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Remediation Effect of Biomass Amendment on the Physical-Chemical Performance and Sustainable Utilization of Sandy Soil

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ABSTRACT

Soil desertification affects the service functions of the ecosystem. In severe cases, it even causes a decline in agricultural productivity and shrinkage of animal husbandry, posing a threat to regional eco-environment and economic sustainability. The previous research on soil remediation research mainly concentrates on heavy metal degradation, saline soil improvement, and eroded and degraded soil improvement. There is little report on the biomass improvement and restoration of sandy soil. Therefore, this paper explores the remediation effect of biomass amendment on the physical-chemical performance and sustainable utilization of sandy soil in Huangyangtan, the largest sandy land in northern China's Hebei Province. Specifically, the authors detailed the strategies to measure the physical-chemical indices and microbial diversity of Huangyangtan sandy soil, and introduced the materials and mode of the biomass amendment test on Huangyangtan sandy soil, followed by an elaboration on the test results. The influence of different test fertilizers on the soil was analyzed in four dimensions, namely, physical performance, chemical performance, biological performance, and crop yield. The results show that biomass amendment can effectively remediate sandy soil, and promote its sustainable utilization.

1. INTRODUCTION

There are several urgent issues to be solved in agricultural production of China, namely, secondary salinization, acidification, desertification, high heavy metal content, and quality degradation. In recent years, biomass amendment provides a new solution for soil remediation, with features like rich carbon, fine particle size, and high porosity. Nature hails "biomass improvement and its application" as one of the world's top 15 environmental issues [1-4]. Chinese and foreign scholars have explored extensively into the porosity, saturated water content, cation exchange capacity, and organic matter ratio of soil after the addition of biomass amendment, and further investigated the action mechanism of biomass amendment on farmland soil with microbial diversity, an indicator of the status of the soil ecosystem [5-8].

After entering the soil environment, the heavy metals cannot be biodegraded. If they find their ways into the human body, the human might suffer from chronic poisoning and even death [9-12]. To repair the soil contaminated by heavy metals and fully utilize resources, Rocco et al. [13] took the biochar produced through sludge pyrolysis as a biomass amendment to remediate soils in areas severely polluted by heavy metals; the sludge pyrolysis biochar features a porous structure, rich nutrient elements, and stable carbon elements. Then, they tested different mix ratios of sludge and sludge pyrolysis biochar, identified the optimal mix ratio that leads to the best remediation effect, and evaluated the biological risk of soil heavy metals after the application of biomass amendment. McWatters et al. [14] prepared two kinds of biochar from corn stalks and high-concentration fermentation waste liquid, and synthetized them into an amendment for sandy and contaminated soils; through pot tests, the physical-chemical performance in sandy soil was studied under different application ratios; the results demonstrate that the sludge-straw biomass amendment can fix and passivate the heavy metal elements Pb and Cr in the soil. Focusing on farmland soil in mining areas, Soltaninejad et al. [15] characterized the physical-chemical properties of the biomass amendment developed from rice straw through elemental analysis, Fourier infrared spectroscopy, and specific surface area analysis, and verified that the prepared amendment can stabilize heavy metals Cu, Cd, As, and Zn in the soil through biomass amendment-soil culture experiment in simulated natural environment. Vidonish et al. [16] tackled three modified biomass amendments compounded with ZnO, MnO and chitosan, respectively, and extracted the heavy metal distribution on each amendment under physical, chemical, and other types of adsorption; on this basis, the adsorption process was described realistically by setting up a Langmuir isotherm adsorption model and a quasi-second-order kinetic model, and the different effects between the amendments were verified in terms of the complexation of oxidation functional groups, the adsorption effect of mineral precipitation, and bio-availability.

Biomass amendment, with certain absorbability, can inactivate heavy metal ions in the soil, and improve the water

and fertilizer retention in the soil to a certain extent [17-19]. Dias-Ferreira et al. [20] improved the water content, available phosphorus, alkali hydrolyzable nitrogen, and organic matter eroded and degraded farmland soil, which effectively alleviates the crop failure induced by soil erosion and degradation. Balawejder et al. [21] took pertinent measures to improve the alkali lime soil in karst regions, which faces problems like calcium enrichment, low fertility, and poor aggregate structure; many pot experiments were conducted to compute and check the optimal particle size and charcoal-soil ratio of the biomass amendment; the results confirm that applying biomass amendment can boost the natural water content and enzyme activity of lime soil, and greatly promote soil improvement and vegetation growth. Soobhany [22] combined polymeric aluminum ferric sulphate (PAFS) and biomass amendment to improve the severely salinized and alkalized soda saline-alkaline soil, proved that the combined method can reduce the pH and volume weight of soil, and thus enhance the saturated water holding capacity; furthermore, the mix ratio of the two amendments were rationalize to balance the contents of water-soluble ions, such as Na^+, K^+, Cl^-, CO_3^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, and SO_4^{2-}.

As the most harmful way of land degradation, soil desertification not only affects ecosystem services, but also leads to decline in agricultural productivity and shrinkage of animal husbandry, threatening regional eco-environment and economic sustainability [23-26]. However, there is little report on the biomass improvement and restoration of sandy soil. Therefore, this paper collects the field survey data of 11 consecutive years about the vegetation on grasslands with different degrees of desertification in Huangyangtan, the largest sandy land in northern China's Hebei Province. Then, the authors explored the remediation effect of biomass amendment on the physical-chemical performance and sustainable utilization of sandy soil, aiming to provide a scientific basis for ecological reconstruction and vegetation restoration in the study area. Section 2 details the strategies to measure the physical-chemical indices and microbial diversity of Huangyangtan sandy soil; Section 3 introduces the materials and mode of the biomass amendment test on Huangyangtan sandy soil; Section 4 elaborates on the test results, including the influence of different test fertilizers on the soil in terms of physical performance, chemical performance, biological performance, and crop yield, and thus verifies the positive effect of biomass amendment on the restoration and sustainable utilization of the sandy soil in Huangyangtan.

2. PARAMETER DETERMINATION

Huangyangtan sandy land is dominated by aeolian sandy soil, which was formed mainly through wind erosion and wind deposition. In terms of texture, the sandy soil is mostly silty sand and gravel sand; in terms of zonality, the soil belongs to mountain brown soil, with a low organic matter content and a large particle size. Due to sand burial and sand hitting, semi-fixed and mobile sand-covered grasslands have formed between sand ridges.

The test area is the transition zone from the semi-humid zone to the semi-arid zone in Xuanhua County, Zhangjiakou, Hebei Province. Wind erosion and wind deposition have turned the area into a sandy land dominated by aeolian sandy soil. Lacking diversified vegetation, the test area (total area: $10.2\times10^4 km^2$; elevation: 600-1,000m) faces harsh natural conditions and frequent meteorological disasters. The annual mean rainfall, evaporation, wind speed, and temperature are 400.3mm, 1,862.5mm, 2.9km/h, and 7.6℃, respectively.

2.1 Measurement of physical-chemical indices

The sample soil was passed through a soil sieve to remove large particles and plant fibers. By wet sieving method, the diameter and weight ratio were determined for different grades of soil aggregates. On this basis, weight coefficients were configured, and used to obtain the weighted mean of the measured diameters. The mean diameter characterizes the stability of the soil aggregates. Let d_i and K be the diameter and number of apertures on sieve i, respectively; p_i be the weight ratio of clusters on sieve i; w_i be the weight of p_i. Then, the stability coefficient of soil aggregates can be calculated by:

$$\gamma = \sum_{1}^{K} \frac{d_{i+1} + d_i}{2} w_i \tag{1}$$

To accurately measure the water holding capacity of each test sample, the soil was immersed in water for 24h to reach saturation, and dried for 6h. Then, the mass of the soil in saturated water holding state M_1, and the mass of the soil dried to constant weight M_2 were measured separately. Thus, the water holding capacity can be computed by:

$$\text{Water holding capacity} = (M_1\text{-}M_2) / M_2 \times 100\% \tag{2}$$

Table 1. Physical-chemical indices of the soil and their measurement methods

Index	Water content	Bulk density	pH	Conductivity	Organic carbon content	Total nitrogen
Method	Gravimetric method	Ring shear testing	pH meter	Conductivity meter	External heating of potassium dichromate	Kjeldahl method
Index	Total phosphorus	Available nitrogen content	Available phosphorus content	Available potassium content	Cation exchange capacity	Biomass carbon, and microbial biomass nitrogen of soil microbes
Method	Perchloric acid-molybdenum-antimony anti-colorimetric method	Alkali diffusion method	Sodium bicarbonate extraction-molybdenum-antimony anti-colorimetric method	Flame photometry	Ammonium acetate exchange method	Chloroform fumigation-K_2SO_4 extraction-potassium dichromate volumetric method

Table 1 summarizes the measurement methods for other methods: The water content was measured by the gravimetric method, the bulk density by ring shear testing, and pH and electrical conductivity with pH meter and conductivity meter.

2.2 Measurement of microbial diversity

Figure 1 explains the flow of statistical analysis on soil microbes. The microbial sequencing results on soil microbes were outputted from Illumina PE250, and subject to sequence splicing and quality control. Based on the resulting valid sequence, operational taxonomic unit (OTU) clustering and diversity analysis were carried out to obtain an abundance table of arbuscular flora. Then, integrated analyses were performed on α diversity, species composition, β diversity, species difference, as well as species, functions, and physical-chemical factors.

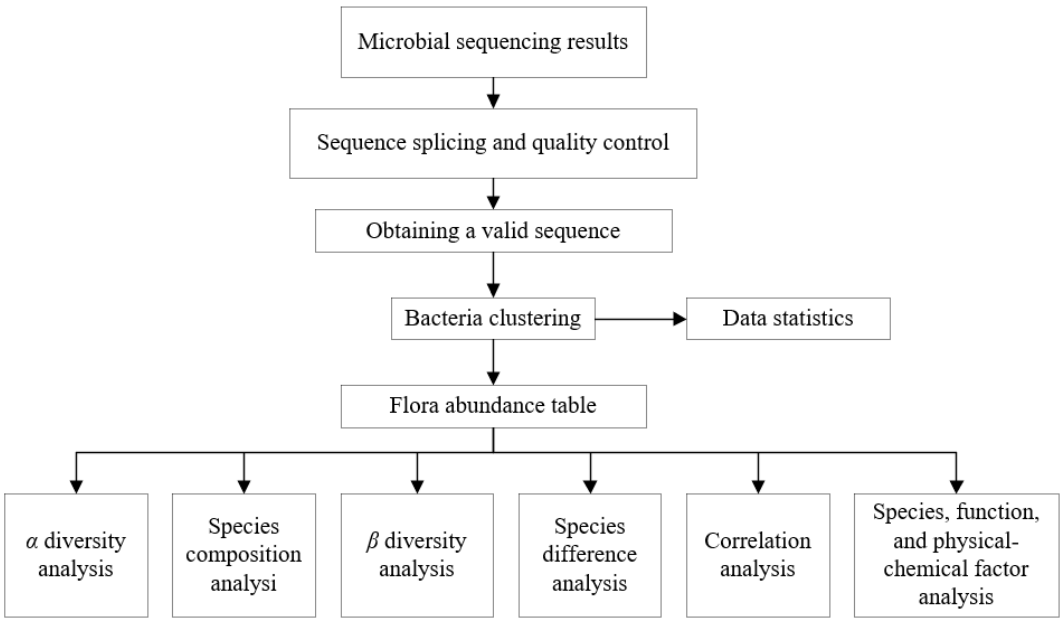


Figure 1. Flow of statistical analysis on soil microbes

(1) Determination of fungal infection rate of crop roots

The fungal infection intensity and rate of crop roots in each soil sample were measured by the classification standards of infection and arbuscular abundance. The fungal infection rate of crop roots can be calculated by:

$$F_{fi} = (\text{number of root segments infected by fungus} / \text{total number of root segments}) \times 100\% \quad (3)$$

The fungal infection intensity of the entire root system of the crop can be calculated by

$$I_{rsy} = (N_1+5N_2+30N_3+70N_4+95N_5) / \text{total number of root segments} \quad (4)$$

where, N_1, N_2, N_3, N_4, and N_5 are the number of root segments suffering fungal infection on levels 1-5, respectively. The fungal infection intensity of a root segment can be calculated by:

$$I_{rse} = I_{rsy} \times \text{total number of root segments} / \text{number of root segments infected by fungus} \quad (5)$$

Let A_1, A_2, and A_3 be the arbuscular abundance of different grades in the root segments. Then, the arbuscular abundance of an infested root segment can be calculated by:

$$A_{rse} = (10A_1+50A_2+100A_3) / 100 \quad (6)$$

The arbuscular abundance of the entire root system can be calculated by:

$$A_{rsy} = A_{rse} \times \left(I_{rsy} / 100\right) \quad (7)$$

(2) Determination of diversity indices

To accurately measure the microbial diversity in soil samples, it is necessary to calculate and draw the relevant evaluation indices, box plots, and dilution curves. The Chao diversity index, which estimates the total number of species and the number of OTU classes in the microbial community, can be calculated by:

$$C_{Chao} = C_A + \frac{g_1(g_1-1)}{2(g_2+1)} \quad (8)$$

where, C_A is the observed number of OTU classes of the flora; g_1 and g_2 are the number of OTU classes containing only one and two sequences, respectively. Let N_i be the number of sequences contained in the i-th OTU class, and N_T be the total number of sequences. Then, the Shannon-Weiner diversity index, which reflecting the diversity of the community, can be calculated by:

$$DL_{Shannon} = \sum_{i=1}^{C_A} \frac{N_i}{N_T} \ln \frac{N_i}{N_T} \quad (9)$$

The Simpson's diversity index, which quantifies the microbial diversity in a region, can be calculated by:

$$ADL_{Simpson} = \frac{\sum_{i=1}^{C_A} N_i(N_i - 1)}{N_T(N_T - 1)} \quad (10)$$

The Shannon- Weiner diversity index and Simpson's diversity index are negatively correlated with the microbial diversity in soil samples. The Coverage index, which reflects whether the sequencing results are in line with the actual situation of the soil samples, can be calculated by:

$$R_{Coverage} = 1 - \frac{N_i}{N_T} \quad (11)$$

3. TEST MATERIALS AND MODE

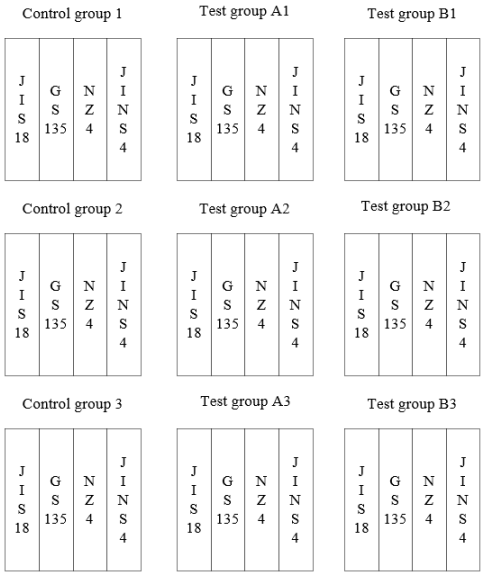


Figure 2. Test area arrangement

The test fertilizers mainly include organic biomass amendments (including organic fermentation products, biochar, microbial strains, and water retention agents), substrates (including organic fermentation products, and water retention agents), and compound fertilizers (including nitrogen, phosphorus, potassium, and other essential elements for plant growth). The test crops were sweet potatoes of the varieties Jishu 18, Guangshu 135, Ningzi 4, and Jingshu 6. For clarity, the four varieties are coded as JIS18, GS135, NZ4, and JINS6 in turn.

Our tests were carried out in a flat and neatly-shaped area. A total of nine 10m×10m plots were set up, namely, Control Groups 1-3 (adding compound fertilizers), Test Groups A1-3 (adding compound fertilizers and substrates), and Test Groups B1-3(adding compound fertilizers and organic biomass amendments). In each type of groups, 1-3 indicate the dosage of materials. The four varieties of sweet potatoes were sown separately in the test area. The arrangement is described in Figure 2.

Table 2 presents the physical-chemical performance of soil samples from Huangyangtan sandy land. The soil samples were collected from each plot following the application of organic biomass amendments. After sowing, samples were collected again in rooting and slow seedling stage, branching and tuberization stage, full leaf stage, and tuber expansion stage, respectively. Some of the samples were stored in fridge for measuring microbial diversity, and the others were passed through soil sieves with different aperture sizes for measuring physical-chemical indices.

4. TEST RESULTS AND ANALYSIS

4.1 Influence of different fertilizes on physical performance of soil

Table 3 presents the bulk density and water holding capacity of soil in each group. The samples in Test Groups B had lower bulk density than those in Test Groups A, mainly because of the biochar in the organic biomass amendment; the microbial agent also exerted an effect, but not very obvious. Compared with the Control Groups, the fertilizers in Test Groups A and B increased the water holding capacity of soil; Test Groups B, which added biochar and microbial agent, achieved the most prominent promoting effect on water holding capacity, a sign of high sustainability.

4.2 Influence of different fertilizes on chemical performance of soil

Table 2. Physical-chemical performance of soil samples from Huangyangtan sandy land

Depth/cm	N/mg·kg^{-1}	P/mg·kg^{-1}	K/mg·kg^{-1}	Organic matter/g·kg^{-1}	pH
0-5	25.9	5.74	98.4	3.32	8.20
5-10	24.9	5.69	94.6	3.34	8.19
10-15	23.7	5.52	91.2	3.37	8.21
15-20	22.0	5.31	88.2	3.36	8.20

Table 3. Bulk density and water holding capacity of soil in each group

Group	Bulk density/g·cm^{-3}	Water holding capacity/%
Control Group 1	1.51±0.025c	11.1±0.42b
Control Group 2	1.55±0.061c	12.4±0.53c
Control Group 3	1.52±0.047b	11.7±0.85a
Test Group A1	1.56±0.012a	14.6±0.21d
Test Group A2	1.57±0.064a	15.3±0.34c
Test Group A3	1.56±0.081d	15.6±0.48a
Test Group B1	1.55±0.042d	17.3±0.19c
Test Group B2	1.55±0.073c	17.5±0.12b
Test Group B3	1.54±0.037a	18.1±0.11c

The first task is to measure and compare the pH values of soil samples. Figure 3 reveals the overall trend of pH: a year-on-year slow decrease. It can be inferred from Figure 3 that the pH of soil samples from spring harvest periods slightly increased in Test Groups A and B, with the application of biomass amendment, but did not change significantly as compared to Control Groups. The soil samples from autumn harvest periods all saw a decline in pH.

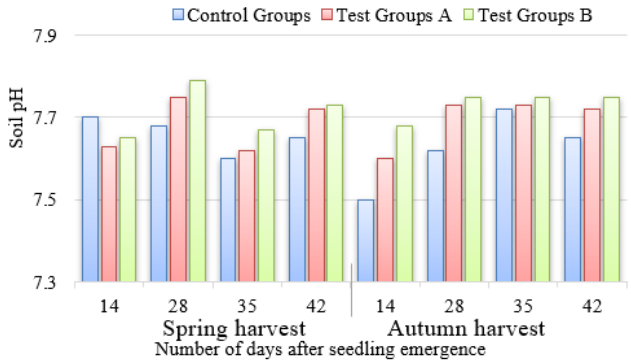


Figure 3. Influence of biomass amendment on soil pH in Huangyangtan sandy land

Table 4 shows the organic matter content of each group, which characterizes the biological structure and properties of the corresponding soil sample. Comparing the organic matter contents between two depths (0-10 and 10-20) and the four growth stages, except the Control Groups, all Test Groups had a clear increase in organic matter content. The increment was between 6%-11% in the soil at the depth of 0-10cm, and between 4-8% in the soil at the depth of 10-20cm. Test Group B2 achieved the largest rise in organic matter content, a signal of sustainability. Compared with the soil of 10-20cm, the soil of 0-10cm had an abundance of organic matter, but without any clear distribution pattern or transition law. Figure 4 provides the influence of biomass amendment on the organic matter content of soil samples from Huangyangtan sandy land.

Table 5 lists the content of soil alkali hydrolysable nitrogen that can be directly absorbed by crops in each group. Through the four growth stages, the content of alkali hydrolysable nitrogen in the soil of each test group was higher than that of Control Groups. During the tuber expansion stage, Test Groups A achieved 6%-9% higher nitrogen content than Test Groups B. Test Group B2 realized the most prominent growth in the content of soil alkali hydrolysable nitrogen, an evidence of sustainability. Test Groups A, which apply substrates and conventional compound fertilizer, did not achieve a high nitrogen content. This is mainly because the organic biomass amendment is rich in high-quality microbial agents, which effectively increase the nitrogen content in the soil.

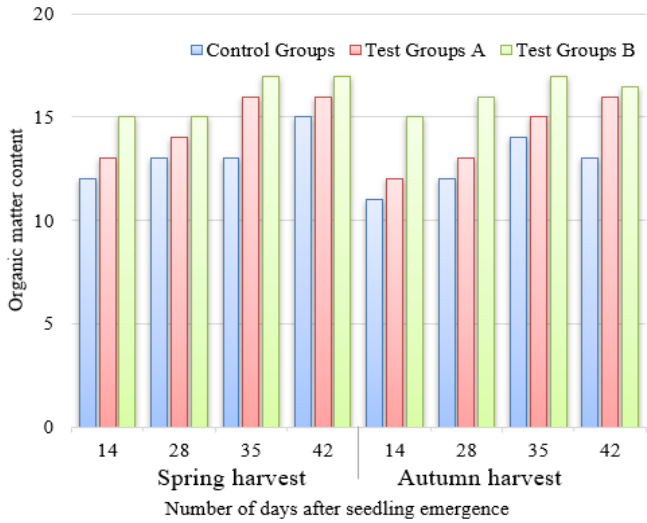


Figure 4. Influence of biomass amendment on soil pH in Huangyangtan sandy land

Table 4. Organic matter content of soil samples in different groups

Soil depth/cm	Growth stage	Groups					
		Test Group A1	Test Group A2	Test Group A3	Test Group B1	Test Group B2	Test Group B3
0-10	Rooting and slow seedling stage	3.21±0.33b	3.56±0.24a	3.15±0.34b	3.77±0.79a	3.76±0.45a	3.84±0.15a
	Branching and tuberization stage	3.47±0.15c	3.87±0.52b	3.33±0.27c	4.01±0.11a	3.96±0.31b	4.64±0.23b
	Full leaf stage	3.49±0.25c	4.02±0.36b	3.36±0.06c	4.46±0.64a	4.18±0.23b	4.91±0.11b
	Tuber expansion stage	3.62±0.16b	4.09±0.44a	3.48±0.48b	4.24±0.83a	3.54±0.71ab	4.87±0.37ab
10-20	Rooting and slow seedling stage	3.13±0.41b	3.51±0.19a	3.22±0.17b	3.55±0.97a	4.18±0.62a	3.41±0.11a
	Branching and tuberization stage	3.36±0.18b	3.46±0.08a	3.37±0.02b	3.65±0.18a	4.16±0.22a	3.48±0.14a
	Full leaf stage	3.39±0.15b	3.61±0.11a	3.19±0.23b	3.79±0.63a	4.29±0.37a	3.51±0.18a
	Tuber expansion stage	3.47±0.03b	3.53±0.23a	3.33±0.16b	3.63±0.19a	4.14±0.32a	3.59±0.17a

Table 5. Nitrogen content of each group

Soil depth/cm	Growth stage	Groups					
		Test Group A1	Test Group A2	Test Group A3	Test Group B1	Test Group B2	Test Group B3
0-10	Rooting and slow seedling stage	46.3±2.01a	31.1±0.87c	28.4±1.54d	52.5±2.13c	56.4±1.47b	55.3±1.31b
	Branching and tuberization stage	51.0±4.7a	33.5±2.41b	29.4±3.23c	52.4±1.81b	57.1±1.32b	55.1±2.47b
	Full leaf stage	45.3±2.36a	38.7±1.88c	27.5±2.69d	55.4±2.66b	51.0±2.65b	56.1±3.63c
	Tuber expansion stage	42.4±0.87a	37.6±0.49b	29.1±1.69d	53.4±0.69a	52.7±1.57ab	56.9±1.74c
10-20	Rooting and slow seedling stage	32.2±1.24a	25.2±1.23b	26.1±1.31c	45.9±0.47b	48.6±2.17a	47.4±0.58b
	Branching and tuberization stage	28.8±2.92a	27.5±0.99a	24.7±0.86b	46.0±1.72a	48.9±1.69a	48.1±1.27a
	Full leaf stage	28.6±1.46a	27.7±1.71a	21.3±1.56b	47.3±1.37a	49.1±0.74a	47.7±1.16a
	Tuber expansion stage	29.9±0.13b	28.1±0.64c	22.6±1.45c	48.7±0.22a	49.5±0.38ab	49.1±1.93c

Table 6. Phosphorus content of each group

Soil depth/cm	Growth stage	Groups					
		Test Group A1	Test Group A2	Test Group A3	Test Group B1	Test Group B2	Test Group B3
0-10	Rooting and slow seedling stage	7.45±0.24b	7.65±0.61b	8.02±0.73b	8.46±0.11d	9.35±0.16a	9.35±0.42c
	Branching and tuberization stage	8.23±0.84b	8.47±0.79b	8.45±0.55b	8.84±0.15d	10.20±0.67a	9.68±0.24c
	Full leaf stage	9.41±0.76a	9.19±0.24a	9.16±0.47b	8.93±0.27c	8.17±0.48b	9.04±0.54a
	Tuber expansion stage	9.56±0.66a	9.66±0.72a	9.67±0.12a	8.97±0.45c	8.35±0.77b	9.18±0.64a
10-20	Rooting and slow seedling stage	6.41±0.23b	6.46±0.41b	6.64±0.13b	7.48±0.17d	8.54±0.38a	7.21±0.22c
	Branching and tuberization stage	6.57±0.49c	6.96±0.22bc	6.87±0.47b	7.64±0.53e	8.42±0.44a	7.35±0.33d
	Full leaf stage	6.85±0.25c	6.99±0.31bc	7.27±0.54b	7.55±0.37d	7.37±0.59a	7.48±0.42c
	Tuber expansion stage	7.14±0.65a	7.32±0.04a	7.59±0.16b	7.54±0.16b	7.12±0.66a	7.04±0.15a

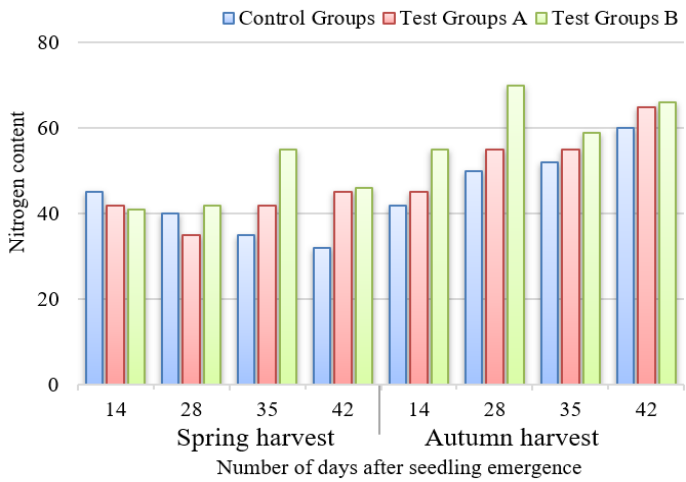
Table 6 shows the group difference in soil phosphorus content, an important limiting factor of plant productivity. It can be seen that the effective phosphorus content in each test group was higher in the four growth stages compared to that in Control Groups. During the tuber expansion stage, Test Groups A and B surpassed Control Groups by 21% -45% in effective phosphorus content; the 10-20cm soil layer had a slightly lower effective phosphorus content than the 0-10cm soil layer. Test Group B2 achieved the most significant effect on improving the effective phosphorus content, a sign of sustainability. The improving effect of Test Groups A was not as strong as that of Test Groups B. The main contributor to the effect is biochar, while microbial agent did not play an important role.

Table 7 shows the group difference in soil potassium content, a key determinant of the chemical quality of the soil. Compared with Control Groups, all test groups had relatively high effective potassium content in all four growth stages. During tuber expansion stage, Test Groups A and B achieved an 18%-33% higher potassium content than Control Groups. In both soil depths, Test Group B3 boasted the best effect, suggesting the sustainability of its treatment.

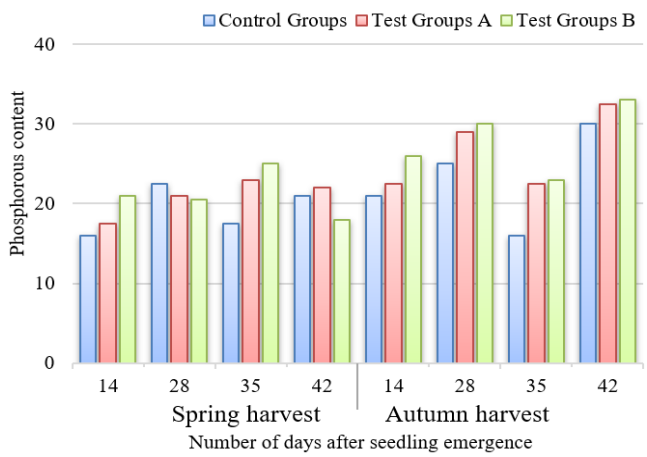
Table 7. Potassium content of each group

Soil depth/cm	Growth stage	Groups					
		Test Group A1	Test Group A2	Test Group A3	Test Group B1	Test Group B2	Test Group B3
0-10	Rooting and slow seedling stage	111±5.41c	115±4.57b	95±4.16d	121±7.01a	133.71b	151±3.77b
	Branching and tuberization stage	121±4.17b	127±5.64b	94±3.96c	154±4.43a	142±6.28b	173±5.17b
	Full leaf stage	137±2.23b	142±2.53a	98±2.28c	111±6.72b	148±3.39b	179±4.42b
	Tuber expansion stage	141±6.67a	157±7.31a	99±3.54c	158±6.16b	154±5.53a	187±4.69a
10-20	Rooting and slow seedling stage	94±3.41bc	94±2.71b	91±4.35c	15±4.87a	96±5.92bc	96±3.28b
	Branching and tuberization stage	94±5.35bc	111±3.78b	96±5.98c	123±2.96a	99±3.41bc	115±4.32b
	Full leaf stage	91±4.16a	126±6.42a	89±3.47b	143±7.26a	106±4.25a	123±5.07a
	Tuber expansion stage	111±3.71a	186±5.15a	89±2.51c	129±3.41b	109±7.44a	123±4.17a

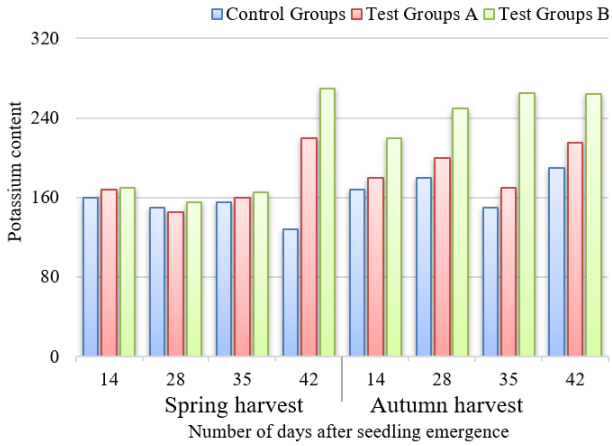
Figure 5 displays the influence of biomass amendment on nitrogen, phosphorous, and potassium contents in Huangyangtan sandy land. With the growing application of compound fertilizer, substrate, and organic biomass amendment, the nitrogen, phosphorous, and potassium contents in every group first increased and then decreased. The reason is that the treatments in all groups contain compound fertilizer. By contrast, the nitrogen, phosphorous, and potassium contents increased linearly in the soil samples applied with substrate and those applied with biomass amendment alone; the latter samples achieved more significant increase. Hence, biochar and microbial agent are more suitable for improving sandy soil, and stronger in fertilizer effect, creating a value of sustainable utilization. Figure 6 illustrates the influence of biomass amendment on the carbon-nitrogen ratio in Huangyangtan sandy land.



(a) Nitrogen content



(b) Phosphorous content



(c) Potassium content

Figure 5. Influence of biomass amendment on nitrogen, phosphorous, and potassium contents in Huangyangtan sandy land

Figure 7 presents the influence of biomass amendment on the total sulfur and exchangeable sodium content in Huangyangtan sandy land. During spring harvest or autumn harvest, the groups did not differ greatly in total sulfur in the soil. During the seedling period, the soil samples from the autumn harvest periods had slightly lower total sulfur than those from the spring harvest periods. During the tuber expansion stage of autumn harvest crops, Test Groups A and B were much higher than Control Groups in exchangeable sodium content. With the higher exchangeable sodium content, Test Groups A's treatment has a certain value of sustainable use.

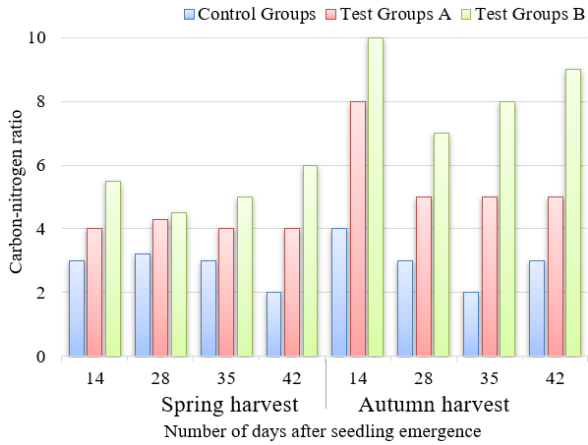
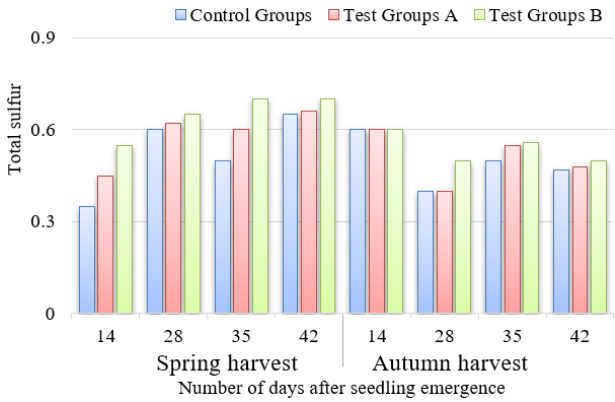
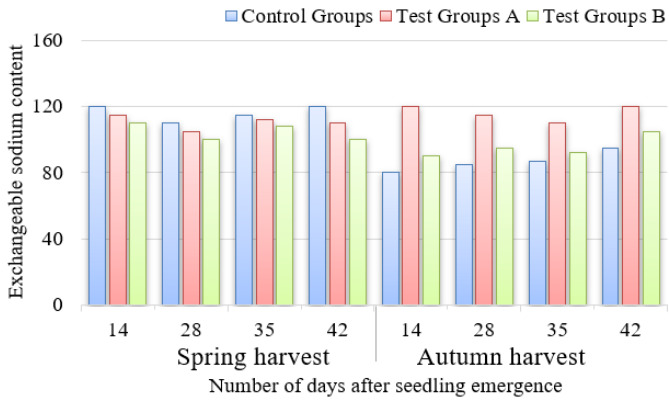


Figure 6. Influence of biomass amendment on the carbon-nitrogen ratio in Huangyangtan sandy land



(a) Total sulfur



(b) Exchangeable sodium content

Figure 7. Influence of biomass amendment on the total sulfur and exchangeable sodium content in Huangyangtan sandy land

4.3 Influence of fertilizers on biological performance of soil

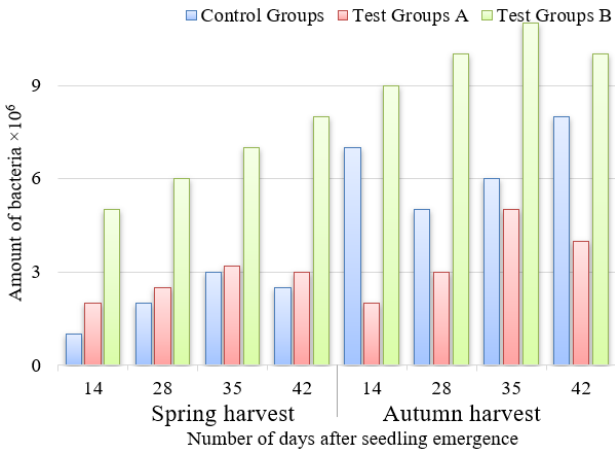


Figure 8. Influence of biomass amendment on the amount of bacteria in Huangyangtan sandy land

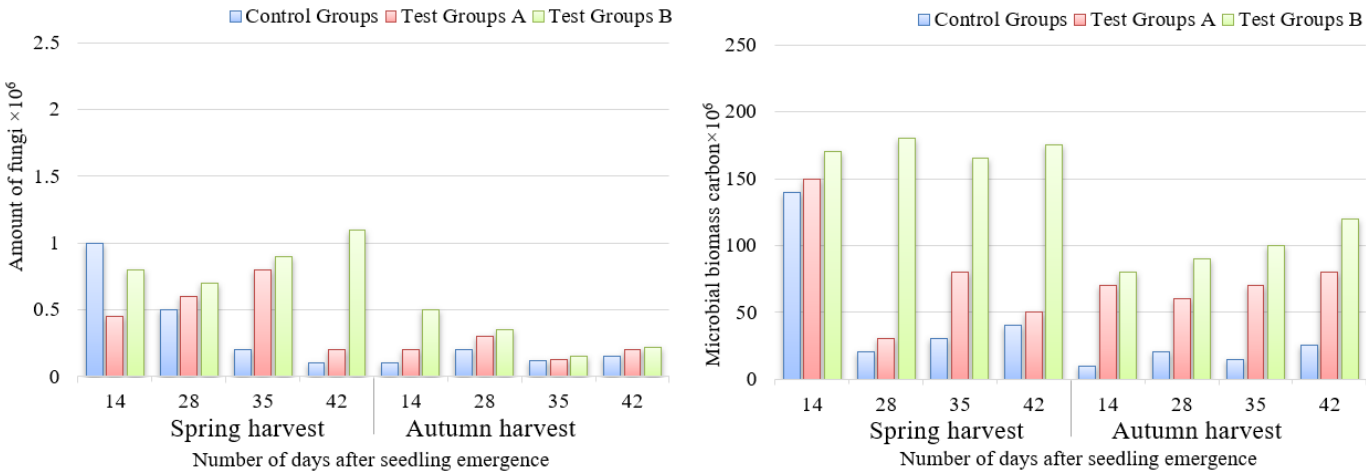
After optimizing the original sequencing, clustering analysis was performed on the flora formed through OTU classification, followed by biological diversity analysis. Table 8 provides the diversity index values and number of OTU classes. Judging by Shannon-Weiner index, Test Group B1 had the highest microbial diversity, followed by Test Group B3; the same trend was observed from the Simpson's index. From Coverage values, it was learned that the data coverage was high (>0.99) in every group. Figure 8 shows the influence of biomass amendment on the amount of bacteria in Huangyangtan sandy land. It can be seen that, whether the soil samples were collected from spring or autumn harvest period, the amount of bacteria in the samples increased significantly with the addition of organic biomass amendment. As shown in Figure 9, the organic biomass amendment had similar influences on the amount of fungi and microbial biomass carbon in Huangyangtan sandy land.

Color change rate is a key indicator of microbial activity in soil. The higher the color change rate, the more active the microbes in soil. Figure 10 provides the color change rate of microbial community in soil samples during spring harvest

and autumn harvest. During spring and autumn harvests, the color change rate of Test Groups A and B increased greater than the Control Groups, with the elapse of time. The highest rate was observed in Test Groups B, which adds both biochar and microbial agent. Hence, organic biomass agent can effectively improve the microorganism activity in sandy soil.

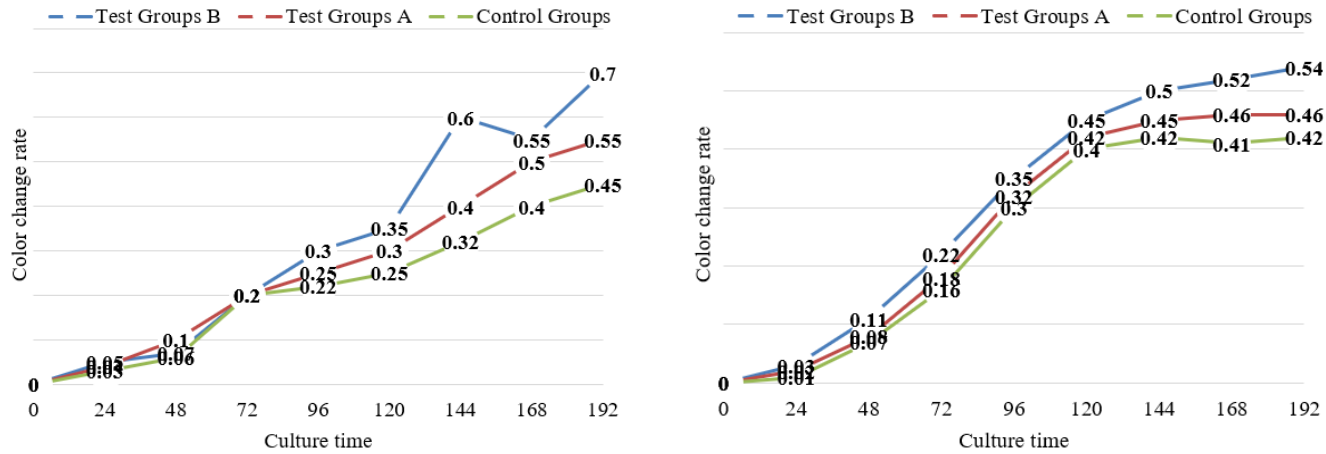
Table 8. Microbial diversity indices of soil samples

Group	Number of sequences	Diversity index				
		Shannon-Weiner	Coverage	Chao	Simpson	OTU
Test Group A1	54238	0.0547	0.991	487	3.25	413
Test Group A2	52695	0.0543	0.995	495	3.17	453
Test Group A3	51886	0.0495	0.994	484	3.85	442
Test Group B1	55297	0.1326	0.997	398	4.14	397
Test Group B2	56864	0.0639	0.997	424	3.22	364
Test Group B3	49867	0.0897	0.999	542	4.06	448



(a) Amount of fungi (b) Microbial biomass carbon

Figure 9. Influence of biomass amendment on the amount of fungi and microbial biomass carbon in Huangyangtan sandy land



(a) Spring harvest (b) Autumn harvest

Figure 10. Color change rate of microbial community in soil samples during spring harvest and autumn harvest

4.4 Influence of fertilizers on crop yield

The yield and yield indices of sweet potatoes change to varied degrees after the application of different fertilizers. Table 9 summarizes the yield of different groups. The sweet potato yield was significantly enhanced by any of the three fertilizers: compound fertilizer, substrate, and organic biomass amendment. The most prominent enhancement was achieved by organic biomass amendment, about 1,229-2,071 kg·hm^{-2} more than that of the Control Groups, followed by substrate, and compound fertilizer (the enhancement by the latter was 502-782 kg·hm^{-2} greater than that by the former). The plots treated with different fertilizers also differed in leaf length, number of leaves, number of tubers, and single tuber weight. Their impacts on these indies were similar as those on yield. This means biochar and microbial agent can indeed promote crop yield and create the value of sustainable utilization.

Table 9. Yield of different groups

Group	Yield index				Yield/kg·hm^{-2}
	Leaf length/cm	Number of leaves	Number of tubers	Single tuber weight/g	
Test Group A1	5.8±1.27a	9.9±3.68a	5.41±2.38b	153.16±0.19b	6547±411.68c
Test Group A2	5.2±0.48a	10.8±3.11a	4.47±9.12ab	164.61±0.43ab	6694±296.09ab
Test Group A3	5.8±1.56a	13.9±3.22a	5.56±2.57a	175.11±1.60a	6218±375.48a
Test Group B1	6.3±0.77a	14.4±2.12a	6.47±4.31ab	151.92±1.31b	7154±132.01b
Test Group B2	6.1±1.42a	13.7±4.81a	7.63±2.25b	153.86±1.16ab	7783±213.93b
Test Group B3	6.8±1.58a	16.0±1.84a	6.52±4.14a	144.71±1.27ab	7396±175.72ab

5. CONCLUSIONS

This paper chooses the grasslands with different degrees of desertification in Huangyangtan, the largest sandy land in northern China's Hebei Province, as the object, and explores the remediation effect of biomass amendment on the physical-chemical performance and sustainable utilization of sandy soil. Firstly, the authors detailed the strategies to measure the physical-chemical indices, determine fungal infection rate of crop roots, and evaluate microbial diversity of Huangyangtan sandy soil. Next, a complete test design was made for the biomass amendment on Huangyangtan sandy soil, including the materials and test procedure. After that, the test results were analyzed in details to reveal the influence of different test fertilizers on the soil in terms of physical performance, chemical performance, biological performance, and crop yield. The analysis verifies that biomass amendment can promote the amelioration of sandy soil, optimize its physical-chemical performance, and increase the beneficial bacteria, thereby promoting the sustainable use of the sandy land.

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