

The Proportional Optimization of Kitchen Waste Composting in Saline-Alkaline Soil Improvement

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Abstract. This study investigates the application value of kitchen waste composting technology in the amelioration of saline-alkali soil, highlighting that aerobic composting, due to its simplicity, low cost, and high agricultural value, is more suitable for kitchen waste treatment. Kitchen waste compost is rich in organic matter and mineral elements, which can significantly increase the organic carbon content in soil, reduce heavy metal content, and improve soil physical structure, thereby promoting plant growth. This study focuses on saline-alkali soils in Shandong and Jilin provinces, analyzing the effects of different compost ratios on soil physicochemical properties and plant growth through experiments. The results indicate that in Shandong saline-alkali soil, a mixture ratio of 80% soil and 20% compost is most suitable, maximizing seed germination rate. In Jilin saline-alkali soil, a mixture ratio of 70% soil and 30% compost is more effective. This suggests that an appropriate proportion of kitchen waste compost can significantly improve the soil environment of saline-alkali land and promote plant growth. This study provides an effective solution for urban kitchen waste treatment and saline-alkali soil amelioration.

Keywords: Food waste; Composting; Amelioration of saline-alkali land; Soil physicochemical properties; Plant growth.

1. Introduction

In recent years, the urbanization process in China has advanced further, resulting in a continuous increase in urban waste generation. Since 2019, waste sorting has gradually gained attention among the public. In 2021, the total volume of urban municipal solid waste collected nationwide reached 248.7 million tons[1]. The primary component of municipal solid waste is kitchen waste, which accounts for more than 50%, and in some regions, this figure can reach up to 70%[2].

Domestic and international kitchen waste treatment technologies include aerobic composting, anaerobic digestion, and animal feed utilization. Although anaerobic digestion provides effective treatment with high efficiency, it requires pre-treatment of the kitchen waste, which may result in higher processing costs. Moreover, the biogas and digestate produced are generally unsuitable for direct use as fertilizers and necessitate further harmless treatment, leading to higher subsequent costs[3]. Animal feed utilization has a comparatively lower negative environmental impact than anaerobic digestion. However, the outbreaks of Bovine Spongiform Encephalopathy and Foot-and-Mouth Disease in the UK have demonstrated the risks associated with feeding food waste to animals. As a result, concerns regarding the transmission of bacteria, parasites, and viruses have remained the primary barrier to recycling food waste containing animal-derived tissues into animal feed[4]. The aerobic composting process is relatively simple, cost-effective, and has high agricultural value[5], making it more suitable for the on-site and decentralized treatment of kitchen waste.

Kitchen waste composting is rich in organic materials such as cellulose, lignin, and mineral elements, which can enhance the organic carbon content in the soil and improve both crop yield and quality. Additionally, composting kitchen waste can reduce the concentration of heavy metals in the soil, thereby mitigating their harmful effects on crop growth and human health[6]. Most importantly, kitchen waste composting can effectively improve the physical structure of the soil, enhancing its permeability and thereby increasing its water retention capacity.

Currently, the Huangzhunhai Plain and coastal areas in Dongying, Binzhou, Weifang, and Dezhou in Shandong Province are characterized by large expanses of saline-alkali soils. These soils, due to their high salt and alkali content, experience significant alterations in their physical and chemical

properties. As a result, soil compaction, poor structure, elevated pH levels, and nutrient deficiencies severely impact soil quality and hinder the growth of both plants and animals[7]. Therefore, it is essential to explore the utilization of kitchen waste for aerobic composting to produce fertilizers and improve saline-alkali soils.

Biochar, due to its unique porous structure, large surface area, and anionic exchange properties, has the potential to reduce nitrogen loss, accelerate organic matter decomposition, and enhance microbial activity. In an experiment conducted by Comino et al. (2020)[8] to improve degraded agricultural soils, the biochar-compost group showed a significant increase in aboveground total biomass and corn yield compared to all other organic amendments. Grain yield increased by 10% to 29%, and certain plant parameters, such as chlorophyll content, were also significantly enhanced through organic treatments. Experiments by Shi et al. (2023)[9] confirmed that adding agricultural and forestry waste, along with corn straw, to kitchen waste composting could enrich bacteria with xylanase and cellulase activities during the maturation phase, promoting humification and improving it by 75%.

EM (Effective Microorganisms) consists of over 80 beneficial microorganisms from 10 genera, including lactic acid bacteria, yeast, actinomycetes, and photosynthetic bacteria, and is an indispensable microbial agent in the composting process. Chen et al. (2022)[10] discovered that the addition of microbial agents accelerates the temperature rise in the compost pile and promotes maturation, while also achieving varying degrees of greenhouse gas emission reduction. Fu et al. (2020)[11] investigated the effects of inoculating kitchen waste aerobic composting with beneficial microbial groups, including EM, organic fertilizer fermentation bacteria, and nitrogen-fixing bacteria. The results indicated that microbial agents enhance organic matter degradation and increase the total nitrogen and total phosphorus content in the compost products.

The current measures for the improvement of saline-alkali soils in China primarily include industrial, agronomic, biological, and chemical approaches. Among these, agronomic measures are the most widely applied, primarily aiming to increase soil moisture and reduce salinity through practices such as plowing, covering, and the application of organic fertilizers[12]. This paper provides a summary of the effects of composting kitchen waste mixed with biochar, EM, and other materials in fixed proportions on the physical and chemical properties, nutrient availability, soil biological characteristics, and plant growth of saline-alkali soils in Jilin and Shandong. Additionally, it investigates the optimal soil-to-fertilizer mixing ratio for enhancing the improvement of saline-alkali soils, offering a theoretical foundation and reference for the ecological restoration and sustainable development of saline-alkali soils.

2. Methods

2.1 Experimental Location

Soil samples from saline-alkali soils were collected from two locations: Dongying, located along the coastal region of Shandong, and Baicheng, situated in the western Songnen Plain of Jilin. At each sampling site, samples were collected using the five-point sampling method. The samples were air-dried naturally, sieved through a 1 mm mesh, and thoroughly mixed before use.

2.2 Experimental Materials

The compost used in the experiment consisted of a mixture of kitchen waste, biochar, and landscaping waste, which had undergone the post-maturation phase of composting. The physical and chemical properties of the soil and compost are presented in the table. The experimental plants used were ryegrass and mung bean seeds.

2.3 Experimental Instruments

The instruments used in the experiment included a pH meter (PHS-3E), an electronic balance (ME204), an electric blast drying oven (Model 101), an ultrasonic cell disruptor (FB120), compost bins (20L), a climate chamber, and 12-cell seedling trays (3.7 cm * 3.7 cm * 5.5 cm).

2.4 Composting Experimental Design

Composting Pretreatment: Kitchen waste, EM bacteria, biochar, and landscaping waste were mixed in a ratio of 3:2:1:1 and placed into a rotating drum compost bin for uniform mixing. After drying for two days, the mixture was transferred to different composting sites.

Two experimental groups were established: indoor composting and outdoor open windrow composting.

(1) Indoor Composting

Small compost bins were prepared and placed inside insulated foam boxes. Cotton, straw, and other materials were used as thermal insulation between the bin and the foam box. Several ventilation holes were made in the foam box. Temperature and humidity were measured daily. The bin was opened and stirred every 3 days, and excess leachate was drained.

(2) Outdoor Composting

Prior to the experiment, the site was cleared of debris, leveled, and compacted. A double layer of 1.2 mm rainproof cloth was laid down for water isolation to prevent the compost leachate from penetrating into the ground. The composting area measured 2.3 m x 2.3 m x 1.5 m. Since the experiment was conducted during the winter, a double-layer film with a 15 cm gap was used for insulation to maintain temperature and protect the compost from rain.

To ensure the effectiveness of aerobic composting, the pile was regularly turned every three days. After two weeks of complete compost maturation, samples were taken. The sampling depth and points are shown in Figure 1.

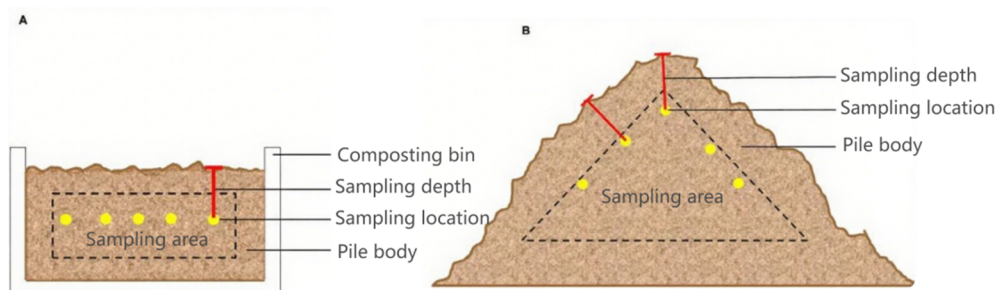


Figure 1 Sampling Depth and Sampling Points for the Two Composting Methods

2.5 Pot Experiment Design

The pot containers used were 12-cell seedling trays with dimensions of 3.7 cm * 3.7 cm * 5.5 cm. The soil and compost mixture was prepared in a specified mass ratio, with a total weight of 0.2 kg, and evenly distributed into one column (three cells) of the seedling tray. The number of ryegrass seeds planted in each cell was kept consistent.

Table 1 Substrate Formulations and Quantities for the Eight Experimental Groups

Treatment ID	Substrate Composition	Soil Quantity	Compost Quantity
Sample 1-1	100% Shandong Saline-Alkaline Soil	0.2 kg	0 kg
Sample 1-2	90% Shandong Saline-Alkaline Soil + 10% Fertilizer	0.18kg	0.02 kg
Sample 1-3	80% Shandong Saline-Alkaline Soil + 20% Fertilizer	0.16 kg	0.04 kg
Sample 1-4	70% Shandong Saline-Alkaline Soil + 30% Fertilizer	0.14 kg	0.06 kg

Sample 2-1	100% Jilin Saline-Alkaline Soil	0.2 kg	0 kg
Sample 2-2	90% Jilin Saline-Alkaline Soil + 10% Fertilizer	0.18kg	0.02 kg
Sample 2-3	80% Jilin Saline-Alkaline Soil + 20% Fertilizer	0.16 kg	0.04 kg
Sample 2-4	70% Jilin Saline-Alkaline Soil + 30% Fertilizer	0.14 kg	0.06 kg

Note: Samples 1-2 to 1-4 and Samples 2-2 to 2-4 were assessed two weeks after the ryegrass had been thoroughly mixed and cultivated. Mowing was conducted every 10 days following sowing. The temperature in the controlled environment chamber was maintained at 20-25°C with a relative humidity of 60%-70%.

2.6 Analytical Methods

(1) Soil pH Measurement

Soil was mixed with deionized water in a 1:5 (w/v) ratio, shaken for 2 minutes to ensure thorough mixing, and then allowed to equilibrate for 30 minutes. The pH was measured using a pH meter.

(2) Plant Height Measurement

Ten plants were randomly selected from each germination tray. Plant height was measured using a ruler with a range of 0-100 cm, and the average plant height was subsequently calculated.

(3) Aboveground and Belowground Biomass Measurement

A 3 cm x 3 cm quadrat was used for sampling, with three replicates for each treatment. The aboveground portions of the plants within the quadrat were cut close to the ground and placed in paper envelopes. After the final cutting, the belowground portions of the plants were completely removed from the quadrat, washed with water in a mesh bag, and then dried with paper towels to remove excess moisture. The plant samples were then placed in paper envelopes and weighed to determine the biomass for each treatment.

(4) Soil Organic Matter Content Measurement

Soil organic matter content was determined using the potassium dichromate oxidation method, as specified in NY/T 1121.6.

(5) Soil Alkali-Hydrolyzable Nitrogen Content Measurement

Alkali-hydrolyzable nitrogen content was measured using the semi-micro Kjeldahl method, according to the procedure outlined in NY/T 53-1987.

(6) Soil Available Phosphorus Content Measurement

Available phosphorus content was determined using the alkaline solution-aluminum anti-colorimetric method, as described in LY/T 1232-2015.

(7) Soil Available Potassium Content Measurement

Available potassium content was determined using the ammonium acetate extraction-flame photometry method, as outlined in LY/T 1234-2015.

(8) Soil Organic Carbon Content Measurement

Organic carbon content in the soil was measured using the potassium dichromate oxidation-spectrophotometric method, as specified in HJ 615-2011.

3. Results and Discussion

3.1 Analysis of the Physicochemical Properties of the Original Soil Samples and Soil Samples Amended with Different Substrates

Table 2 Analysis of Physicochemical Properties

Indicator	Group							
	Sample 1-1	Sample 1-2	Sample 1-3	Sample 1-4	Sample 2-1	Sample 2-2	Sample 2-3	Sample 2-4
pH	7.40	6.88	6.62	6.80	7.23	6.91	6.89	6.77
TN(g/kg)	0.251	0.261	0.298	0.271	0.168	0.177	0.196	0.223
C/N		14.41226576				12.93617021		

Organic Matter(g/kg)	3.54	4.20	5.10	4.50	3.11	3.57	4.22	4.45
TK(g/kg)	1.9	18.8	25.0	5.5	4.9	5.6	8.3	11.3
TP(g/kg)	1.43	1.53	1.10	1.26	0.59	1.36	1.17	1.87
Appearance	Black-brown, granular, loose, with no unpleasant odor							
Particle Size(mm)	5	5	5	5	5	5	5	5

The electrical conductivity of Shandong saline-alkali soil was measured at 3.986 mS/cm, indicating a moderate level of salinization. In contrast, the electrical conductivity of Jilin saline-alkali soil was 4.5 mS/cm, classifying it as high-conductivity soil with a more severe degree of salinization.

Following a two-week composting period, the pH values of both composts ranged from 6.0 to 7.0, which is slightly neutral to mildly alkaline. This pH range is considered suitable for maintaining the availability of soil nutrients.

Soil organic nitrogen, which is derived from ammonium and nitrate nitrogen, plays a crucial role in supporting microbial growth and serves as a key indicator of compost maturity^[13]. In the case of Shandong saline-alkali soil, the total nitrogen content in samples 1-2, 1-3, and 1-4 was higher than that of the control soil group. Sample 1-3 exhibited the highest total nitrogen content at 0.298 g/kg, while sample 1-1 showed the lowest at 0.261 g/kg. For the Jilin saline-alkali soil samples, the total nitrogen content in samples 2-2, 2-3, and 2-4 was also higher than in the control soil group. Sample 2-4 had the highest total nitrogen content at 0.271 g/kg, while sample 2-3 had the lowest at 0.258 g/kg.

The C/N ratio reflects the degree of decomposition and transformation of organic matter in compost and serves as a reliable indicator of compost maturity. As the composting process progresses, the carbon in the organic matter is gradually broken down and released, while nitrogen loss remains relatively minimal, resulting in a decrease in the C/N ratio of the compost^[14]. Typically, a higher degree of compost maturity correlates with a lower C/N ratio. Initially, the C/N ratio of both experimental groups was 25, and after composting, the C/N ratios were 14.41 and 12.93 respectively. This demonstrates that the organic matter in the compost has been sufficiently decomposed, making it suitable for application as fertilizer in the soil to be tested.

Organic matter is a critical component of soil fertility, playing a significant role in improving soil water retention, nutrient-holding capacity, soil structure, and promoting microbial activity^[15]. Generally, soils with higher organic matter content tend to exhibit better fertility, which in turn supports crop growth and enhances yield. As shown in Table 1, the best improvement effects were observed in the 7:3 ratio for both the Shandong and Jilin experimental groups.

Adequate potassium levels can enhance soil fertility and promote crop growth^[16]. Measurements indicated that in Shandong saline-alkali soil, the total potassium content in sample 1-3, which received compost 1, was the highest at 25.0 g/kg, while the lowest was found in sample 1-4 at 5.5 g/kg. In Jilin saline-alkali soil, sample 2-4 exhibited a slightly higher total potassium content than the other groups, reaching 11.3 g/kg.

Phosphorus is one of the essential macronutrients required for plant growth and development. Due to its low availability in the soil, phosphorus is prone to fixation or the formation of insoluble compounds with other elements, often necessitating artificial fertilization to meet crop phosphorus requirements^[17]. Measurements revealed that sample 1-2, which received compost 1, had the highest total phosphorus content, while sample 1-3 had the lowest. The total P content in sample 1-4 was slightly lower than the total P content in the soil, and, in comparison with total nitrogen and total potassium, the advantage of total P was less pronounced. In the Jilin group treated with compost 2, sample 2-4 exhibited a total P content of 1.87 g/kg, which was significantly higher than in the other groups.

3.2 Effects of Different Substrates on Seed Germination Rate

Table 3 Seed Germination Rate

Days	Germination Rate (%)							
	Sample 1-1	Sample 1-2	Sample 1-3	Sample 1-4	Sample 2-1	Sample 2-2	Sample 2-3	Sample 2-4
Day 1	30	50	80	70	20	40	60	70
Day 2	80	80	100	90	70	90	90	100
Day 3	80	80	100	90	70	90	90	100

The compost leachate from kitchen waste contains essential nutrients such as nitrogen, phosphorus, and potassium, which are necessary for plant growth. These nutrients can support the germination of ryegrass seeds, thereby promoting seed germination and growth^[18]. First, as shown in Table 2, the seed germination rates for the compost-soil mixture samples from Shandong and Jilin are higher than those for the corresponding pure soil samples. This suggests that the addition of kitchen waste compost effectively enhances the nutrient content in saline-alkali soils, thereby facilitating seed germination. Furthermore, as the growth period progresses, the seed germination rate gradually increases and ultimately stabilizes, further confirming the positive impact of compost on the improvement of saline-alkali soils.

3.3 Impact of Different Substrates on Ryegrass Growth

3.3.1 Impact of Different Substrates on Ryegrass Height

Table 4 Ryegrass Height

Frequency	Height (cm)							
	Sample 1-1	Sample 1-2	Sample 1-3	Sample 1-4	Sample 2-1	Sample 2-2	Sample 2-3	Sample 2-4
First Mowing	4.28	6.27	9.9	7.66	0.92	1.34	1.67	2.14
Second Mowing	5.41	6.77	10.16	7.78	1.53	2.58	2.56	3.64
Third Mowing	6.93	7.00	10.65	8.54	2.13	3.62	4.87	5.56

Kitchen waste compost has a significant effect on the height of ryegrass. The appropriate addition of compost can promote ryegrass growth and increase its height. However, the amount of compost added should not be excessive. An overabundance of compost may increase the salt content in the substrate, which can suppress ryegrass growth and lead to a reduction in height. Therefore, when using kitchen waste compost to enhance ryegrass growth, it is essential to control the compost addition carefully and determine the optimal application ratio. As observed in Table 3, the ryegrass height and average height after each mowing in the compost-soil mixture samples from Shandong and Jilin are consistently higher than those in the corresponding pure soil samples.

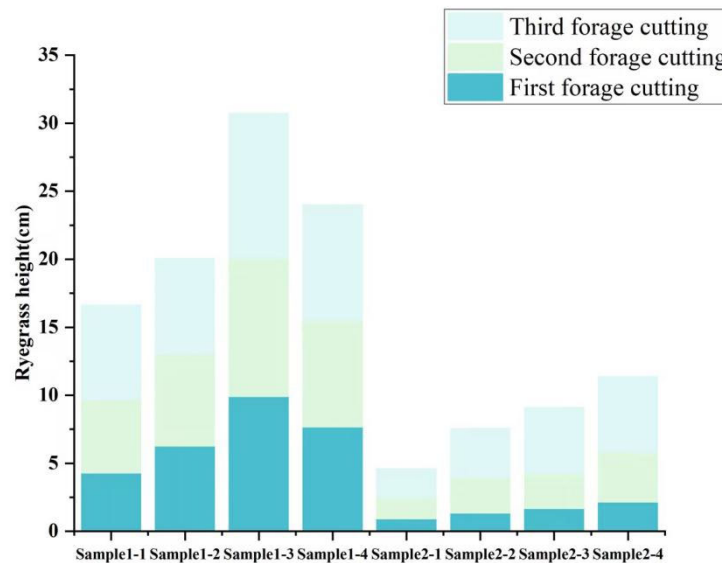


Figure 2 Impact of Different Substrates on the Height of Ryegrass

This finding suggests that the addition of kitchen waste compost can effectively enhance the nutrient content in saline-alkaline soils, thereby promoting the growth of ryegrass. As shown in Figure 2, for saline-alkaline soil in Shandong, a 20% compost addition significantly promotes ryegrass growth, making it the optimal fertilization ratio. This supports the previous conclusion that excessive compost may not lead to better growth outcomes. For saline-alkaline soil in Jilin, both ryegrass growth and height increase with the increasing proportion of compost. The highest ryegrass height was observed in the treatment with 70% compost and 30% soil. This indicates that increasing the compost application rate in Jilin's soil can still effectively promote ryegrass growth.

3.3.2 Impact of Different Substrates on Ryegrass Aboveground Biomass

Table 5 Ryegrass Aboveground Biomass

Mowing Frequency	Aboveground Biomass (g)							
	Sample 1-1	Sample 1-2	Sample 1-3	Sample 1-4	Sample 2-1	Sample 2-2	Sample 2-3	Sample 2-4
First Mowing	0.4863	0.7452	0.5529	1.4398	0.1442	0.1366	0.2242	0.4327
Second Mowing	0.5632	0.7632	0.6239	1.5136	0.1586	0.1965	0.2893	0.5234
Third Mowing	0.5963	0.8236	0.7397	1.5823	0.2638	0.2742	0.2968	0.6981

As shown in the table, the application of compost promotes ryegrass growth and significantly increases its aboveground biomass. In the experiment with saline-alkaline soil in Shandong, the average aboveground biomass of samples 1-3 from the three mowing cycles was higher than that of the other samples, at 5.7013g. The total aboveground biomass of the control group after three mowing cycles was 0.4863g, 1.5963g, and 2.4866g, with a total weight of 5.4154g. In terms of yield, samples 1-3 showed the greatest increase in ryegrass weight. Compared to the control group, the weight gain of the second and third cuts was 262.53% and 210.1%, respectively, while the other groups showed an increase ranging from 40% to 171%. Overall, the addition of compost significantly promoted plant growth. Under different compost application rates, the aboveground biomass of the plants significantly increased. As shown in Figure 3, the third cut accounted for the largest proportion of aboveground biomass across the four sample groups, which may be because, in the later stages, the ryegrass roots gradually expand and penetrate deeper into the soil, allowing for better absorption of water and nutrients. The plants carry out more photosynthesis, producing more nutrients, which ultimately leads to an increase in grass biomass.

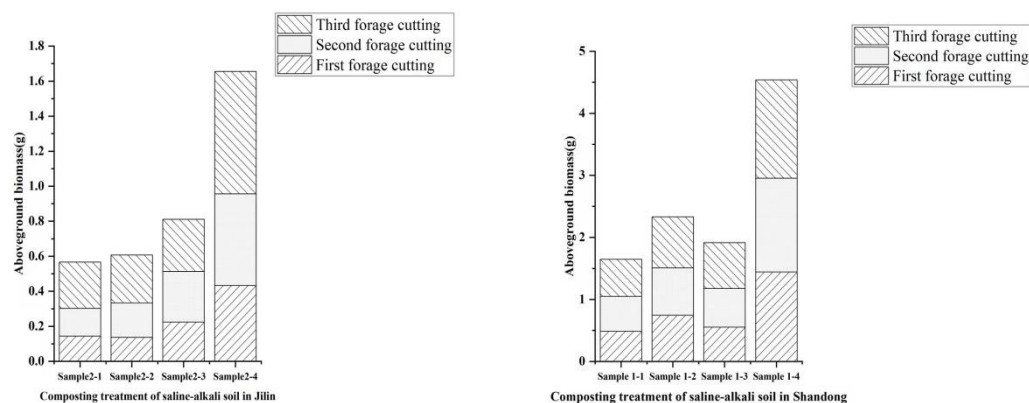


Figure 3 Impact of Different Substrates on Ryegrass Aboveground Biomass

In the experiment conducted with saline-alkaline soil in Jilin, the average aboveground biomass of samples 2-4 across the three mowing cycles was higher than that of the other samples, with a value of 5.7013g. In the control group, the total aboveground biomass for the three mowing cycles was 1.4422g, 1.5846g, and 2.2638g, resulting in a total weight of 5.667g. In terms of yield, samples 2-4 exhibited the largest increase in ryegrass biomass. Compared to the control group, the weight increase for the second and third cuts was 230.0% and 164.6%, respectively, while the other groups showed increases ranging from 39.5% to 82.4%. Overall, the addition of compost significantly promoted plant growth. In comparison to the saline-alkaline soil experiment in Shandong, the aboveground biomass in the Jilin saline-alkaline soil experiment was lower, which may be attributed to the higher concentration of exchangeable salt ions in the original soil of Jilin, which inhibited the plants' growth rate.

4. Conclusion

This study focused on the improvement effects of kitchen waste compost on saline-alkaline soils from Shandong and Jilin provinces. Four different fertilizer-to-soil ratios were designed for the experiment: 30% fertilizer + 70% soil, 40% fertilizer + 60% soil, 10% fertilizer + 90% soil, and 100% soil, to identify the optimal compost application ratio. Composting was carried out both indoors and outdoors with identical material ratios in each region. The pH, carbon-to-nitrogen ratio, organic matter, electrical conductivity, total phosphorus (TP), total potassium (TK), and other soil indicators of the improved soils were measured. Ryegrass seeds were then cultivated in these soils, and seed germination rate, plant height, aboveground biomass, and belowground biomass were assessed. The conclusions drawn from this study are as follows:

(1) The mixed compost of kitchen waste, biochar, and agricultural and forestry waste exhibited good maturity, with a carbon-to-nitrogen ratio close to 10:1. This mixture effectively improved soil properties and enhanced plant growth. Compared to the untreated soils, the electrical conductivity of the fertilized soils decreased significantly, alleviating salinization, while the levels of essential nutrients such as nitrogen, phosphorus, and potassium increased.

(2) The seed germination rate varied in response to changes in the compost application ratio. In Shandong saline-alkaline soil, the mixture of 80% soil and 20% compost was the most effective, maximizing seed germination. In contrast, in Jilin saline-alkaline soil, the most effective mixture was 70% soil and 30% compost.

(3) Kitchen waste compost has a significant effect on promoting ryegrass growth in saline-alkaline land improvement. Proper compost addition provides a rich supply of organic matter and nutrients, supporting the growth and development of ryegrass. However, the compost application must be carefully controlled to avoid excessive salinity, which could inhibit ryegrass growth. In the Shandong saline-alkaline soil trials, the mixture of 20% compost and 80% soil was most effective in promoting ryegrass plant height, increasing both aboveground and belowground biomass, and significantly

enhancing plant density and coverage in the community. For Jilin saline-alkaline soil, the mixture of 30% compost and 70% soil was found to be most suitable for optimal plant growth.

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