavailability varied (10-80%) depends on the source of biomass used[86].

The positive and significant correlation between soil properties and maize crop traits, as observed in this study, demonstrates that the improvement in soil chemical properties and availability of nutrients under BLBA addition integrated with and without CF resulted in better crop growth, increased leaf and grain tissue nutrient accumulation and improved uptake of N, P and K. Consequently, betterment in these parameters equally contributed in enhancing biological and grain yield of maize. Several researchers have reported that biochar addition increased TOC and nutrients status in soil that were positively associated with maize gain yield[87]. Therefore, it is evidenced from the study that banana leaf based biochar (BLBA) application integrated with chemical fertilizer (CF) under calcareous soil has the potential to improve soil properties and maize growth.

5 Conclusion

This study explored the influence of organic amendments integrated with chemical fertilizer on soil properties and growth of maize crop grown in calcareous soil under pot condition. The results averaged across banana leaf based amendments (BLBA), chemical fertilizer (CF) and the interaction of BLBA and CF revealed significant effect of higher biochar rate (40 t ha^{-1}) on soil CEC, TOC, TN, AB-DTPA and K while compost and NP applied exhibited higher AB-DTPA extractable P concentration but the interaction of BLBA and CF noted at par variations on them. Nutrient uptake by maize was improved across sole application of BLBA, CF and interaction of BLBA x CF that led to improved maize growth particularly leaf area, cob weight and seed index. Subsequently, improvement in soil properties and maize growth equally contributed in enhancing biological and grain yield of maize that is further evidenced from the positive and significant correlation between soil properties and grain yield. Among the BLBA, compost and low biochar rate (20 t ha^{-1}) produced higher biological and grain yield. Overall, higher rate of biochar (40 t ha^{-1}) performed better over lower rate (20 t ha^{-1}) and compost (5 t ha^{-1}) in buildup of nutrients and improvement in soil properties. From this study it is inferred that lower biochar rate and compost of banana leaf origin with chemical fertilizers can serve as an alternate for maize nutrition and improvement in soil fertility and quality. So, it is suggested that BLBA may be tested under long term field experiments on different crops.

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