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Enhancement of Soil Organic Carbon, Water Use Efficiency and Maize Yield (*Zea mays* L.) in Sandy Soil through Organic Amendment (Grass Peat) Incorporation

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Abstract: The efficient use of organic amendment (OM) is considered an economic, environmental and sustainable practice to improve soil quality, especially the accumulation of organic carbon (C) and water use efficiency (WUE) in dryland agriculture. However, the effect of different OM on soil nutrients, organic carbon fractions, water content and maize yield is unclear in arid and semi-arid regions with sandy soil. Field experiments with four OM, grass peat (GP), biochar (BC), organic fertilizer (OF) and maize straw (MS), were conducted with an equivalent amount of C input on the southeastern edge of Mu Us Sandy Land in China. Results indicated that the soil nutrients and labile organic carbon (DOC, MBC, $KMnO_4$-C and POC) concentrations were higher under OM (GP, BC, OF and MS) treatments than in CK in the 0–0.10 m soil layers. GP treatment remarkably improved carbon pool index values (1.63, 2.51 and 2.24, respectively) in all layers compared to CK (1.00). At maturity stages of maize, the soil water content (SWC) under GP and OF treatments (11.3–13.4%) was remarkably higher than that in CK treatment (around 10.0%). Yield and WUE were remarkably greater in GP and OF treatments compared to CK. The results proved that GP amendment is superior for barren sandy soil than BC, OF and MS treatments in improving soil nutrients, organic carbon sequestration, WUE and crop yield in China.

Keywords: organic amendment; labile organic carbon; water content; water use efficiency; crop yield

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1. Introduction

Drylands cover approximately half of the global land surface area [1,2]. Water shortage, low soil nutrients and soil desertification are the major restrictions on agricultural production in this region, especially in barren sandy soil [3,4]. Meanwhile, in order to achieve high crop yield, excessive application of inorganic fertilizer has resulted in a lot of ecosystem deterioration problems (e.g., pollution and land degradation) [5,6]. In turn, the desertification and salinization of land lead to a reduction in soil efficiency. Especially in the sandy environment, if only chemical fertilizers are added, it is necessary to consider the residual migration of related chemical substances in the underground to the surrounding fragile ecology. Therefore, it is important to reduce environmental costs and improve soil quality while increasing crop production.

To address these issues, many strategies (e.g., organic materials and integrated soil measures) are being researched around the world [7,8]. Previous studies have shown that OM (widely distributed and inexpensive) is recommended to enhance soil quality, productivity and soil organic C retention [9]. Soil organic C is a pivotal element in soil quality evaluation due to its crucial index in enhancing soil properties and microbe-mediated soil functions [10]. Previous studies have reported that OM maintains or increases organic C stocks through direct carbon input and indirect contributions from enhanced plant roots and foliage [11]. Labile organic C (including dissolved organic C (DOC), microbial biomass C (MBC), potassium permanganate-oxidizable C ($KMnO_4$-C) and particulate organic C (POC)) is the active fraction of soil organic C (SOC), which has a quick turnover time and high bioavailability [12,13]. Soil labile C fractions have been suggested as likely soil quality indexes [14,15]. Some researchers have reported that labile organic C fractions were associated with mean crop yields under dryland farming [16,17]. Meanwhile, the carbon pool index (CPI) and carbon management index (CMI) have been successfully applied in many crop fields (maize, millet, rice, etc.) for evaluating soil quality in response to exchanges in environmental situations and management measures [18]. Higher CPI and CMI values suggest that the soil is being restored, strengthened and maintained [19]. In addition, water use efficiency (WUE) is related to transpiration efficiency and is viewed as an essential factor affecting productivity, especially in drylands [20]. Thus, improving WUE is also important for ensuring grain yield and productivity. Ullah et al. [21] found that OM improved crop growth and yield under drought conditions. However, the response of soil features (e.g., soil porosity, aggregates and nutrients) to OM was strongly regulated by many factors (e.g., climatic, soil texture and the concentration and properties of OM) [22,23]. Therefore, it is crucial to know the properties of organic modifiers under different conditions for their rational utilization.

After years of afforestation and sand fixation in the Mu Us Sandy land, the ecological environment of the sandy land has been significantly increased. However, there are still some problems, such as loose soil texture, serious water leakage and fertilizer leakage. The rational development and utilization of land to improve maize yield is an important way to explore the sand industry in the region. A continuous maize cropping system is common in Northern China [24]. Mazie straw (MS) could be utilized as the most easily available OM in this region [25]. Direct returning straw to soil is generally regarded as a universal measure to use and recycle biomass resources [26]. It has the potential to increase SOC levels, increase soil aggregation and promote crop growth [27]. Nevertheless, some studies have found that adding MS may reduce crop yield and MS return exacerbates soil acidification [28]. Organic fertilizer (OF) and its abundance of available minerals help improve soil fertility and crop productivity [29,30]. However, OF incorporation has also been found to diminish the effect of improving carbon stock over time with gradual decomposition [31]. Grass peat (GP) is another traditional type of OM with high porosity and large organic C [32,33]. Nevertheless, Zhang et al. [34] found that GP application reduced the SWC by 10.5% under field conditions after one year. In addition, biochar (BC) can also enhance crop nitrogen use efficiency [35–37]. However, several studies have shown that BC incorporation leads to an improvement in soil pH and excessive salinization and can also cause weight loss and even death of earthworms [38,39]. With OM gaining increasing attention in drylands agriculture [26,40], the effects of different types of OM (GP, BC, OF and MS) on soil quality and crop yield still need to be further studied.

Our hypothesis is that the incorporation of OM will significantly improve soil nutrients, WUE and crop yield. The findings of the study will help increase agronomic productivity while improving SOC stocks and WUE in dryland agriculture.

2. Materials and Methods

2.1. Experimental Site

Field experiments were managed in the Gechougou watershed of Shenmu City, Shaanxi Province, China, located on the southeastern edge of Mu Us Sandy Land from 2018 to 2020 (38°53′ N, 109°52′ E, altitude 1250 m). The study area has a temperate continental climate, with annual temperature and precipitation of 9.4 °C and 320 mm (from 2018 to 2020), respectively.

2.2. Experiment Design

Four different types of OM treatments (GP, BC, OF and MS) were incorporated into a maize field, respectively. The GP was collected from the Mu Us Sandy Land. OF was bought from Shaanxi province. BC was prepared from apple branches. The MS was from the field harvest of the aboveground biomass. The properties of the OM are shown in Table 1. The OM was evenly employed on the soil surface (0–0.35 m). Each treatment was a randomized block with three plots (5 m × 8 m) from 2018 to 2020.

Table 1. The total carbon, total nitrogen content and an additional amount of organic amendment.

Amendment	Total Carbon ($g\ kg^{-1}$)	Total Nitrogen ($g\ kg^{-1}$)	C/N	Addition Amount ($kg\ ha^{-1}$)
Grass peat	151.7	9.0	16.9	24,300
Biochar	681.4	7.4	92.0	5400
Organic fertilizer	113.7	12.0	9.5	32,430
Maize straw	409.7	12.8	32.1	9000

2.3. Management Measure

The tested maize (*Zea mays* L.) cultivar was Dafeng-014, which has the characteristics of drought resistance and adaptability to nutrient-poor environments and was planted from 2018 to 2020. Maize was sowed on 3 May and harvested on 30 September 2020. The planting spacing was 0.50 m × 0.30 m (75,000 plants per hectare). The initial fertilizer schedule was 355-150-0 (N-P_2O_5-K_2O) kg ha^{-1} $year^{-1}$.

2.4. Survey of Soil and Plant Growth Characteristics

Soil samples were acquired from three soil layers (0–0.10 m, 0.10–0.20 m and 0.20–0.40 m) using an auger in October 2020. SWC and nutrients were measured by [41–45].

2.5. Calculation

Carbon management index (CMI), actual evapotranspiration (ET_a) and WUE of maize were measured by [12,46].

$$\text{Lability of C(L)} = \frac{\text{C in fraction oxidized by KMnO}_4}{\text{TOC} - \text{KMnO}_4} \quad (1)$$

$$\text{Lability Index (LI)} = \frac{\text{Lability of C in sample soil}}{\text{Lability of C in references soil}} \quad (2)$$

$$\text{Carbon Pool Index (CPI)} = \frac{\text{Sample total C}}{\text{Reference total C}} \quad (3)$$

$$\text{Carbon Management Index (CMI)} = \text{CPI} \times \text{LI} \times 100 \quad (4)$$

where the soil sampled in the CK treatment was used as the reference soil.

ET_a of maize was estimated through the soil water balance Equation (5)

$$ET_a = P + I + \Delta S - R - D + CR \quad (5)$$

where P is precipitation (mm), I is irrigation (mm), ΔS is the variation in soil water storage at a depth of 0–2.0 m (mm), R is surface runoff (mm), D is drainage below the 2.0 m soil profile, and CR is the capillary rise into the root zone, which was negligible because the groundwater table was more than 20 m deep at the experimental site. R and D are also considered negligible.

WUE (kg ha^{-1} mm^{-1}) was calculated using the following Equation (6):

$$WUE = \frac{GY}{ET_a} \quad (6)$$

where GY is grain yield (kg ha^{-1}), ET_a is evapotranspiration.

2.6. Statistical Analysis

Mean values and standard error were calculated using descriptive statistical analysis tools by SPSS 16.0. Data obtained from various experimental sites were analyzed using two-way ANOVA followed by the least significant difference (LSD) post hoc multiple comparison tests at the significance of $p < 0.05$ for the differences between soil depths and organic treatments on soil nutrients, organic C fractions, CPI and CMI.

3. Results

3.1. Soil Nutrients

The STN, STP, NO_3^--N, NH_4^+-N and Olsen-P were higher under OM (GP, BC, OF and MS) treatments compared with CK in the 0–0.10 m soil layer (Figure 1). The STN, STP and NO_3^--N concentrations were significantly higher under GP than in CK in the 0–0.20 m soil layers ($p < 0.05$). In addition, there were no differences in NH_4^+-N in all soil layers (except for BC treatment).

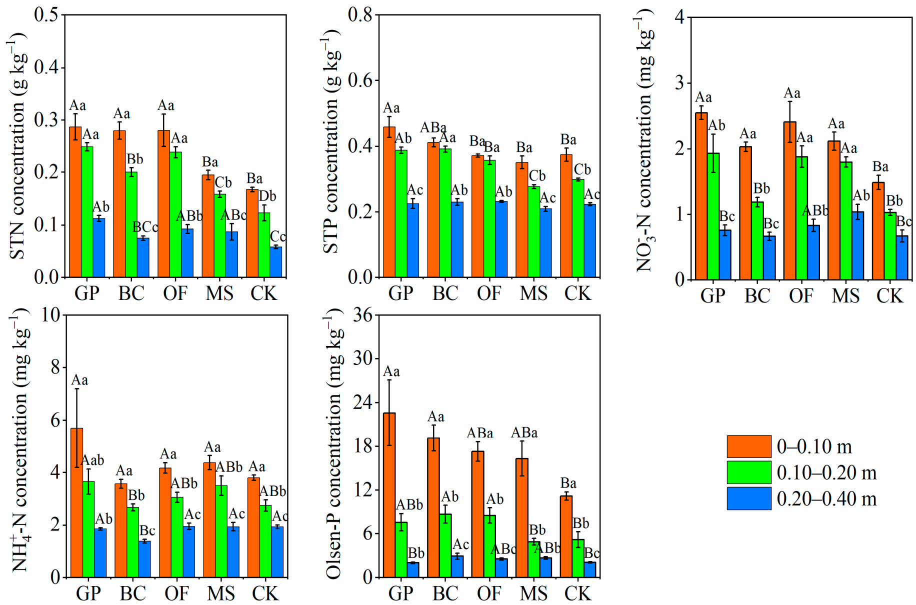

Figure 1. Effects of organic amendment incorporation on the soil nutrients in the 0–0.40 m in 2020. Different uppercase letters indicate significant differences among all treatments at the same soil depth ($p < 0.05$). Different lowercase letters indicate significant differences among all soil depths at the same treatment.

3.2. Soil Labile Organic C Fractions

The TOC, DOC, MBC and POC concentrations were higher in OM (GP, BC, OF and MS) treatments than in CK in the 0–0.10 m soil layer (Figure 2). There were no significant differences in $KMnO_4$-C under GP and BC treatments compared to CK in the 0–0.10 m soil layer (Figure 2). However, the $KMnO_4$-C was greater in OM (GP, BC, OF and MS) treatments than in CK in 0.10–0.40 m soil layers. There were no significant differences in DOC and MBC concentrations under BC treatment compared to CK in the 0.10–0.40 m soil layers.

The DOC/TOC and POC/TOC ratios were remarkably higher in 0.20–0.40 m soil layers under GP, BC and OF treatments (Table 2). The DOC/TOC ratios were higher in GP, BC, OF and MS treatments (0.6–1.4%) than in CK (0.5–0.6%) in the 0–0.20 m soil layers. The MBC/TOC ratios were greater in GP, OF and MS treatments (1.3–1.9%) than in CK (1.1–1.3%) in all layers. However, the ratios were lower in BC treatment than in CK in all layers. By comparison with CK (26.6–42.1%), the $KMnO_4$-C/TOC ratios were lower in GP, BC and OF treatments (18.4–40.5%) in all layers. By comparison with CK (6.1–32.6%), the POC/TOC ratios were significantly greater in BC treatment in all layers (13.3–33.7%).

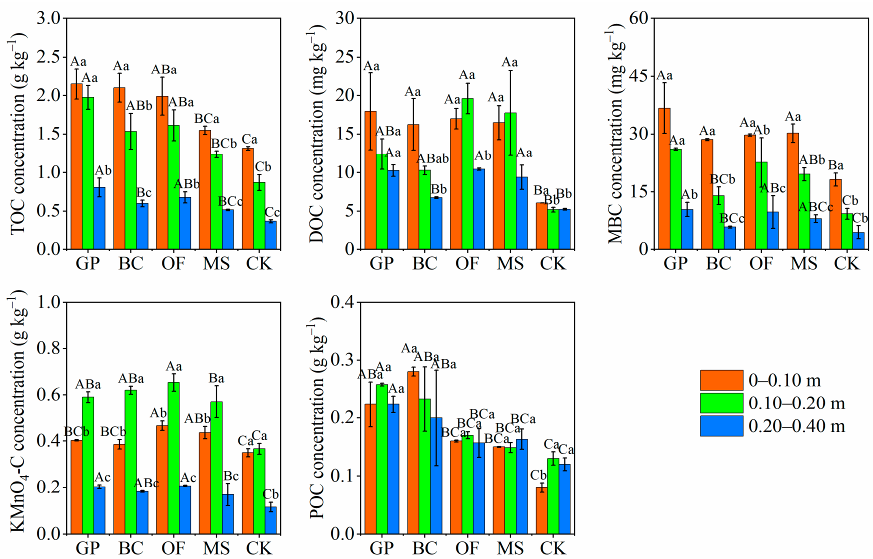

Figure 2. Effects of organic amendment incorporation on the soil TOC, DOC, MBC, $KMnO_4$-C and POC concentrations in the 0–0.40 m in 2020. Different uppercase letters indicate significant differences among all treatments at the same soil depth ($p < 0.05$). Different lowercase letters indicate significant differences among all soil depths at the same treatment.

Table 2. Effects of organic amendment incorporation on the proportions of labile organic carbon fractions in the TOC.

Soil Depth (m)	Treatment	DOC/TOC (%)	MBC/TOC (%)	$KMnO_4$-C/TOC (%)	POC/TOC (%)
0–0.10 m	Grass peat	0.8 ± 0.2 ABab	1.7 ± 0.3 ABa	18.8 ± 0.6 Cc	10.4 ± 1.8 Bb
	Biochar	0.8 ± 0.2 ABb	1.4 ± 0.1 Ba	18.4 ± 0.9 Cc	13.3 ± 0.3 Ab
	Organic fertilizer	0.9± 0.1 ABc	1.5 ± 0.1 ABa	23.4 ± 1.1 Bc	8.1 ± 0.1 BCb
	Maize straw	1.1 ± 0.1 Aa	1.9 ± 0.2 Aa	28.2 ± 1.7 Ab	9.9 ± 0.1 Bb
	Control	0.5 ± 0.1 Bc	1.4 ± 0.1 Ba	26.6 ± 1.3 ABb	6.1 ± 0.4 Cc
0.10–0.20 m	Grass peat	0.6 ± 0.1 Bb	1.3 ± 0.1 Aa	29.9 ± 1.2 Ba	12.9 ± 2.8 ABb
	Biochar	0.7 ± 0.1 Bb	0.9 ± 0.2 Ab	40.4 ± 1.1 Aa	15.2 ± 3.6 Ab
	Organic fertilizer	1.2 ± 0.1 ABb	1.4 ± 0.3 Aa	40.5 ± 2.3 Aa	10.3 ± 0.3 Bb
	Maize straw	1.4 ± 0.5 Aa	1.6 ± 0.1 Aa	46.1 ± 0.9 Aa	11.1 ± 0.2 ABb
	Control	0.6 ± 0.1 Bc	1.1 ± 0.1 Aa	42.1 ± 2.7 Aa	14.9 ± 1.3 ABb
0.20–0.40 m	Grass peat	1.3 ± 0.1 Ba	1.3 ± 0.2 Aa	25.2 ± 1.1 Bb	27.7 ± 1.8 ABa
	Biochar	1.1 ± 0.1 Ba	0.9 ± 0.1 Ab	30.6 ± 0.6 ABb	33.7 ± 2.2 Aa
	Organic fertilizer	1.5 ± 0.1 ABa	1.4 ± 0.6 Aa	30.5 ± 1.3 ABb	23.2 ± 3.6 Ba
	Maize straw	1.8 ± 0.3 Aa	1.6 ± 0.2 Aa	32.9 ± 2.9 Ab	31.9 ± 0.6 Aa
	Control	1.4 ± 0.1 ABa	1.2 ± 0.5 Aa	31.7 ± 2.4 Ab	32.6 ± 3.1 Aa

TOC: total organic C, DOC: dissolved organic C, MBC: microbial biomass C, $KMnO_4$-C: potassium permanganate-oxidizable C, POC: particulate organic C. The level of significance is $p < 0.05$. Different uppercase letters indicate significant differences among all treatments at the same soil depth ($p < 0.05$). Different lowercase letters indicate significant differences among all soil depths at the same treatment.

3.3. C Pool Index and C Management Index

Table 3 indicated that the L and LI values were smaller in GP, BC and OF treatments than in CK in all layers. However, the values were higher in MS treatment compared with CK in the 0–0.40 m soil layers. GP treatment significantly enhanced CPI values in all layers (1.63, 2.51 and 2.24, respectively) compared to CK (1.00). The CMI value was greater in OM (GP, BC, OF and MS) treatments than in CK in all layers.

Table 3. Effects of organic amendment incorporation on the soil CPI and CMI.

Soil Depth (m)	Treatment	L	LI	CPI	CMI
0–0.10 m	Grass peat	0.23 ± 0.01 Cc	0.64 ± 0.04 Ca	1.63 ± 0.14 Aa	104.51 ± 6.22 ABb
	Biochar	0.23 ± 0.01 Cc	0.63 ± 0.07 Ca	1.60 ± 0.15 Aa	100.95 ± 11.10 Bb
	Organic fertilizer	0.31 ± 0.02 Bb	0.85 ± 0.09 Ba	1.50 ± 0.17 ABa	128.38 ± 11.18 Aa
	Maize straw	0.39 ± 0.03 Ab	1.09 ± 0.09 Aa	1.18 ± 0.03 BCa	128.17 ± 4.72 Ab
	Control	0.36 ± 0.02 ABb	1.00 ± 0.00 ABa	1.00 ± 0.00 Ca	100.00 ± 0.00 Ba
0.10–0.20 m	Grass peat	0.43 ± 0.02 Ca	0.59 ± 0.03 Ba	2.51 ± 0.46 Aa	147.44 ± 10.17 ABa
	Biochar	0.68 ± 0.03 Ba	0.95 ± 0.01 ABa	1.77 ± 0.15 ABCa	166.92 ± 20.52 Aa
	Organic fertilizer	0.69 ± 0.07 Ba	0.98 ± 0.01 Aa	1.90 ± 0.22 ABa	185.19 ± 39.50 Aa
	Maize straw	0.86 ± 0.03 Aa	1.18 ± 0.04 Aa	1.54 ± 0.22 BCa	182.10 ± 15.14 Aa
	Control	0.74 ± 0.08 ABa	1.00 ± 0.00 Aa	1.00 ± 0.00 Ca	100.00 ± 0.00 Ba
0.20–0.40 m	Grass peat	0.34 ± 0.02 Bb	0.74 ± 0.08 Ba	2.24 ± 0.36 Aa	164.54 ± 16.84 Aa
	Biochar	0.44 ± 0.01 ABb	0.96 ± 0.09 Aa	1.46 ± 0.25 ABa	141.06 ± 13.86 ABab
	Organic fertilizer	0.44 ± 0.03 ABb	0.95 ± 0.11 Aa	1.81 ± 0.45 ABa	173.04 ± 12.19 Aa
	Maize straw	0.50 ± 0.06 Ab	1.06 ± 0.03 Aa	1.42 ± 0.07 ABa	150.20 ± 4.55 Aab
	Control	0.47 ± 0.05 ABb	1.00 ± 0.00 Aa	1.00 ± 0.00 Aa	100.00 ± 0.00 Ba

L: Lability of carbon, LI: Lability index, CPI: carbon pool index, CMI: carbon management index. The level of significance is $p < 0.05$. Different uppercase letters indicate significant differences among all treatments at the same soil depth ($p < 0.05$). Different lowercase letters indicate significant differences among all soil depths at the same treatment.

3.4. Soil Water Content

There were remarkable differences in SWC among the treatments (Figure 3). At the tasseling and milking stages, the SWC in the 0.60–1.20 m soil layer under OF treatment (8.8–9.9%) was remarkably higher than that in other (GP, BC, MS and CK) treatments. At maturity stages, compared to BC and CK treatments (around 10.0%), GP and OF treatments remarkably increased the SWC (11.3–13.4%) in the 0.60–1.00 m soil layer.

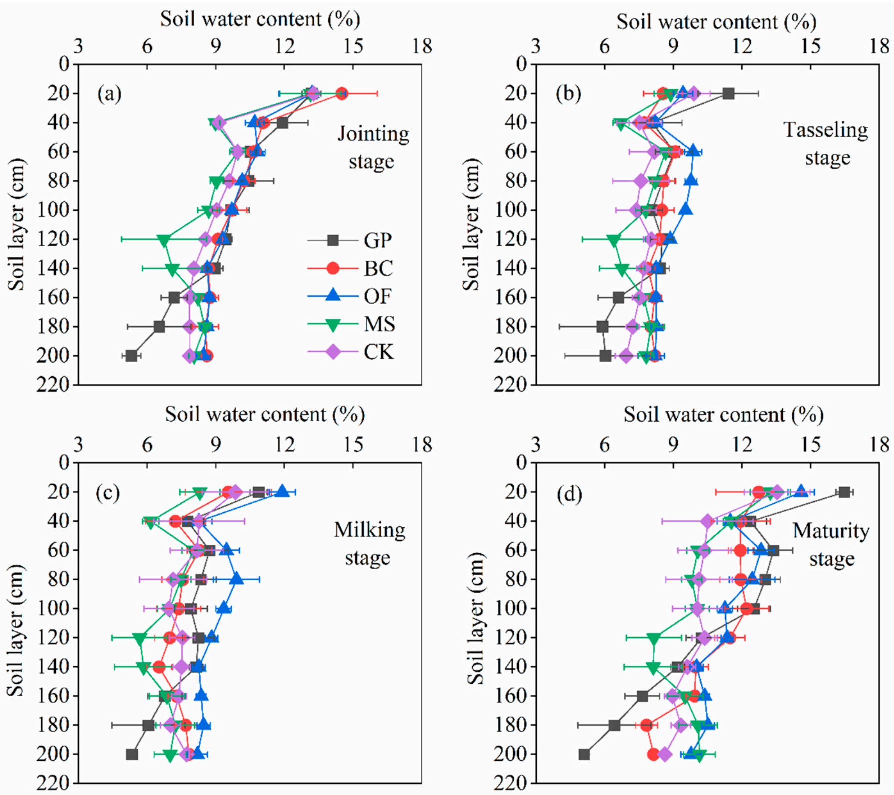

Figure 3. Effects of organic amendment incorporation on the soil water content in 2020. (**a**–**d**) represent jointing, tasseling, milking and maturity stages, respectively.

3.5. Grain Yield, 1000-Kernel Weight, Plant Height, ET_a and WUE

Grain yield under OM incorporation (GP, BC, OF and MS treatments) remarkably increased compared to CK (Table 4). 1000-kernel weight of maize increased under GP, BC, OF and MS treatments compared to CK. GP, BC and OF treatments (1.49 m, 1.60 m and 1.60 m) significantly increased the plant height of maize compared to that of CK (1.19 m). There were no differences in ET_a under OM (GP, BC, OF and MS) treatments compared to CK. The WUE under the GP, BC, OF and MS treatments were 5.9 kg ha^{-1} mm^{-1}, 3.8 kg ha^{-1} mm^{-1}, 4.6 kg ha^{-1} mm^{-1} and 1.2 kg ha^{-1} mm^{-1} higher than that under the CK treatment (2.8 kg ha^{-1} mm^{-1}), respectively.

Table 4. Grain yield, 1000-kernel weight, plant height, ET_a and water use efficiency under different treatments in 2020.

Treatment	Grain Yield (t ha^{-1})	1000-Kernel Weight (g)	Plant Height (m)	ET_a (mm)	WUE (kg ha^{-1} mm^{-1})
Grass peat	4.4 ± 0.7 A	177.4 ± 13.3	1.49 ± 0.04 A	510.5 ± 1.7	8.7 ± 1.5 A
Biochar	3.4 ± 0.6 AB	166.4 ± 12.8	1.60 ± 0.07 A	517.5 ± 17.8	6.6 ± 1.1 AB
Organic fertilizer	3.8 ± 0.4 A	176.7 ± 6.4	1.56 ± 0.04 A	517.0 ± 11.0	7.4 ± 0.7 A
Maize straw	2.1 ± 0.3 AB	163.9 ± 2.7	1.29 ± 0.05 B	521.6 ± 12.7	4.0 ± 0.5 BC
Control	1.5 ± 0.4 C	155.0 ± 5.8	1.19 ± 0.03 B	533.1 ± 12.7	2.8 ± 0.8 C

ET_a: actual crop evapotranspiration, WUE: water use efficiency. Different uppercase letters indicate significant differences among all treatments. The level of significance is $p < 0.05$.

4. Discussion

4.1. Effect of Amendments on Soil Nutrient Content

OM was advantageous in enhancing soil nutrients and improving crop growth and yields [47]. In this research, OM (GP, BC, OF and MS) treatments significantly increased STN and STP concentrations at 0–0.20 m soil layers after three growing seasons, which could alleviate soil desertification and solve the problem of low soil quality (Figure 1). OM (GP, BC, OF and MS) treatments may remarkably enhance soil organic carbon, improve crop productivity and promote plant biomass, ultimately contributing to nitrogen inputs [48]. Meanwhile, our results showed an obvious improvement in soil NO_3^--N, NH_4^+-N and Olsen-P concentrations at the topsoil depth with the application of OM than CK. The enhancement in nutrient availability with OM is ascribed to the promotion of active N and P in these materials due to variations in the soil condition [49]. However, soil NO_3^--N, NH_4^+-N, and Olsen-P concentrations of BC were lower than in GP, OF and MS treatments in 0–0.40 m soil layers. This may be due to BC's slower breakdown than GP, OF and MS treatments [50,51].

4.2. Effect of Amendments on Soil Labile Organic C Fractions

In this study, the TOC, DOC, MBC and POC concentrations were higher in OM (GP, BC, OF and MS) treatments in 0–0.10 m soil layers, which indicates that OM can enhance SOC quality pool and improve biological yield. The $KMnO_4$-C and DOC have been diffusely recognized as beneficial markers for the possibility of organic matter release and nutrient cycling [52]. The MS treatment enhanced the DOC concentration and the DOC/TOC ratio in all soil layers, which indicates a higher release rate of soluble organic matter in MS treatment. The MS treatment improved the $KMnO_4$-C and $KMnO_4$-C/TOC; in turn, the $KMnO_4$-C/TOC ratios were lower in GP, BC and OF than in CK in all layers, which suggests that a lower rate of nutrient cycling in GP, BC and OF treatments [44]. The enhancement of MBC is crucial because it represents the enhancement in the activity of the soil microbial [53]. The MBC/TOC ratios were higher in GP, OF and MS in 0–0.40 m soil layers. However, MBC levels significantly fell in the BC treatment. The possible reason was that the BC and soil water situations changed the soil microbial community structure.

The POC is mainly composed of crop residues and microbial biomass debris, which are energy sources for microorganisms and short-term stores of maize nutrients [54]. Thus, the POC/TOC values were higher, and POC had a relatively slow turnover time compared to other labile organic C. The POC concentration and POC/TOC values were higher in all soil layers under BC as compared with CK treatment, which indicates that a greater part of the BC was converted to POC.

The CPI and CMI values have been diffused and applied to evaluate the effects of soil management measures on soil organic C and soil quality [31]. GP remarkably increased the CPI in all soil layers compared with CK, and this was mainly because of the higher TOC and $KMnO_4$-C values in the 0–0.20 m soil layers. Several studies have shown that labile organic C, L and LI significantly correlate with carbon accretion in plant leftovers [45]. Our results suggested that GP treatment had a higher restoration rate compared to other OM treatments (BC, OF and MS) in the experiment.

4.3. Effect of Amendments on Yield and WUE

WUE is an indicator utilized to evaluate how efficiently a maize uses water. GP and OF remarkably enhanced the WUE as compared to CK treatment, this indicated that GP and OF were advantageous to enhance the water productivity of maize [55].

The effects of GP and OF on maize height were slightly smaller than that of BC treatment but remarkably greater than that of MS and CK, which may be due to straw as an amendment requires a large amount of returning to the field or other OM. Therefore, the improvement of soil nutrient status is not obvious in MS treatment (Figure 1). Although GP and OF are carbon materials, they are more complex in composition than MS. In addition, MS lacks features such as the larger specific surface area and good adsorption effect of BC, so the texture and structure of the soil are improved more slowly than that of BC treatment, and the height of the maize is less than that of BC treatment.

Crop yield was greatly affected by many factors (e.g., climate, soil quality and management measures) [56]. Maize yield was remarkably positively correlated with STN, TOC, MBC and POC ($p < 0.05$) (Table 5). Thus, maize yield under different OM treatments changed remarkably after inputting three years (Table 4). By comparison with CK, the OM (GP, BC, OF and MS) treatments presented a remarkable improvement in grain yield. Maize yield increased significantly under GP and OF treatments, possibly because GP and OF were much more advantageous for the nutrient (nitrogen) supply than BC and MS (Table 1). Our results were similar to Liao et al. [57], who found that BC addition did not significantly enhance crop yields during a four-year study period. In addition, the significantly higher grain yields of GP and OF treatments may be related to the enhanced SWC and plant nutrient uptake during milking and maturity stages (Figure 3), which further enhanced the photosynthetic capacity and biomass output (e.g., plant height and leaf area) of the crop [58].

Table 5. Spearman's correlation between soil nutrients and yield.

	STN	STP	NO_3^--N	NH_4^+-N	Olsen-P	TOC	DOC	MBC	$KMnO_4$-C	POC	Yield
STN	1	0.923 **	0.918 **	0.824 **	0.859 **	0.991 **	0.752 **	0.927 **	0.727 **	0.464	0.643 **
STP	0.923 **	1	0.821 **	0.846 **	0.868 **	0.939 **	0.532 *	0.851 **	0.692 **	0.360	0.466
NO_3^--N	0.918 **	0.821 **	1	0.930 **	0.874 **	0.913 **	0.823 **	0.977 **	0.651 **	0.230	0.490
NH_4^+-N	0.824 **	0.846 **	0.930 **	1	0.885 **	0.842 **	0.640 *	0.932 **	0.548 *	0.092	0.304
Olsen-P	0.859 **	0.868 **	0.874 **	0.885 **	1	0.862 **	0.617 *	0.907 **	0.406	0.273	0.381
TOC	0.991 **	0.939 **	0.913 **	0.842 **	0.862 **	1	0.724 **	0.935 **	0.734 **	0.480	0.642 **
DOC	0.752 **	0.532 *	0.823 **	0.640 *	0.617 *	0.724 **	1	0.806 **	0.630 *	0.352	0.501
MBC	0.927 **	0.851 **	0.977 **	0.932 **	0.907 **	0.935 **	0.806 **	1	0.605 *	0.329	0.556 *
$KMnO_4$-C	0.727 **	0.692 **	0.651 **	0.548 *	0.406	0.734 **	0.630 *	0.605 *	1	0.250	0.391
POC	0.464	0.360	0.230	0.092	0.273	0.480	0.352	0.329	0.250	1	0.710 **

** $p < 0.01$, * $p < 0.05$.

5. Conclusions

OM (GP, BC, OF and MS) treatments significantly increased the soil nutrients and labile organic carbon concentrations. Meanwhile, GP treatment significantly increased CPI values in all layers compared to CK. The CMI value was greater in OM (GP, BC, OF and MS) treatments than in CK in all layers. At maturity stages, compared to CK treatment, GP, BC and OF treatments enhanced the SWC in the 0–1.20 m soil layer. Yields of OM (GP, BC, OF and MS) treatments were remarkably enhanced compared to CK treatments. In conclusion, GP treatment can be an effective method for enhancing soil nutrients, organic C accumulation, crop yield and WUE of sandy soil.

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