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Effects of Environmentally Friendly Materials on Saline Soil Improvement and Sunflower Yields in the Hetao Irrigation Region, China

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Abstract: The Hetao irrigation region is located in Inner Mongolia, China, within a dry and semi-dry region. This region suffers from poor agricultural productivity and environmental damage due to the presence of saline soil. To explore the growth of salty lands using a more environmentally friendly method, this research employed three eco-conscious amendments to improve the soil. These include flue gas desulfurization gypsum (S), humic acid (H), and biochar (C). During a two-year study, the amendments were utilized to enhance the soil quality for planting sunflowers. Humic acid was used prior to every seedling season, whereas the remaining two substances were only used once. These additions increased the soil's water-holding capacity, reduced soil salinity during sunflower growth, and improved the macroaggregate proportion. The most effective treatment for decreasing the soil's salt content after the seedling stage was the application of humic acid (0.6 t ha^{-1}). Biochar (15 t ha^{-1}) decreased the soil's bulk density (from 1.49 to 1.34 g cm^{-3}) and mostly increased the sunflower seed yield up to 3133−3964 kg ha^{-1}. Humic acid addition significantly increased the aggregate (>0.25 mm) content up to 27.88% after the experiment, but it led to a lower seed yield (2607−3686 kg ha^{-1}). In 2019, the temperature was lower compared to 2018, which may have led to a reduction in the yield. However, these three amendments could potentially increase yields by more than conventional methods. These three environmentally friendly amendments are useful for improving saline soil and increasing yields. More studies are required to understand their impacts on larger areas and over extended periods.

Keywords: sunflower; gypsum; humic acid; biochar; saline soil; soil amendments

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1. Introduction

Soil salinity is a widespread environmental issue that affects all continents in more than 100 countries of the world [1]. High salt levels damage agricultural sustainable development, and they are becoming a big problem for the environment and the economy worldwide [2]. However, saline lands have a huge potential to increase agricultural production to alleviate food scarcity [3]. According to an investigation by the FAO in 2021, there was about 835 million ha of saline soils globally [4]. Saline soil occupies the vast inland and coastal areas in China, accounting for about 99 million ha [5]. The Hetao irrigation area is mainly located in the Inner Mongolia of China; it is the leading center for producing grains and feeding animals. It has approximately 0.32 million ha of saline lands, accounting for 45% of arable lands in this area [6]. Every year, the Yellow River supplies nearly 5 billion m^3 of water for the Hetao Plain, and 1.7 billion kg of salt from the Yellow

River water is deposited in this area [7]. Therefore, agricultural development in these lands is confronted with a significant obstacle in soil salinity, and thus, it is urgently necessary to ameliorate soil salinity during crop cultivation. Several attempts have been made to address soil salinity in water-scarce regions, such as engineering measures [8], water leaching [9], planting halophyte varieties [10], the addition of acid chemical materials [11], the addition of soil amendments [12], and so on. Among all remediation measures, soil amendment is considered to be a useful and environmentally friendly method, especially in water-scarce regions, due to its beneficial effects on improving soil quality and remediating soil salinity stress [13,14]. However, numerous amendments with different advantages are accessible in the market. The Hetao irrigation area has encountered a major biological issue after years of using chemical fertilizers and dealing with a shortage of fresh water. It is important to take into account environmental issues when managing agriculture in arid lands in order to create a sustainable development model. Amendments that are easy to implement and use environmentally friendly materials are the primary goal for application in saline soils [12]. For instance, biochar, humic acid, and flue gas desulfurization gypsum are ideal remediation matters.

Biochar is a carbon-rich product obtained when biomass is heated in a closed container with little or no available air. It is also produced at relatively low temperatures (<700 °C). Biochar application has been proven to be an effective measure for improving degraded soil [15]. Its special characteristics include its rich porosity, abundant element composition, stability, and extensive raw materials [16]. It can also increase the soil's water-holding capacity [17], improve nutrient retention [18], promote rhizobacteria [19], adsorb soil salts [20], and thus accelerate product formation. These benefits of biochar make it good for use in water-lacking saline lands. Humic acid is derived from plant materials that are comparable to biochar. However, humic acid has more active organic materials that can enhance soil fertility [21], regulate the biological community [22], ameliorate soil aggregate compositions [23], increase fertilizer utilization efficiency [24], and improve seedling growth [25] in saline soils. The abundant functional groups of humic acid allow it to form complexes with ions, thus reducing salt toxicity [26]. Furthermore, flue gas desulfurization (FGD) gypsum is a byproduct of the processing of sulfur dioxide by lime during coal-fired power generation [27]. FGD gypsum consists of many calcium elements, which makes it beneficial for plants in alleviating salt stress [28]. In addition, FGD gypsum is a kind of acidic material, showing big potential in saline or alkaline soil remediation. Research has reported that FGD gypsum application could significantly reduce soil pH and salinity to different levels [29]. Amendments offer unique benefits for enhancing saline soil, and they are readily available for production or collection, making them ideal resources for improving saline soil conditions. These three materials have been used for saline soil remediation in many studies. However, we know less about their use in the arid Hetao irrigation region of Inner Mongolia for planting sunflowers.

Sunflower (*Helianthus annuus*) has been widely planted worldwide, even in areas with little rainfall and significant evaporation. It is the primary feeding and industrial plant in the Hetao irrigation district, Inner Mongolia, China. It is considered a kind of salt-tolerant plant, but its yield and growth are inhibited when the soil contains excessive salts [30]. So, using soil amendments is important for increasing grain yield and salt resistance in sunflowers. Although some studies have reported on biochar, humic acid, and FGD gypsum application in arid regions, little is known about their long-term effects on sunflower growth in the special field conditions of the Hetao irrigation region of Inner Mongolia. During the two-year field cultivation experiment, our primary goals encompassed evaluating the impact of these three substances on the growth and yield of sunflowers, as well as on the salt and water properties of the soil. We postulate that the utilization of amendments may enhance soil conditions and augment sunflower yields. Due to each treatment's distinct qualities and the numerous studies that have documented its positive benefits, it is anticipated that each treatment will have a substantial impact on various soil attributes.

2. Materials and Methods

2.1. Experiment Site

The field study took place during the sunflower growing seasons in 2018 and 2019 under rain-fed conditions in the Hangjinhou banner, Bayannur City (40°49′42.7″ N, 06°54′28.5″ E), Inner Mongolia, China. The area has a typical semi-arid climate and, with an altitude of 1038 m, this unique spot is perfect for conducting field experiments. The land has long been used for crop cultivation, making it a crucial hub for China's grain production. The mean annual precipitation in this region is approximately 138 mm, with the majority of the precipitation falling between July and September. About 2096 mm of evaporation occurs annually on average. The mean annual temperature is 6 °C, with monthly averages ranging from 20 °C in July to −11 °C in January. The groundwater table is quite low (1−3 m) and swings substantially due to irrigation, as agriculture depends on Yellow River water irrigation. Farmers also historically employ flood irrigation before sowing sunfloers and after salt leaching.

The texture of the soil is classified as Solonetzes, and sand and clay contents are 78.9%, 5.3%, and 15.8%, respectively. The fundamental physical and chemical properties of surface soil at a depth of 0~20 cm prior to the experiment are outlined in Table 1. The ion content was determined in soil extract (soil: water, 1:5) via potentiometric titration method using METTLER TOLEDO SevenExcellecne T7 instrument (METTLER TOLEDO, Zurich, Switzerland). The nutrient element was measured by the combustion method using a FlashSmart Thermo Fisher instrument (METTLER TOLEDO, Zurich, Switzerland).

Table 1. Soil physical and chemical properties of the experiment site.

Salt Content (g kg^{-1})	pH	Total Nitrogen (g kg^{-1})	Soil Organic Matter (g kg^{-1})	Bulk Density (g cm^{-3})	HCO_3^- (g kg^{-1})	Cl^- (g kg^{-1})	SO_4^{2-} (g kg^{-1})	Ca^{2+} (g kg^{-1})	Mg^{2+} (g kg^{-1})	$Na^+ + K^+$ (g kg^{-1})
7.06	8.19	0.86	17.0	1.49	0.68	1.10	3.17	0.15	0.14	1.83

2.2. Experimental Design and Implementation

This study was conducted using a randomized complete block design and included three replications. The dimensions of each plot were 4.2 m × 10 m, and ridges (30 cm wide) separated them to minimize the effects of water and salt movement between treatments (Figure 1). The fields were separated in a tillage area that had been farmed for many years, but the productivity was still limited by soil salinity. This experiment involved four treatments, including control (CK), biochar (15 t ha^{-1}, C), humic acid (0.6 t ha^{-1}, H), and desulfurized gypsum (3 t ha^{-1}, S). The biochar (sawdust pyrolysis) was bought from Tairan Organic Fertilizer Company in Shandong Province, China. The humic acid (Biological Fermentation through wheat straw) was procured from Tianxinyuan Biochemical Company in Niangxia Province, China. The desulfurized gypsum (particle size of 40~60 µm) was bought from the Xuhai company in Dongying City. Our previous study gave us the best results for soil improvement and yield, which was the basis for the amendments dosage designed.

Principal soil amendment features and application amounts are shown in Table 2. The amendments and the base fertilizer were evenly distributed on the soil surface on April 21, 2018, and then mixed with the 0~20 cm soil using the tilling machine. The initial fertilizer used was diammonium phosphate at a quantity of 375 kg ha^{-1}. Urea was applied at the sunflower bud and flowering stage at rates of 240 kg ha^{-1} and 100 kg ha^{-1}, respectively, according to local practices. The desulfurized gypsum and biochar were limited to 2018, but the application of humic acid in 2019 was identical to that of 2018. For each designated area, the ground was flattened and covered with white plastic film using a mechanical device. To leach the soil salt, the plots were subjected to flood irrigation with Yellow River (with an average salt content of 0.6 g L^{-1}) in early May and late October. Approximately 10 m^3 (equal to 3000 m^3 ha^{-1}, 300 mm depth) of water was irrigated to each plot. Before

planting, the soil salt was leached by two flood irrigations on 1 May and 18 May 2018, and two waterings were carried out on 5 May and 20 May 2019 to leach soil salt.

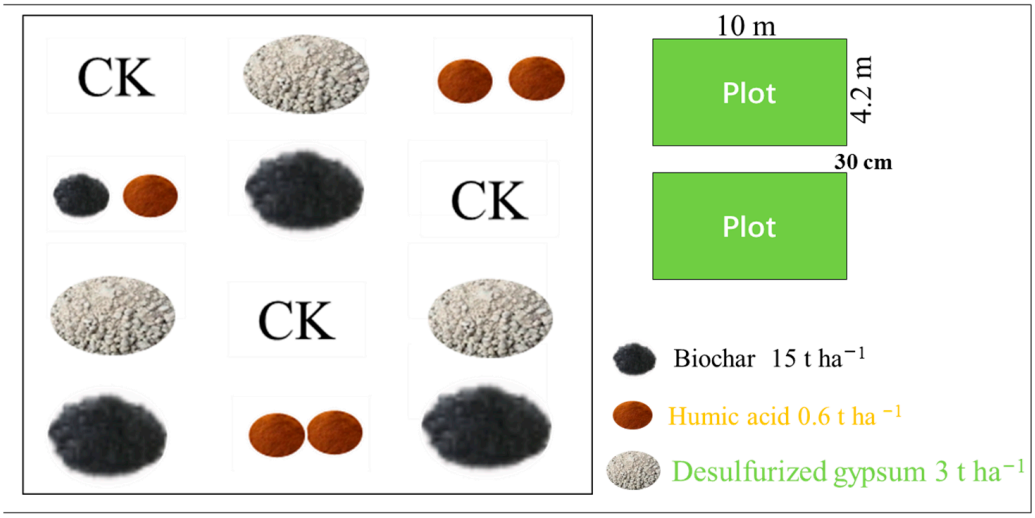


Figure 1. Experimental design in the field plots.

Table 2. The major properties and application amount of the amendments.

Materials	pH	Salt Content (g kg^{-1})	Total Nitrogen (g kg^{-1})	Organic Matter (g kg^{-1})	Application Amount (kg ha^{-1})
Biochar (C)	8.02	0.82	4.0	493.1	15,000
Humic acid (H)	6.71	0.41	7.5	884.9	600
Desulfurized gypsum (S)	7.61	2.02	0.06	2.8	3000

Sunflower was manually sown on 30 May 2018, and 8 June 2019, at a row spacing of 60 cm, plant spacing of 50 cm, and a density of 33,000 plants per ha. The crops were collected in late September of each year. Other ways of management were aligned with the agricultural practices typically employed in the region.

2.3. Soil Sampling and Measurements

To assess the impact of the three amendments on the soil and sunflower yields, we established a sampling strategy and evaluation criteria. Three soil samples were collected from each plot at sowing, harvesting, and each crop growth to test soil bulk density at depths of 0−20 and 20−40 cm. The sampling point was between two rows of plastic mulching that had been buried. Gravimetric soil water content was measured by the oven-drying method. The samples were then ground to pass through a 2 mm mesh to test the water-soluble salts. The concrete steps were as follows. A 1:5 mix of soil and water was taken from soil water. The suspension was first stirred up. After that, it was centrifuged for 5 min. The water and soil combination was dried to determine the level of salt in it. The pH values of the solution were determined using pH meter (METTLER TOLEDO, Seven Excellence S400-Basic, Zurich, Switzerland). Each year, the bulk density (BD) of soil was measured at a depth of 0−20 cm before planting and after harvesting period. The undisturbed soil cores were obtained using sharpened steel cylinders of 100 cm^3 volume (5 cm inner diameter and 5 cm height) at the soil surface layer (10–15 cm) and were oven-dried for 24 h in a ventilated oven to measure BD. The water-stable aggregate (>0.25 mm, $R_{0.25}$) was determined by wet sieving, as described by [31]. The mean weight diameter (MWD) and mean geometric diameter (GWD) were each calculated by the following equation [31]:

$$\mathrm{MWD} = \sum_i^n (x_i w_i) \quad (1)$$

$$\mathrm{GWD} = e^{\frac{\sum_i^n (Wi \ln xi)}{\sum_i^n w_i}} \quad (2)$$

where x_i is the mean diameter of aggregate size fractions, w_i is the weight proportion of the aggregate size fractions on each size, and n is the aggregate size.

2.4. Sunflower Yields

During the harvest, 15 sunflower heads were randomly selected from 3 rows within each plot. Then, free seeds were extracted by hand. After that, the heads were oven-dried for two days at 50 °C and weighed to find the net yield. The sunflower yield per hectare was calculated by multiplying the seed yield per plant by the total number of plants.

2.5. Statistical Analyses

All data were the mean value of three replicates and were subjected to analysis of variance (ANOVA) and LSD's tests ($p < 0.05$) using Excel 2022 and SPSS 22.0. Excel 2016 software was used to draw the data maps.

3. Results

3.1. Soil Water Content

Figure 2 depicts the average amount of precipitation observed throughout the growing seasons. The primary influencing factor, subsequent to the flooding irrigation prior to planting seedlings, was the rainfall, which had the potential to impact the soil water content. The soil water content was monitored on 30 May 2018, and 8 June 2019, respectively (Figure 3). The soil water content was measured five times during each stage of growth. During the two years of sunflower growth, the soil water content changed consistently in all treatments. From the planting period until the second measurement in early July, the soil moisture content decreased and then fluctuated somewhat over the rainfall period until the end of the growing season.

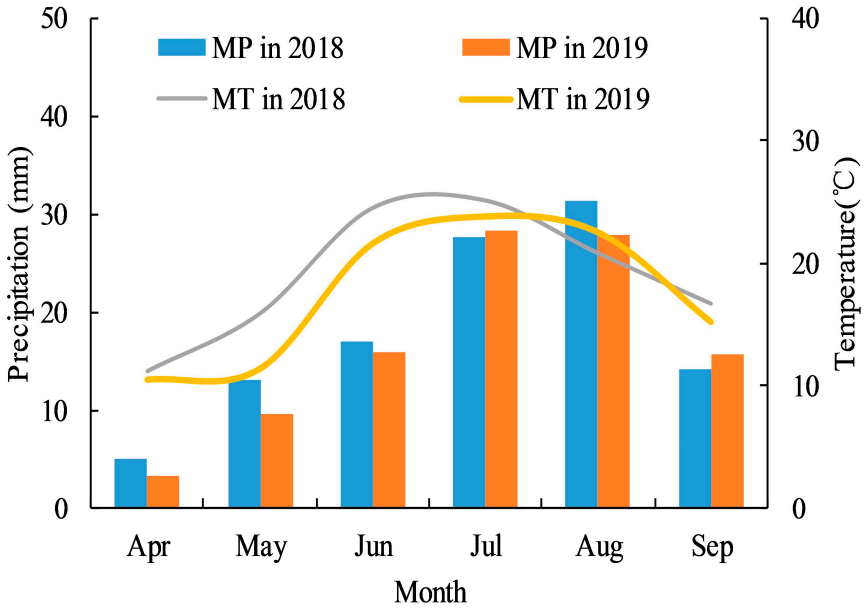


Figure 2. The climate characteristics during the experiment. Note: MP, mean precipitation; MT, mean temperature.

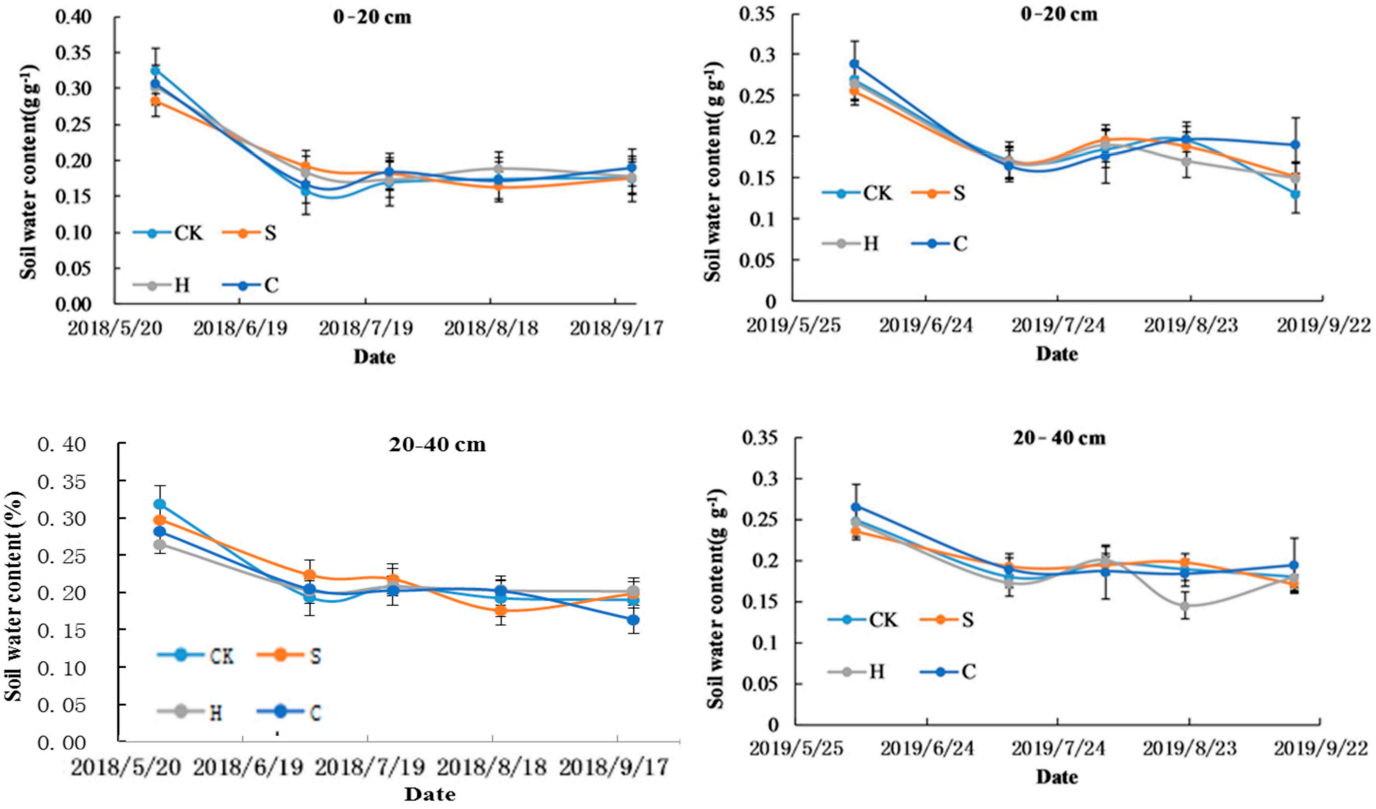


Figure 3. The soil water content during the two-year experiment (S: flue gas desulfurization gypsum, H: humic acid, C: biochar).

The soil water content of CK in the 0–20 cm soil layer varied from 16% to 32% and to 27% during the entire growth period of sunflower, respectively, for 2018 and 2019. The soil water content of S, H, and C treatments varied from 16% to 28%, 17% to 30%, and 17% to 31% in 2018 and 15% to 26%, 15% to 26%, and 16% to 29% in 2019. The fluctuation ranges of soil water content were less than that of the CK; it is obvious that treatments with soil amendment materials improved the soil's water-holding capacity.

At a depth of 20–40 cm in the soil layer, the fluctuation ranges of soil moisture content of CK were 13% and 7% in 2018 and 2019, respectively. The soil moisture content of S, H and C treatments was12%, 6% and 12%, 7%, 4% and 9%, respectively, for 2018 and 2019. Except for S and C treatments in 2019, the change trend in soil water content in each treatment was the same as that in 0–20 cm soil. The variation in soil water content at depth of 20–40 cm depth was less than that at 0–20 cm, which is attributed to the greater impact of rainfall and evapotranspiration on the surface soil. The soil moisture levels were similar across all treatments, with only minor differences. However, the average moisture content in the H treatment was slightly higher and with little fluctuations. The variances indicated that adding humic acid boosted the soil's ability to retain water.

During the harvest seasons of 2018 and 2019, soil moisture levels were lower when the crops were gathered (Table 3). Moreover, the soil water content of the indentical soil layer was decreased in the year 2019. The biochar treatment is capable of holding more water at depths within 20 cm, where the amendments were mixed. The soil water content did not rise from the surface to 60 cm depth. This may be due to tillage before each planting season, which disrupted the soil distribution.

Table 3. Effects of different treatments on soil moisture (g g^{-1}) in different soil layers (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm) at harvest in 2018 and 2019 (each distinct letter in a column indicates a notable difference in treatment during a single planting season).

Treatment	0–20 cm	20–40 cm	40–60 cm	60–80 cm	80–100 cm
2018					
CK	0.17 b	0.19 b	0.23 a	0.27 a	0.29 a
S	0.18 b	0.20 a	0.24 a	0.20 b	0.29 a
H	0.18 b	0.20 a	0.23 a	0.25 a	0.28 a
C	0.21 a	0.17 b	0.14 b	0.24 a	0.29 b
2019					
CK	0.15 b	0.19 a	0.13 b	0.22 a	0.24 a
S	0.15 b	0.15 b	0.15 b	0.19 b	0.23 a
H	0.19 a	0.17 a	0.23 a	0.23 a	0.24 a
C	0.18 a	0.17 a	0.16 b	0.24 a	0.23 a

3.2. Soil Salinity Change in the Treatments

The salt content of the soil was assessed simultaneously with the examination of soil moisture levels (Figure 4). In 2018, the average soil salt content at a 0–20 cm depth was higher than in 20–40 cm, but this situation reversed in 2019. The soil salt content displayed a similar trend of variation throughout each planting season. The standard treatment in the experiment region was food prior to the seedling season. The initial decrease in soil salt levels was due to the infiltration of water into the soil. Subsequently, they rise as a result of evaporation. All of the amendments decreased the salt content. Humic acid was the most effective at reducing soil salt over a two-year period. After a duration of two years of experiment, the humic acid treatment exhibited the lowest soil salt content in the range of a 0 to 20 cm soil depth, while the biochar treatment exhibited the lowest value at a depth of 20 to 40 cm.

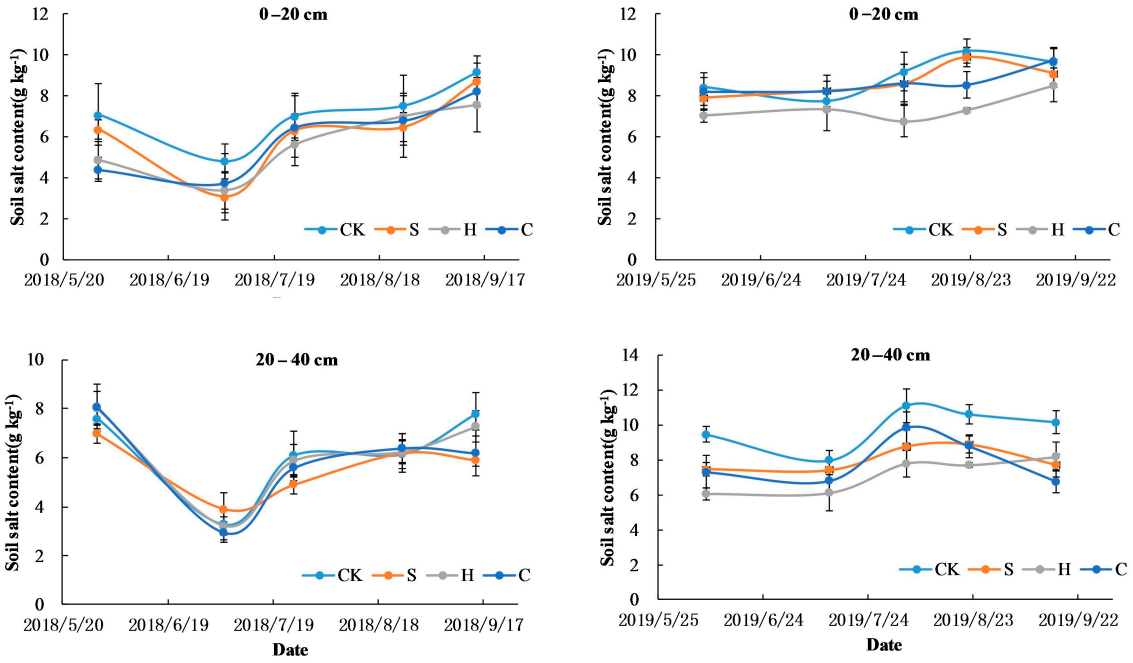


Figure 4. Soil salt content at different layers during sunflower growth in 2018 and 2019 (S: flue gas desulfurization gypsum, H: humic acid, C: biochar).

During the harvests of 2018 and 2019, soil with a depth of 0–40 cm accumulated more salts than soils in a deeper layer (Table 4). The addition of biochar resulted in greater absorption of salts at the application depth of 0 to 20 cm. After two years of experimentation,

it was discovered that incorporating humic acid resulted in the lowest level of salt in the soil, particularly within the range of 0 to 20 cm depth. However, the deeper soil exhibited a lower level of soil salt in the three amendment-treated plots. Amendments improved plant growth, thus allowing the roots to absorb more salts within their growth range.

Table 4. Effects of different treatments on soil salt content (g kg^{-1}) in different soil layers (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm) at harvest in 2018 and 2019 (each distinct letter in a column indicates a notable difference in treatment during a single planting season).

Treatment	0–20 cm	20–40 cm	40–60 cm	60–80 cm	80–100 cm
2018					
CK	7.91 c	7.30 c	7.37 a	6.60 a	7.75 a
S	9.98 b	10.83 a	7.21 a	4.16 c	7.59 a
H	7.56 c	8.71 b	5.81 b	5.96 b	5.79 b
C	11.98 a	8.43 b	6.17 b	5.38 b	5.17 b
2019					
CK	9.66 a	10.15 a	4.89 b	6.17 b	6.09 a
S	9.09 b	7.71 c	4.37 b	5.61 b	4.88 b
H	8.52 b	8.18 b	6.12 a	7.07 a	6.28 a
C	9.74 a	6.78 c	7.34 a	6.03 b	5.54 b

3.3. Soil Bulk Density

At the beginning of the 2018 experiment, the initial soil bulk density (BD) was 1.49 g cm^{-3}. The BD experienced a significant decrease in all treatments following a single cropping season (October 2018). At harvest, the values obtained with the CK, S, H, and C treatments were 4.03%, 8.1%, 8.7%, and 10.7%, respectively, and they were lower than the initial value. In contrast to the CK treatment, the BD values of the S, H, and C treatments were significantly reduced by 4.2%, 4.9%, and 7.0%, respectively (Table 5). There were no significant differences found between the S and H treatments, but the BD value of the C treatment was significantly lower than that of those treatments.

Table 5. Effects of different treatments on soil bulk density (0–20 cm) (g cm^{-3}) at different dates. Values were described as average values with standard error (n = 3). Each distinct letter in a column indicates a notable difference in treatment during a single planting season.

Treatment	October 2018	April 2019	October 2019
CK	1.43 ± 0.02 a	1.45 ± 0.02 a	1.41 ± 0.01 a
S	1.37 ± 0.02 b	1.39 ± 0.01 b	1.37 ± 0.05 ab
H	1.36 ± 0.01 b	1.38 ± 0.02 bc	1.36 ± 0.02 b
C	1.33 ± 0.01 c	1.36 ± 0.02 c	1.34 ± 0.01 b

BD values slightly increased in April 2019 compared to October 2018 due to flood irrigation post-harvest and winter snowfall, but they remained lower than the original value. In contrast to the CK treatment, the S, H, and C treatments significantly reduced the BD with values of 4.2%, 4.9%, and 6.3%, respectively (Table 5). Significant differences in the BD were observed between the C and S treatments, whereas no significant variances were observed between the H and C treatments.

Observable variations in bulk density (BD) were consistently noted when comparing the application of enhanced material treatments with CK treatment in October 2019, with the exception of the S treatment. The treatment differences did not differ significantly, but C showed the biggest drop, down by 4.96% from CK. In both years, new materials, particularly biochar, decreased BD values significantly.

3.4. Soil Size Distribution and Aggregate Stability

The aggregate with a size larger than 0.25 mm experienced a significant increase from the beginning to the conclusion of the experiment (Table 6). The proportion of aggregate in

CK treatment nearly tripled within the two years of the experiment. However, plowing prior to every planting season might disrupt the soil structure. Adding humic acid over two years increased $R_{0.25}$ from 5.19% to 27.88%, improving nutrient retention. Furthermore, biochar improved soil porosity with lower MWD and GWD in aggregates compared to other treatments.

Table 6. Soil aggregate composition (0–20 cm) before seedling in 2018 and after harvest in 2019 ($R_{0.25}$: the water-stable aggregate bigger than 0.25 mm; MWD: the mean weight diameter; GWD: the mean geometric diameter). Each distinct letter in a column indicates a notable difference in treatment during a single planting season.

	April 2018			October 2019		
	$R_{0.25}$/ %	MWD/ mm	GWD/ mm	$R_{0.25}$/ %	MWD/ mm	GWD/ mm
CK	6.28 b	0.06 a	0.62 b	17.61 c	0.28 b	1.00 a
S	3.78 d	0.04 b	0.71 a	18.11 c	0.25 bc	0.89 ab
H	5.19 c	0.06 a	0.76 a	27.88 a	0.33 a	0.78 b
C	7.26 a	0.07 a	0.62 b	20.24 b	0.21 c	0.69 c

3.5. Sunflower Yield

The sunflower seed yield significantly increased when the three amendments were applied (Table 7). Compared with CK, the seed yield in the year 2018 growing season was enhanced by 10.8%, 24.0%, and 33.3% for the S, H, and C treatments, respectively. In 2019, the seed yield experienced an increase of 37.7%, 42.5%, and 59.5% for the S, H, and C treatments in comparison to CK. Each year, the C treatment produced the greatest number of seeds. The H treatment further replicated this pattern. On average, the seed yield of the C treatment was 44.2% superior to that of the CK treatment.

Table 7. Seed yield of sunflower (kg ha^{-1}) in response to different treatments. Each distinct letter in a column indicates a notable difference in treatment during a single planting season.

Year	CK	S	H	C
2018	2983 ± 15 d	3293 ± 10 c	3686 ± 24 b	3964 ± 33 a
2019	1992 ± 35 c	2699 ± 34 b	2607 ± 47 ab	3133 ± 39 a
Mean	2487 ± 23 d	2995 ± 41 c	3146 ± 61 b	3548 ± 14 a

4. Discussion

Sunflower growth was impeded by soil salinization and a shortage of water in North China's Hetao irrigation region. It has been considered a practical approach to boost production levels by improving soil quality in the root zone by applying soil amendments [32]. The two-year field experiment provided scientific results. The application of flue gas desulfurization gypsum, biochar, and humic acid to saline soil was investigated for growing sunflowers. The experiment confirmed our hypothesis that the amendments could improve soil conditions and increase sunflower yields.

4.1. Effects of Amendments on Soil Quality Improvement

In China's arid and semi-arid regions, there exists a dearth of water resources. It is essential to optimize water usage for agricultural development. Additionally, high altitudes resulted in faster land surface evaporation. The biochar, humic acid, and flue gas desulfurization gypsum utilized in our study demonstrated advantageous effects on enhancing and retaining soil water content during the two-year field experiment (Figure 3). When compared to the CK, the most significant differences were found in the humic acid treatments. This may be due to the fact that the humic acid was applied twice during the experiment, and the other two amendments were only added once. All three amendments were applied 20 cm deep into the soil. Therefore, the soil water content at the 20–40 cm

layer did not exhibit significant variations. Similar results were obtained from [33,34] wherein the deeper soil layer had a similar soil water content in differently treated plots. During harvest, the soil was moister in the deep layer than on the surface. Nevertheless, the addition of biochar resulted in an increase in the moisture content of the shallow layer's moisture, which may have been attributed to rainfall (Figure 2). Biochar exhibited the highest porosity among the three amendments. This was great because it helped to increase the soil's water-holding capacity and improved soil aeration [35]. The soil amendments caused a reduction in the soil bulk density, which in turn altered the physical properties of the soil and indirectly impacted the conditions for soil growth (Table 5). During the second sampling, soil salt levels decreased during both planting seasons (Figure 4). This occurred subsequent to the annual surface irrigation. Nonetheless, in 2018, salt increased as a result of soil water evaporation, whereas in 2019, the increase was less significant. All treatment methods resulted in a decrease in soil salt content. The majority of the salt was found to accumulate at a 0–20 cm depth, indicating the significant impact of evaporation on the growth of sunflowers (Figure 2). The distribution of soil salinity is also irregular across the field [36], which makes it necessary to mix the soil composition during tillage before planting [37]. Humic acid, being an organic substance, is naturally present in soils and can be rapidly broken down by microbiology in the soil [38]. Therefore, its effects on soil physical characteristics are primarily determined by its material composition in the short term [39], but its long term effects are indirectly influenced by affecting plant growth and the microbial community [14]. The biochar and the FGD gypsum have an impact on the soil's physical parameters primarily due to their solid structure [40]. The biochar is capable of maintaining its structure for an extended period. However, the act of tillage will alter the soil's structure [20]. Despite the presence of dissolved ions that could be utilized by soil biology, the FGD gypsum proved to be challenging to dissolve thoroughly [27]. The addition of amendments significantly reduced soil density in the two-year experiment, and biochar significantly contributed to reducing soil density [41]. This demonstrated the stable structure of biochar within the two years of experiments in our research. The application of biochar has the potential to significantly enhance the formation of soil aggregation formation (Table 5). The humic acid treatment significantly improved the $R_{0.25}$ up to 5.5 times compared to its initial value before the experiment. Plant growth promoted the formation of aggregates [42], and salt ions could prevent the accumulation of soil particles [43]. Amendments to the soil could protect the organic matter. They increased the root vitality, which in turn accelerated the formation of aggregates [23]. Otherwise, the stability of soil aggregates is regarded as an ideal soil quality indicator, and the stability of the soil structure can be characterized by MWD and $R > 0.25$ [44]. The enhancement in soil fertility and quality is contingent upon the creation and endurance of aggregates. The amendments used in our study significantly enhanced soil quality in comparison to the conventional planted soils. The enhancement in soil quality had beneficial effects on plant growth and had the potential to reduce the cost of agricultural management. It created a favorable environment for the development of healthy agriculture in arid lands.

4.2. Soil Amendments Affect Sunflower Seed Yield

The sunflower, which can tolerate moderate levels of salt, is negatively affected by soil salinity stress [45]. Annually, sunflowers are planted for the purpose of extracting oil from their seeds or for human consumption. The primary goal of sunflower planting is to increase seed yield. The three amendments used in this study increased the seed yield, and the biochar treatment had the highest yield, up to 3964 kg ha^{-1} in 2018. In 2018, the seed yield in all treatment plots was higher than in 2019. The amended soils still produced more than the CK. The lower temperature in Figure 1 may reduce seed yield by harming plant photosynthesis in 2019 [46]. Sunflower is the main crop in the Hetao irrigation district, Inner Mongolia, China. Breeding high-production varieties or enhancing seed yield through soil remediation methods offers significant economic benefits [47]. Adding biochar boosted yields but was costly compared to the other amendments. Biochar produced from diverse

materials had distinct effects on sunflower yield, and the utilization of poultry litter biochar resulted in a higher yield as compared to wood biochar [48]. It is best for small farms to select special biochar while considering the raw materials and costs. However, its dry initial nature may increase water consumption during cultivation [49]. However, the annual application of humic acid would increase the cost of artificial and mechanical engineering. The FGD gypsum was the cheapest material. However, if the dosage exceeds the recommended limit, it may decrease soil quality and lead to soil compaction [50]. The amendments raised inquiries regarding the utilization of larger areas for extended periods. However, they demonstrated potential during the two-year experiment. They have the ability to reduce soil salinity, adjust soil quality, and boost sunflower yields. Our study is of theoretical importance in understanding the arid land's agricultural utilization with nature-friendly materials. Amending the soil and altering the growing conditions can greatly improve plant growth. In order to achieve high yields, it is essential to have good soil properties. This iss beneficial to the development of sustainable agriculture. Moreover, the utilization of materials amendments used in actual production has broadened the spectrum of applications for these substances.

5. Conclusions

This research explored how biochar, humic acid, and FGD gypsum could improve the quality of saline soil and boost sunflower yields. Over two years, all three improved soil quality and sunflower seed yields. Biochar achieved the highest yield increase. In the meantime, humic acid proved to be the most effective in reducing soil salinity. However, further investigation is required to evaluate the impact of its extensive and prolonged use.

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