Research Article

Sustainable Maize Farming: Organic Soil Amendments Boost Maize Production and Soil Quality

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ABSTRACT

Soil organic matter depletion leads to soil structural degradation in cultivated ecosystems. Organic soil amendment reduces inorganic fertilizer dependency, maintains soil properties, and enhances crop production. Organic soil amendments are crucial for sustainable agriculture, providing nitrogen, phosphorus, and potassium to soil and plants. They help address soil organic carbon depletion and environmental issues, as inorganic fertilization hinders sustainable agriculture by affecting soil fertility and crop productivity. A two-year field experiment at the Agriculture Research Farm, University of Agriculture Peshawar-Pakistan, examined the effects of combining organic and inorganic amendments on maize variety Azam and hybrid CS 220, aiming to compensate for soil organic carbon loss. Treatments were Control, Half (H) NPK, Full NPK, Legume Residues (LR) @ 10 tons ha^{-1}, Humic Acid (HA) @ 5 kg ha^{-1}, Biochar (BC) @ 10 tons ha^{-1}, LR + HNPK, HA + HNPK, BC + HNPK, HLR +HHA+ HNPK, HLR + HBC + HNPK and HBC + HHA + HNPK. The study used a two-factorial randomized complete block design with three replications to study maize two-year data. Results showed significant cob lengths in HLR + HBC + HNPK treatment, while maximum results in plant population, 1000 grain weight, and biological yield were in HBC + HHA + HNPK treatment. The highest soil organic matter was recorded in plots with only BC application at 10 tons ha^{-1}, with the highest soil K recorded in BC + HNPK treatment. The hybrid CS 220 maize variety showed superior yield and component performance compared to the Azam variety, while the Azam variety yielded the best results in soil parameters. The maize production improved significantly in the second year compared to the first year. The study suggests that combining organic and half-inorganic fertilizers improves soil fertility, making it a viable strategy for crop yield regulation and sustainable maize production. This can be achieved using efficient organic soil amendments alone or in combination with commercially available inorganic fertilizers.

Keywords: Biochar, Humic acid, Legumes Residues, Maize, yield, and soil fertility

INTRODUCTION

Climate change-induced hydrological variations are expected to threaten water resources for rainfed and irrigated agriculture, potentially affecting food security and economic prosperity in many countries [1] Agronomic drought is the most frequent type, affecting water capacity mainly due to soil properties, particularly organic carbon contents and aggregation. To alleviate water scarcity in agricultural production, soil organic matter (SOM) increases are typically used as a solution [2]. The global population's growth is causing increased resource demands, reduced cultivation land, and food security challenges, affecting all types of droughts. Factors like development, demand for food, land tenure, government policies, and manufacturing are causing farmlands to become scarce, reducing fallow periods and soil nutrient replenishment practices.[3]. Manures are utilized to stabilize soil structures, improve nutrient retention, aeration, soil moisture holding capacity, and water infiltration.[4]. The modification in new fertilization practices, such as manipulating the quantity and type of organic amendments, improves soil ecosystems and fertility [5]. Organic fertilizers like Humic Acid, legume residues, and biochar can replace chemical-based fertilizers in crop production and serve as an organic amendment for soil rehabilitation [6].

Article History

Received: October 18, 2023, Accepted: November 04, 2023, Published: November 18, 2023

Fertilizer is crucial for maintaining soil fertility, increasing yields, and improving harvest quality. However, a significant portion of fertilizers are lost, increasing agricultural costs, wasting energy, and polluting the environment. To address these challenges, environmentally friendly fertilizers (EFFs) have been developed to reduce environmental pollution from nutrient loss. EFFs are typically used in the form of coated fertilizers, with research focusing on using degradable natural materials as a coating for soil amendment [7]. Pakistan's favorable environmental conditions for maize production result in low yields compared to other countries like the USA, Canada, and Egypt [8]:[9]. The low yield is due to poor quality seed, indiscriminate application of fertilizers without soil test, poor tillage methods and lack of modern technology [10]. Incorporation of plant residues is a useful means to sustain organic matter content and there by enhance the biological activity, improve soil physical properties and increase nutrient availability [11]:[12]. Alternative farming, characterized by a reliance on local agricultural bio-resources is now in great demand, because they are more cost-effective [13]. Organic matter is the life of soil and the practices that support organic matter build-up also favours sustainable productivity [14]. Operational constraints have led to a decrease in organic manuring, including conventional farmyard manure, mulching, and green manuring. Legumes are nearly eliminated from cropping systems, affecting soil fertility. However, legumes maintain soil fertility by converting atmospheric nitrogen into available form through symbiosis [15].

Humic acid (HA), a natural product found in lignite coal, is used in agriculture and industry to improve crop yield by providing nitrogen and phosphorus to plants. However, 1-2 kg ha^{-1} HA added to crops as fertilizer is often insufficient to supply the necessary nutrients, which is far below the overall nutrient requirements of agricultural crops. HA also improves the physicochemical and biological properties of soils [16]:[17]. Humic acids is not only found in soil, plants, peat, natural water, rivers, sea sediments, and other chemically and biologically transformed materials but also extracted from lignite, oxidized bituminous coal [18]. Humic acid is considered a best source for increasing the nutrients uptake in agriculture productivity which is mostly found in the form of natural products like lignite coal [19]. On the other hand, humic acid (HA) is a dark-coloured organic substance and a natural resource used as an alternative for fertilizer to increase crop production. Humic acid has been reported to enhance nutrient absorption, plant growth, physiology and metabolism [20]:[21]. Enrichment of organic matter in soil decrease soil temperature and mitigates salinity effect and increase moisture conservation and as result stimulates crop growth and quality [22].

The research explores the variability in biochar production due to production temperature and oxygen control systems. It highlights the importance of understanding the production technologies and performance mechanisms of biochar and other organic amendments in soil, which enhance soil bio-physicochemical properties, reduce atmospheric CO2, and promote ecological integrity and environmental sustainability [23]. Biochar, a fine-grained charcoal high in organic carbon, is produced from pyrolysis of plants and other organic feedstocks. It is increasingly recognized as a sustainable technology for improving highly weathered or degraded soils [24]. It can enhance plant growth by improving soil chemical characteristics i.e. nutrient retention and availability and soil physical characteristics i.e. bulk density, water holding capacity, permeability and soil biological properties i.e. soil biota and soil microorganisms, all contributing to an increased crop productivity [25]:[26]. In addition, biochar is highly recalcitrant to microbial decomposition and thus guarantees a long-term benefit for soil fertility [27]. It decreases nutrient leaching in soils and enhances nutrient cycling and thus has positive impacts on yield of crops. A beneficial impact of biochar on the plant-available phosphorus has been observed in soils enriched with biochar [28]:[29].

Biochar and humic acid are being used in agricultural land as a strategy for carbon sequestration and soil quality improvement. Biochar sequesters 50% of the carbon in biomass feedstock, while humic acid improves soil properties due to carboxyl and phenolic groups. The calcium acetate method was used to determine -COOH groups in both biochar and humic acid [30]. The experiment involved three factors: inorganic fertilizers levels, biochar levels, and humic acid levels. Results showed a significant increase in soil pH when Biochar was combined with inorganic fertilizers in a randomized completely block design [31]. Similarly, CEC was found high with the usage of NPK with Biochar and humic levels. Biochar increases levels of carbon from 0.51-0.62. Therefore, usage of Biochar and humic acid is a good source for improving sustainable agriculture. Further studied are needed to carry out this usage under different circumstances [30].

Corn, also known as maize, is an annual, cross-pollinated crop that is the fourth largest crop in Pakistan, ranking third among the world's most important cereal crops, but second in Khyber Pakhtunkhwa province [32]:[33]. In Pakistan, the most dependable, profitable, and staple crop after potato is maize [34]. Maize varieties and hybrids that take long to mature may not be suitable for fields due to their slow maturity, disrupting cropping patterns. Therefore, quick, early maturing hybrids with high yield are needed. Breeders have developed thousands of maize hybrids that can thrive in various soil and climate combinations in farming areas [35]. Hybrids also incorporate favourable qualitative traits to be adapted to diverse environmental conditions, specifically changing the day length [20]. The study explores the effects of biochar, Humic acid, legume residues, and mineral nitrogen on maize yield and soil fertility in maize-wheat cropping systems. It focuses on identifying high-yielding varieties, planting them at suitable times, controlling weeds, and comparing synthetic fertilizer levels, while also examining maize growth, water relations, and photosynthesis under limited water supply. The hypothesis was that biochar amendments enhance water retention capacity, increase photosynthesis, and improve plant-soil water relations, leading to higher biomass yields. The beneficial effects were more pronounced during limiting water supply and drought stress.

MATERIAL AND METHODS

Experimental Site

The experiment was conducted at New Developmental Farm of the University of Agriculture Peshawar during summer 2018 and summer 2019. The experimental site located at 31°1`21``N, 71°28`5``E has subtropical climate with average annual rainfall of 350 mm most of which occur during August and December. The average temperature in summer is 40°C and winter is 18°C. The soil is silty clay loam and alkaline in reaction and low in organic matter (less than 0.5%). The soil is lacking in most of the macronutrients like N and P (23.72±1.75 and 3.2±0.5 mg.kg-1), respectively.

Experimental Materials and Design

The experiment was a randomized complete block design (RCBD) having three replications. 2019. The experimental field was irrigated before sowing of maize and ploughed with cultivator to prepare a fine seed bed for sowing. Two years (2018-2019) maize field experiments were conducted to investigate the effect of different levels of organic and inorganic fertilizers on yield of maize and soil properties. The experimental field was irrigated before sowing maize and ploughed with cultivator to prepare a fine seed bed for sowing. The experiment was consist of two factors i.e., factor A was of maize variety Azam and hybrid CS 220 and factor B was fertilizer amendments (control, HNPK, full NPK, LR @ 10 ton ha^{-1} , BC @ 10 ton ha^{-1}, HA @ 5 kg ha^{-1}, LR + HNPK, BC + HNPK, HA + HNPK, HLR + HHA HNPK, HLR + HBC + HNPK, HBC + HHA + HNPK). Which were applied before two weeks of sowing. The varieties were allotted to main plots and all the organic amendments were assigned to sub plots. The size of the plot was 3.5 x 3 m2.

The field was thoroughly ploughed with a disc harrow followed by two times ploughing with cultivator along with planking to achieve uniform soil tilth for both crops. Weeding was done twice in the growth season (i.e. 20 and 40 days after emergence) with help of hoe for maize crop. Insecticide (Chlorpyriphos) was sprayed in 0.006% concentration to control stem borer attack in maize crop. The maize cultivar 'Azam' and hybrid CS-220 were sown at seed rate of 30 kg ha^{-1} and thinning was done after one week of emergence and uniform plant population of 65000 ha^{-1} was maintained. Data were recorded on Plant population, cobs length, 1000 grain weight (g), and biological yield, SOM, N, P, K content in soil. Four central rows were harvested, sun dried, weighed for recording data on biological yield of maize crops. The ears of maize were shelled and weighed to record grain yield. The soil organic matter was determined through Walkley-Black procedure as described by [36] The soil P, K content was determined by AB-DTPA extractable P, K procedure suggested by [37].

Statistical Analysis

The data were combined over seasons for soil organic matter, pH, and soil N, P, K content however data on 1000 grain weight and biological of maize crops were not combined over seasons. The ANOVA techniques suitable for randomized complete block design and combined analysis were used. The least significant difference test was applied when F-test was significant using the procedure described by [38].

Soil analysis before the start of experiment

Three core samples were randomly taken on the entire field at 0-15cm depths before sowing. The soil samples were bulked, air-dried soon after collection and were passed through 2mm sieved mesh to remove crop residues, stones, or earth worms. The mechanical analysis of the soil was done by the hydrometer method [39]. The percentage of sand, silt and clay was read on a textural triangle to determine the soil texture and percentage of silt, sand and clay in the experimental site. Table 1 presents the physio-chemical properties of experimental site before launching the field experiments.

RESULTS

Plants Population

The study found that the plant population of maize varieties was significantly affected by fertilizer application from organic and organic sources over two years. The combined effect of treatments was non-significant, and year as a source of variation was also non-significant. In 2019, the plant population was (81088.8) compared to 2018 lighter population of (74889.5) OPV Azam had the lowest plant population (73289.7) compared to hybrid maize CS 220's maximum population (82688.5). Fertilizer application plots treated with HBC + HHA + HNPK resulted in heavier plant populations (80369.5), followed by BC and LR.

Table 1: Basic soil characteristics (physico-chemical properties) before the start of experiment.

Soil physical properties	Unit	Value at the depth of (0-15cm)
Textural class		Silt loam
Sand	%	47.3
Silt	%	40
Clay	%	12.7
Soil bulk density	-	0.27
Soil chemical properties		
pH		7.51
Organic matter	%	0.52
Total N	%	0.06
AB-DTPA P	mg kg^{-1}	4.43
AB-DTPA K	mg kg^{-1}	85.6

Table 2. Plant population ha^{-1} of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

Treatments	Years (YS)		Average
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	63244.4	72766.1	68005.2c
HNPK (75:50:30)	75677.9	79689.5	77683.7b
NPK (150: 100: 60)	76847.1	83298.4	80072.7a
LR (10 ton/ha)	74962.7	81428.3	78195.5b
HA (5kg/ha)	74935.0	83189.1	79062.1ab
BC (10ton/ha)	76531.3	82327.7	79429.5ab
LR + HNPK	74698.2	81326.9	78012.6b
HA + HNPK	77125.9	82446.2	79786.0ab
BC + HNPK	74952.1	82964.8	78958.5b
HLR + HHA + HNPK	76860.8	81426.2	79143.5ab
HLR + HBC + HNPK	75175.6	79125.8	77150.7b
HBC + HHA + HNPK	77662.5	83076.5	80369.5a
LSD for FT	4779.8	4296.3	3168.7
Varieties of Maize (VOM)			
Azam (Opv)	69105.2	77474.3	73289.7b
SC220 (hybrid)	80673.7	84703.3	82688.5a
LSD for VOM	5208.4	6547.1	2518.9
Years (YS)			
Y1: 2018			74889.5a
Y2: 2019			81088.8a
Significance Level (SL)			ns
Interactions (IR)	SL	IR	SL
VOM x YS	ns	YS x FT	ns
FT x VOM	ns	YS x VOM x FT	ns

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) “ns” =Non-significant, while “*”, “**” and “***” indicate significance at levels of probability of 5, 1, and 0.1%.

Cobs length (cm)

Two years of averaged mean data showed that cobs length of maize varieties was significantly affected by the fertilizer's application from organic and in organic sources is shown in Table 03. The combined effect of treatments YS x VOM and YS x VOM x FT were found non-significant whereas YS x FT and VOM x FT were found significant. Year as a source of variation was also found significant. During 2019 cobs length (17.9 cm) were observed in comparison with year of 2018 that produced the lighter cobs length (18.5 cm). Among different maize varieties, OPV Azam resulted in lowest cobs length (17.6 cm) in comparison with hybrid maize CS 220 that produced maximum Cobs length (18.8 cm).

Thousand grains weight (g)

Data regarding thousand grain weight of maize varieties is shown in Table 04. Analysis of the data showed that thousand grain weight was significantly affected by the application of different fertilizers from organic and in-organic sources to the different maize varieties. All the possible interactions were found non-significant except VOM x FT and YS x FT that was found significant. Year as a source of variation was also found significant. Plots treated with HBC + HHA + HNPK produced heavier thousand grains weight (313.2 g) followed full NPK which were statistically at par with each other. Lowest thousand grains weight (181.3 g) were observed by the control plots where no fertilizers were applied. Among different maize varieties, Hybrid CS 220 resulted in produced heavier grains (272.0 g), while OPV Azam variety of maize produced lighter grains (254.7 g). Average of the mean data also showed significant differences, maximum thousand grain weight (271.6 g) was recorded for second year (2019) in comparison with Ist year (2018) with value of (255.1 g).

Table 3. The cob length (cm) of maize varieties as influenced by different organic and inorganic fertilizers applications over both years.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	12.5	12.3	12.4h
HNPK (75:50:30)	17.6	18.3	18.0e
NPK (150: 100: 60)	19.7	20.3	20.0bc
LR (10 ton/ha)	15.0	15.7	15.3g
HA (5kg/ha)	15.5	16.2	15.9fg
BC (10ton/ha)	16.0	16.6	16.3f
LR + HNPK	18.8	19.5	19.1d
HA + HNPK	19.2	19.9	19.5cd
BC + HNPK	19.1	19.7	19.4cd
HLR + HHA + HNPK	20.4	21.1	20.8a
HLR + HBC + HNPK	20.6	21.3	20.9a
HBC + HHA + HNPK	20.4	21.1	20.7ab
LSD for FT	0.7	0.6	0.4
Varieties of Maize (VOM)			
Azam (Opv)	17.3	17.9	17.6b
SC220 (hybrid)	18.5	19.1	18.8a
LSD for VOM	0.4	0.3	0.1
Years (YS)			
Y1: 2018			17.9b
Y2: 2019			18.5a
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
VOM x YS	**ns**	YS x FT	**
FT x VOM	**	YS x VOM x FT	**ns**

This means using various alphabets within the same category are significantly different at (P ≤ 0.05) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

Table 4. Thousands grain weight (g) of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	183.0	179.6	181.3f
HNPK (75:50:30)	250.0	267.7	258.9d
NPK (150: 100: 60)	282.3	302.2	292.3b
LR (10 ton/ha)	242.5	259.5	251.0d
HA (5kg/ha)	229.8	246.0	237.9e
BC (10ton/ha)	228.5	244.5	236.5e
LR + HNPK	263.5	282.0	272.7c
HA + HNPK	264.3	282.8	273.5c
BC + HNPK	275.3	294.7	285.0bc
HLR + HHA + HNPK	263.5	282.0	272.7c
HLR + HBC + HNPK	275.5	294.8	285.2bc
HBC + HHA + HNPK	302.5	323.9	313.2a
LSD for FT	17.6	19.7	13.0
Varieties of Maize (VOM)			
Azam (Opv)	246.7	262.7	254.7b
SC220 (hybrid)	263.4	280.6	272.0a
LSD for VOM	14.2	7.6	4.5
Years (YS)			
Y1: 2018			255.1a
Y2: 2019			271.6a
Significance Level (SL)			**Ns**
Interactions (IR)	SL	IR	SL
VOM x YS	ns	YS X FT	**
FT x VOM	**	YS X VOM X FT	**Ns**

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) “ns” =Non-significant, while “*”, “**” and “***” indicate significance at levels of probability of 5, 1, and 0.1%.

Biological yield (kg ha^{-1})

The study examines the impact of fertilizer application on the biological yield of maize varieties. The results show that organic and in-organic fertilizers significantly influence the yield of different maize varieties. The interaction between YS x VOM, VOM x FT, YS x FT, and YS x VOM x FT was also significant. Year was also a significant source of variation. Regarding different fertilizer applications, plots treated with HBC + HHA + HNPK produced maximum biological yield with value of (14411.1 kg ha^{-1}), followed by the NPK applied at the varying ratio 150:100:60 resulted 14035.6 kg ha^{-1} biological yield. Lowest biological yield (7643.6 kg ha^{-1}) was observed by the control plots where no fertilizer was applied. Hybrid CS 220 maize varieties had the highest biological yield (13088.0 kg ha^{-1}). During 2019, maximum biological yield (12856.1 kg ha^{-1}) was recorded while 2nd year 2018 resulted in lowest (11817.9 kg ha^{-1}) biological yield was obtained by maize crop.

Soil pH

Data regarding soil pH as influenced by different fertilizer applications for maize varieties is shown in Table 6. Statistical analysis of the data showed that soil pH was not significantly affected by varying fertilizer application. Year as a source of variation was also found not significant. The interaction between YS x VOM and YS x VOM x FT was non-significant, while VOM x FT and YS x FT were found significant. Among different varieties of maize i.e. OPV Azam and hybrid CS 220, statistically no significant differences were observed in between them for soil pH.

Table 5. The biological yield (kg ha^{-1}) of maize varieties as influenced by different organic and inorganic fertilizers applications during the years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	7764.4	7522.9	7643.6i
HNPK (75:50:30)	12273.4	12546.5	12410.0f
NPK (150: 100: 60)	13970.6	14100.6	14035.6b
LR (10 ton/ha)	10848.6	12047.7	11448.2h
HA (5kg/ha)	10864.5	11997.3	11430.9h
BC (10ton/ha)	11140.8	12645.4	11893.1g
LR + HNPK	12491.2	13603.5	13047.3d
HA + HNPK	12195.6	13008.5	12602.1ef
BC + HNPK	12176.8	14784.3	13480.6c
HLR + HHA + HNPK	12596.8	13200.2	12898.5de
HLR + HBC + HNPK	12421.2	13064.8	12743.0def
HBC + HHA + HNPK	13071.3	15751.0	14411.1a
LSD for FT	557.4	457.4	355.5
Varieties of Maize (VOM)			
Azam (Opv)	11154.6	12017.5	11586.0b
SC220 (hybrid)	12481.3	13694.6	13088.0a
LSD for VOM	394.7	356.5	155.1
Years (YS)			
Y1: 2018			11817.9b
Y2: 2019			12856.1a
Significance Level (SL)			***
Interactions (IR)	SL	IR	SL
VOM x YS	*	YS X FT	***
FT x VOM	***	YS X VOM X FT	***

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

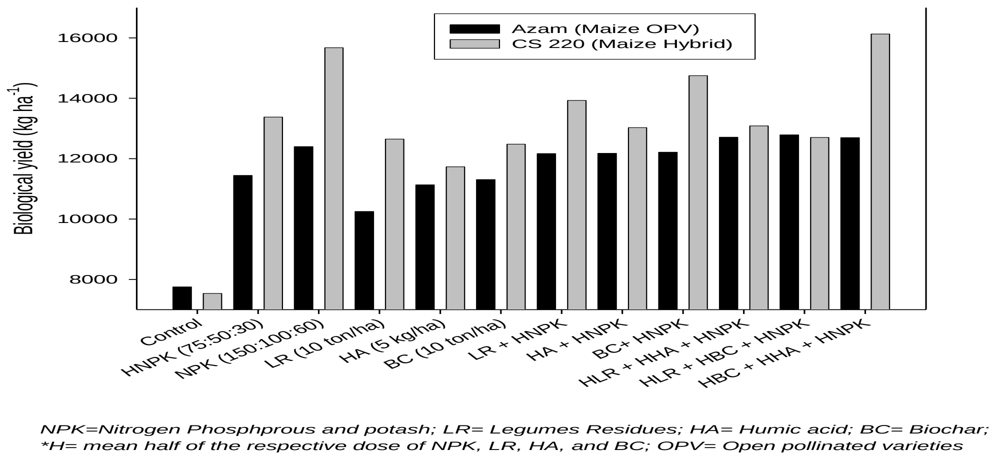


Figure 1. The interactive effect of fertilizer applications and maize varieties for biological yield (kg ha^{-1}) of maize crop.

Soil organic matter (%)

Data about SOM as influenced by different varieties of maize crop and fertilizer application from organic and in-organic sources are shown in Table 7. Analysis of the data showed that soil organic matter significantly affected by the application of fertilizers in different combination and maize varieties. All the possible interactions i.e., YS x FT and YS x VOM x FT and VOM x FT were found significant except YS x VOM which were found significant. Year as a source of variation were found non-significant. Among maize varieties, OPV Azam variety significantly produced higher amount of SOM (0.77%) in comparison with hybrid maize CS 220 that produced less SOM (0.68%). Regarding different fertilizer application, applied from different organic and in-organic sources in combination significantly increased the SOM. Maximum SOM (0.99%) was recorded by BC applied at the rate of 10 tonS ha^{-1} followed by plots treated with HBC + HNPK and LR at the rate of 10 tonS ha^{-1}. The lowest SOM was observed in plots treated with control where no fertilizers were applied. Same data for SOM was recorded for both years, no statistical differences were observed.

Table 6. Soil pH of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	7.6	7.6	7.6ab
HNPK (75:50:30)	7.6	7.5	7.5abc
NPK (150: 100: 60)	7.6	7.4	7.5bc
LR (10 ton/ha)	7.6	7.5	7.5abc
HA (5kg/ha)	7.5	7.6	7.6ab
BC (10ton/ha)	7.5	7.5	7.5abc
LR + HNPK	7.5	7.3	7.4c
HA + HNPK	7.6	7.5	7.6abc
BC + HNPK	7.6	7.5	7.5abc
HLR + HHA + HNPK	7.5	7.6	7.6ab
HLR + HBC + HNPK	7.5	7.5	7.5abc
HBC + HHA + HNPK	7.5	7.7	7.6a
LSD for FT	**ns**	**ns**	**ns**
Varieties of Maize (VOM)			
Azam (Opv)	7.5	7.5	7.5a
SC220 (hybrid)	7.6	7.5	7.6a
LSD for VOM	0.0	**ns**	**ns**
Years (YS)			
Y1: 2018			7.6a
Y2: 2019			7.5b
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
VOM x YS	**ns**	YS X FT	***
FT x VOM	***	YS X VOM X FT	**ns**

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

Table 7. Soil organic matter (%) of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	0.53	0.50	0.51g
HNPK (75:50:30)	0.58	0.58	0.58f
NPK (150: 100: 60)	0.54	0.54	0.54fg
LR (10 ton/ha)	0.81	0.99	0.90b
HA (5kg/ha)	0.67	0.67	0.67e
BC (10ton/ha)	0.89	1.08	0.99a
LR + HNPK	0.72	0.80	0.76c
HA + HNPK	0.73	0.73	0.73cd
BC + HNPK	0.86	0.93	0.89b
HLR + HHA + HNPK	0.68	0.71	0.69de
HLR + HBC + HNPK	0.73	0.73	0.73cd
HBC + HHA + HNPK	0.74	0.74	0.74cd
LSD for FT	0.07	0.06	0.05
Varieties of Maize (VOM)			
Azam (Opv)	0.75	0.79	0.77a
SC220 (hybrid)	0.66	0.70	0.68a
LSD for VOM	0.06	0.05	0.02
Years (YS)			
Y1: 2018			0.71
Y2: 2019			0.75
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
VOM x YS	**ns**	YS x FT	***
FT x VOM	***	YS x VOM x FT	***

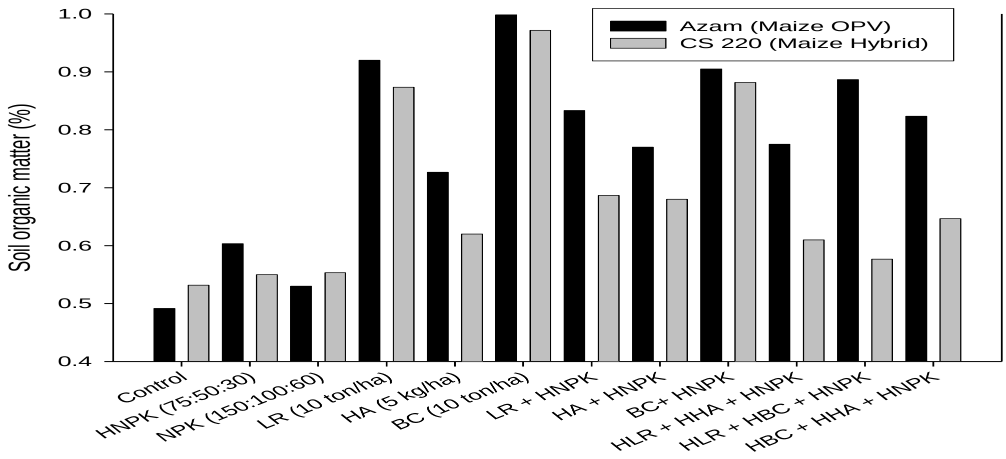
This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

Nitrogen content in soil (%)

Data pertaining to soil N as influenced by maize varieties and fertilizer applications is shown in Table 8. Statistical analysis of the data showed that soil N was substantially affected by the organic and in-organic amendments in the plots. Maize varieties did not differ significantly for soil N. The interaction between YS x VOM was found significant, whereas YS x FT, VOM x FT and YS x VOM x FT were found non-significant. Year as a source of variation was also found non-significant. Plots fertilized with HLR + HBC + HNPK resulted maximum N content in soil (0.22%) followed by BC at the rate of 10 tons ha^{-1} that resulted (0.17%) N in soil. Lowest soil N (0.07%) was resulted by control pots where no fertilizers were applied.

Phosphorus content in soil (mg kg^{-1})

Data pertaining to P content in soil as affected by fertilizer application and maize varieties is shown in Table 9. Statistical analysis of the data showed that P content in soil was significantly affected by different fertilizer applications applied from different organic and in-organic amendments in combination with different ratios and maize varieties.



NPK=Nitrogen Phosphprous and potash; LR= Legumes Residues; HA= Humic acid; BC= Biochar;
**H= mean half of the respective dose of NPK, LR, HA, and BC; OPV= Open pollinated varieties*

Figure 2. The interactive effect of fertilizer applications and maize varieties for soil organic matter of maize crop.

Table. 8. Soil N (%) of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	0.08	0.07	0.08e
HNPK (75:50:30)	0.08	0.14	0.11de
NPK (150: 100: 60)	0.10	0.18	0.14bcd
LR (10 ton/ha)	0.11	0.13	0.12cd
HA (5kg/ha)	0.12	0.16	0.14bcd
BC (10ton/ha)	0.15	0.18	0.17b
LR + HNPK	0.14	0.16	0.15bc
HA + HNPK	0.11	0.15	0.13bcd
BC + HNPK	0.11	0.14	0.13cd
HLR + HHA + HNPK	0.10	0.17	0.14bcd
HLR + HBC + HNPK	0.21	0.23	0.22a
HBC + HHA + HNPK	0.13	0.14	0.14bcd
LSD for FT	0.05	0.05	0.04
Varieties of Maize (VOM)			
Azam (Opv)	0.14	0.15	0.14a
SC220 (hybrid)	0.11	0.16	0.13a
LSD for VOM	**ns**	**ns**	**ns**
Years (YS)			
Y1: 2018			0.12
Y2: 2019			0.15
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
VOM x YS	*	YS x FT	**ns**
FT x VOM	NS	YS x VOM x FT	**ns**

This means using various alphabets within the same category are significantly different at (P ≤ 0.05) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

Year as a source of variation were found significant. All the possible interactions were found non-significant expect Ys x FT, VOM x FT that were found significant. In comparison with different fertilizer applications, the plots that received HLR + HBC + HNPK considerably produced maximum P content in soil (3.87 mg kg^{-1}), where minimum P content in soil was obtained in control plots where no treatments of any fertilizers were applied. During year 2018, lowest P content (2.95 mg kg^{-1}) in soil was observed in comparison with year 2019 that resulted higher P content in soil (3.20 mg kg^{-1}). Among different maize varieties, maize OPV produced less phosphorus content in soil in comparison with hybrid CS 220 of maize.

K content in soil (mg kg^{-1})

Data pertaining to K content in soil affected by fertilizer application and maize varieties is shown in table 10. Statistical analysis of the data showed that K content on soil was significantly affected by different application of fertilizers applied from organic and in-organic sources in combination with different ratios. Maize varieties also showed significant differences for K content in soil. Year as a source of variation were found non-significant. All the possible interactions were found non-significant expect YS x FT, VOM x FT that were found significant for K content in soil. BC applied in combination with HNPK fertilizer resulted in maximum K content in soil (104.7 mg kg^{-1}) followed by NPK (150:100:60) which was statistically similar with each other. Minimum K content in soil was observed by the control plots where no fertilizer was applied. Among different maize varieties, hybrid CS 220 resulted in higher K content in soil (101.9 mg kg^{-1}), whereas OPV Azam synthetic variety of maize produced less K content in soil (90.1 mg kg^{-1}).

Table 9. Phosphorus content in soil (mg kg^{-1}) of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Y1: 2018
Control (C)	2.47	1.92	2.20d
HNPK (75:50:30)	2.66	2.49	2.57c
NPK (150: 100: 60)	2.44	2.38	2.41cd
LR (10 ton/ha)	3.11	3.52	3.31b
HA (5kg/ha)	2.99	3.40	3.19b
BC (10ton/ha)	3.25	3.67	3.46b
LR + HNPK	2.24	2.65	2.45cd
HA + HNPK	3.18	3.59	3.39b
BC + HNPK	3.13	3.54	3.33b
HLR + HHA + HNPK	3.19	3.60	3.40b
HLR + HBC + HNPK	3.66	4.08	3.87a
HBC + HHA + HNPK	3.10	3.52	3.31b
LSD for FT	0.55	0.51	0.37
Varieties of Maize (VOM)			
Azam (Opv)	2.79	3.06	2.92b
SC220 (hybrid)	3.11	3.34	3.23a
LSD for VOM	**ns**	0.53	0.24
Years (YS)			
Y1: 2018			2.95b
Y2: 2019			3.20a
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
VOM x YS	**ns**	YS x FT	***
FT x VOM	***	YS x VOM x FT	**ns**

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

Table 10.K content in soil (mg kg^{-1}) of maize varieties as influenced by different organic and inorganic fertilizers applications during years 2018 and 2019 growing season.

	Years (YS)		
Fertilizer treatments (FT)	Y1: 2018	Y2: 2019	Average
Control (C)	83.7	83.0	83.4e
HNPK (75:50:30)	86.4	92.8	89.6de
NPK (150: 100: 60)	101.2	104.2	102.7ab
LR (10 ton/ha)	94.9	96.6	95.7bcd
HA (5kg/ha)	95.1	100.2	97.7ab
BC (10ton/ha)	90.1	103.8	96.9bc
LR + HNPK	89.5	89.1	89.3de
HA + HNPK	88.1	92.5	90.3cde
BC + HNPK	104.4	105.0	104.7a
HLR + HHA + HNPK	98.7	106.0	102.3ab
HLR + HBC + HNPK	92.9	110.4	101.6ab
HBC + HHA + HNPK	92.4	103.7	98.0ab
LSD for FT	11.7	9.1	7.3
Varieties of Maize (VOM)			
Azam (Opv)	87.3	92.9	90.1b
SC220 (hybrid)	98.9	104.9	101.9a
LSD for VOM	**ns**	12.6	5.8
Years (YS)			
Y1: 2018			93.1b
Y2: 2019			98.9a
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
VOM x YS	**ns**	YS x FT	**
FT x VOM	**	YS x VOM x FT	**ns**

This means using various alphabets within the same category are significantly different at ($P \leq 0.05$) "**ns**" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%.

DISCUSSION

Organic amendment significantly increased plant population in biochar, humic acid, and legume residue plots compared to the control, possibly due to increased soil fertility levels and higher available nitrogen. This positive correlation between N-mineralization and plant growth supports the findings [40]. Similar results were also reported by [41]who also stated from their study that plant population influenced by the organic amendments to the maize crop. The similar results were also in line with [42]who indicated from their study that number of plants of maize crop considerably increase or influenced by the application of different fertilizers applied from organic and in organic amendments. which were not significantly different from each other [43] also observed varietal differences in plant height in their studies.

The study found that the application of organic amendments, either alone or in combination with mineral fertilizer, significantly enhanced the length of the cobs in maize, thereby increasing its yield attributes and enhancing the growth characteristics of the crop [44]. Regarding the fertilizer application plots treated with HLR + HBC + HNPK resulted in heavier cobs length (20.9 cm) followed by HLR + HHA + HNPK which are statistically in line with each other. The lowest cobs length was produced by the control plots where no fertilizers were applied. Similar results were also reported by [45] who also stated from their study that cobs length influenced by the organic amendments to the maize crop. The similar results were also in line with [46] who indicated from their study that cobs length crop considerably increased or influenced by the application of different fertilizers applied from organic and inorganic amendments. [47][48] reported that ear length and ear diameter increased when N was applied in integration with biochar as compared to sole N application.

The increase in the weight of a thousand grains of maize crop may be due to the timely availability of nutrients and lower losses of nutrients than control. Similar results were obtained by [49]. Organic amendments like biochar, Humic acid and Legumes residues in soil can reduce evaporation demand, providing adequate water for plant root growth. This may be due to the soil's softness, allowing roots to expand rapidly into wet soil to meet crop water requirements [50]. where more thousand grain weight was obtained with combined application of different organic amendments. [33] got more thousand grain weight in maize with the application of PM and sheep manure. Our findings are in line with [51] who reported an increase in thousand grain weight with application of different type of organic sources. Combine application of BC assuming more nutrients availability for better growth and translocation of assimilate to ward sink [52].

The increase in biological yield of maize in integrated N applied plots may be due the slow release and timely availability of Nitrogen from organic sources which were less subjected to loses as compared to mineral N applied which loss from soil more rapidly [53]. BC application delayed all growth stages of maize and thus enhance active growing period of maize crop for production of maximum dry matter and improving quality. BC enhanced soil fertility and ensure availability of all essential nutrients that resulted in increased vegetative growth duration [54] [55] reported that an INM strategy (75% of NPK + BC) can improve the productivity and sustainability of a maize–wheat cropping system to maintain the food security. Also, a balanced application of various macro and micronutrients are needed for successful crop production. This strategy also showed that crops with balanced nutrition did not face nutritional stress and had enhanced crop productivity. The similar results were also reported by [56] who resulted from the research that biochar application to the soil enhances the soil structure and fertility which resulted in increases the soil productivity and gives higher yield. Our outcomes are in line with results of [57] who reported that the incorporation of combined inorganic and organic fertilisers led to a higher biological yield of maize, which may be attributable to the availability of additional nutrients and improved nutrient uptake that led to the higher yield.

Soil organic matter and biochar significantly affect soil pH during the second cropping season, with biochar increasing it by 9-15% and inorganic fertilizers decreasing it by 4-6%. The effect of legume residues on soil pH remains consistent and Humic acid decrease soil pH [58]. The acidity and alkalinity of the soil solution are gauged by the soil pH. Depending on their pH levels, which range from around 0 to 14 on a scale, soils are referred to as being acidic, neutral, or alkaline (or basic). Plant nutrient availability and soil functions are significantly influenced by soil pH and organic matter [59]. Particularly, pH affects the chemical solubility and availability of vital plant nutrients, the effectiveness of pesticides, and the breakdown of organic materials [60]. Contrary to our results, other published research papers results showed that biochar alone application increased the soil pH [61]. The results also agree with the findings of [62] who found that soil pH decreased due to application of organic fertilizer.

Soil amendment, particularly biochar and organic fertilizers, significantly enhances soil properties in low organic matter soils dominated by sand or clay [63]. [64] reported that biochar application to degraded soil in arid and semi-arid areas is important soil amendments due to improving soil moisture content and SOM content. BC is a porous C materials having high water holing capacity has got considerable attention of its use for improving organic matter content in high temperature areas or soil which have low native organic matter content. [65] reported similar results that the application of BC in combination with other organic amendments significantly improved soil properties such as water porosity, holding capacity, bulk density, structure, water retention, hydraulic conductivity, nutrient retention, available P, total N, microbial biomass, total organic carbon, and soil aggregation. Fertilizer application from various organic sources also significantly improved soil organic matter and physicochemical properties. [66].

Incorporating high-N soybean crop residues into soil significantly increased soil mineral N content in the first month compared to no-till; no significant tillage effects were recorded with low-N peanut residues [67]. Both crop residues increased soil microbial biomass C, C mineralisation capacity and nitrification capacity. Legumes are the rich source of N as it fix atmospheric N. Generally, legumes residues are incorporated with idea to increase soil N content instead of other organic materials. [68] Legumes enhance soil fertility by symbiotically interacting with microorganisms like rhizobia, which fix atmospheric nitrogen and make it available to crops through BNF. LR leaves a significant amount of nitrogen, and soil microbes convert organic nitrogen into inorganic forms during residue decomposition. Inorganic nitrogen is quickly immobilized by soil microbial biomass. The maximum production, nutrient absorption, residual soil fertility, and microorganism condition are achieved when residue integration with NPK fertilizer is used. [69]. [70] discovered that the application of biochar, poultry manure, NPK fertilizer, and the combination of these enhanced soil total N, available P, exchangeable K, Ca, and Mg concentrations in comparison to the control.

Regarding the P soil's nutritional status, all three organic manures and inorganic fertilizers increased plant growth and production while also significantly raising the NPK content of the soil, which proved to a higher rate of nutrient use when organic manures were present [71]. More microbial activity and nutrient availability may have been evoked by organic additions with a lower dosage of chemical fertilizers than by applying chemical fertilizer alone or using an unfertilized control. When combined with inorganic fertilizers, the application of organic amendments increased the concentrations of N, P, and K in the soil [72]. Compared to inorganic fertilizers, organic manures have a greater positive impact on soil quality, which enhances nutrient release and plant availability [73].

The application of organic manures and biochar can enhance K soil by reducing decomposition and mineralization, promoting slow nutrient release, better crop nourishment, and reducing leaching of nutrients, thus enhancing soil health. [74]. Similarly, combined application of biochar with chemical fertilizers can also improve the soil physical properties to enhance the chemical fertilizers use efficiency by retention of nutrients even if biochar is applied in lesser quantity [75].

CONCLUSION

Organic-amendment application in soil has developed in recent years, as it is a promising method to enhance sustainable agriculture and climate-change mitigation. In this study, the application of amendments resulted in different effects on soil parameters and crop-yield improvement The experiments showed that using biochar or crop residues in combination with half NPK increased maize yield, soil phosphorus, and organic matter content. NPK alone resulted in higher plant height and biological yield. The study recommends integrating crop residues or biochar with mineral NPK fertilizer as the best solution for sustainable maize yield and soil properties improvement. At the same time, the application of biochar produced from nutrient-rich feedstock in soil seems to be indicated as both soil amendment and fertilizer. However, considering the wide range of biochar variability, further studies are needed to assess the agronomic value via a long-term experiment on the field scale.

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