Effects of Different Application Rates of Bioorganic Fertilizer on the Growth of Spinach in a Short Term

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Abstract [**Objectives**] This study was conducted to promote the rational use of bioorganic fertilizers. [**Methods**] Stanley bioorganic fertilizer was selected to investigate the laws and characteristics of the effects of bioorganic fertilizer on spinach growth with different application rates in a short term and found out the precise application rate. [**Results**] As the application rate of bioorganic fertilizer increasing, the emergence rate of spinach decreased. The total weights and leaf areas of spinach plants treated with different application rates of bioorganic fertilizers were all higher than those of the control check (CK). The total weights and leaf areas of spinach plants applied with bioorganic fertilizer at different rates were all higher than those of the CK. The total weight of spinach plants increased linearly with the application rate of bioorganic fertilizer increasing among treatments, while the leaf area fluctuated with the increase of bioorganic fertilizer concentration among various treatments. The average root volumes and average diameters of treatments applied with bioorganic fertilizer at different rates were all higher than those in the CK, but the average root length showed a different trend. The average root length was higher in the CK than in various bioorganic fertilizer treatments in the early growth period, but the differences of various treatments from the CK gradually decreased in the middle period, and in the later period, the root length of spinach treated with organic fertilizer gradually exceeded the CK. [**Conclusions**] This study provides a theoretical basis for the rational application of bioorganic fertilizers in spinach production.

Key words Spinach; Bioorganic fertilizer; Root system; Total weight of plants

In 2020, the total production of spinach in more than 60 countries and regions worldwide was about 31.432 million tons, while China's production was about 28.779 million tons, accounting for 91.56% of the global total production[1]. The application of bioorganic fertilizers can provide comprehensive nutrient elements for crops, which increase crop stress resistance and soil microorganisms, and improve crop taste and quality while increasing crop yield[2]. Bioorganic fertilizers have played an important role in achieving the two major goals of "high yield" and "high-quality" in crops[3-5]. At present, excessive chemical fertilizers are applied in spinach production, which leads to single nutrients, unbalanced fertilizer supply, soil compaction, and a decrease in spinach yield and quality. On the other hand, although there has been an increase in emphasis on the application of bioorganic fertilizers in production from farmers, large growers, to leading enterprises, due to the lack of guidance on the usage and application rate, improper usage is common, and the improvement of spinach yield and quality is limited. Therefore, in this study, with spinach as the research object, Stanley bioorganic fertilizer was selected to investigate the laws and characteristics of the effects of bioorganic fertilizer on spinach growth with different application rates and found out the precise application rate, providing a basis for rational application of bioorganic fertilizers.

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Materials and Methods

Experimental crop and variety

The experimental crop was spinach "Lierijingang F1".

Experimental fertilizer

Bioorganic fertilizer was produced by Stanley Agricultural Group Co., Ltd. The fertilizer indexes were effective viable bacterial count ≥300 million/g (*Bacillus subtilis*) and organic matter ≥ 60%.

Experimental time

The seeds were soaked for 18 h on July 16, 2022, and sown on July 17. The seedling emergence rate reached over 50% on July 21. From July 28 to August 18, seedlings were taken for testing at an interval of 7 d, according to 5 plants from each treatment each time.

Experimental location

Plant culture room, Central Laboratory of Linyi Academy of Agricultural Sciences.

Substrate conditions

After sieving the soil, it was loaded into 30 cm × 42 cm seedling trays, according to a weight of 18 kg excluding the tare weight, with a soil layer thickness of approximately 10 cm. Next, the above-mentioned bioorganic fertilizer was added according to 9.5 g for treatment 1, 14.3 g for treatment 2 and 19 g for treatment 3, equivalent to the amount of bio-organic fertilizer used at 1 500 kg/hm^2 for treatment 1, 2 250 kg/hm^2 for treatment 2, and 3 000 kg/hm^2 for treatment 3, respectively. After thoroughly mixing, 3 000 g of water was added first, and after the water was completely absorbed, 40 spinach seeds were sown in a manner of bunch planting with a depth of 1.5 - 2.0 cm. Each treatment was repeated in three groups, totaling 120 plants. Next, the seeds

were covered with a thin layer of soil, and then irrigated with 500 g of water. Finally, the trays were put on shelves.

Environmental conditions

The soil pot experiment was conducted under indoor supplementary lighting conditions, with an indoor lighting condition of 2 000 lux and an average room temperature of 26 ℃. The two levels of lighting alternated between day and night according to 14/10, and the water was uniformly and quantitatively managed.

Experimental soil nutrients

The soil nutrient conditions were as follows: total nitrogen 0.171%, nitrate nitrogen 104 mg/kg, available phosphorus 273.7 mg/kg, available potassium 275 mg/kg, exchangeable calcium 20.1 cmol/kg, exchangeable magnesium 3.4 cmol/kg, available iron 46.8 mg/kg, available manganese 66.2 mg/kg, available copper 5.78 mg/kg, available zinc 13.0 mg/kg, available boron 1.45 mg/kg, organic matter 34.9 g/kg, pH 7.3, conductivity 80.2 ms/m.

Experimental instruments and equipment

LA-S plant image analysis system, Hangzhou Wanshen Testing Technology Co., Ltd; SPAD-502 plus chlorophyll measuring instrument; UW6200H and KB-W01 electronic balance, Shimadzu, Japan; illuminometer DLY-1802.

Results and Analysis

Emergence of spinach seedlings treated with different application rates of bioorganic fertilizer

The effects of different application rates of bioorganic fertilizer on the emergence rate of spinach are shown in Table 1. On the 4th day after sowing, the highest emergence rate was 77% observed in the CK, while the lowest emergence rate was 58% in treatment 1. The highest emergence rate on the 8th day after sowing was still in the CK, at 91%, and treatments 1 and 3 had the lowest emergence rate of 83%.

Effects of different application rates of bioorganic fertilizer on the growth of spinach leaves

As shown in Fig. 1, among treatments of different application rates of bioorganic fertilizers, it can be intuitively seen that the CK had a total number of leaves significantly small, and the leaves were thin and weak. However, the total number of leaves in treatment 3 was significantly larger, and the leaves were plump.

Table 1 Effects of different application rates of bioorganic fertilizer on the emergence rate of spinach %

Date	Emergence rate			
	CK	Treatment 1	Treatment 2	Treatment 3
Jul. 21	0.77	0.58	0.63	0.61
Jul. 25	0.91	0.83	0.89	0.83

Effects of different application rates of bioorganic fertilizer on total weight and leaf area of spinach

Fig. 2 shows the effects of different application rates of bioorganic fertilizer on the total weight of spinach. The highest total plant weight was in treatment 3 (2.338 3 g), while the lowest was in the CK (1.941 7 g).

The effects of different application rates of bioorganic fertilizer on leaf area are shown in Fig. 3. Treatment 3 had the highest leaf area (1 253.71 mm^2), while the CK had the lowest leaf area (885.23 mm^2). Overall, the total weight and leaf area of spinach plants treated with bioorganic fertilizer were higher than those of the CK.

Effects of bioorganic fertilizer on the root growth of spinach

As shown in Fig. 4, the effects of different application rates of bioorganic fertilizer on the root morphology of spinach can be intuitively observed, indicating that the root system of spinach in the CK was weak and had fewer hair roots. The root system of spinach in treatment 3 was robust and had a large number of hair roots.

Table 1 shows the effects of different application rates of bioorganic fertilizer on the root growth of spinach. On day 7 of growth, the length of the spinach root system was the longest in the CK, reaching 8.090 9 cm; the root volume was the largest in treatment 3, reaching 0.014 2 cm^3; and the average diameter was the largest in treatment 3, reaching 0.060 8 mm. On day 14 of growth, the length of the spinach root system was still the longest in the CK, reaching 10.090 9 cm; the root volume was the largest at 0.018 6 cm^3 in treatment 3; and the average diameter was the largest at 0.083 4 in treatment 3. On day 21 of growth, the length of the spinach root system was the longest in treatment 2, reaching 18.649 1 cm; the root volume was the largest in treatment 3, reaching 0.020 6 cm^3; and the average diameter was the largest in treatment 3, reaching 0.091 5 mm.

Table 2 Effects of different application rates of bioorganic fertilizer on growth of spinach roots

	Length // cm			Volume // cm^3			Average diameter // mm		
	Day 7	Day 14	Day 21	Day 7	Day 14	Day 21	Day 7	Day 14	Day 21
CK	8.090 9	10.090 9	15.794 3	0.011 9	0.012 2	0.013 2	0.050 9	0.060 4	0.074 5
Treatment 1	6.154 4	8.154 4	14.166 33	0.011 3	0.012 5	0.016 5	0.056	0.066 8	0.081 3
Treatment 2	7.665 5	9.665 5	18.649 1	0.013 4	0.013 4	0.017 4	0.051 6	0.079 6	0.087 7
Treatment 3	5.769 2	7.769 2	17.145 5	0.014 2	0.018 6	0.020 6	0.060 8	0.083 4	0.091 5

Conclusions and Discussion

In this study, it was found that the effects of bioorganic fertilizer on the growth of spinach plants began with the effect on the root system. With the application rate of bioorganic fertilizer increasing, the emergence rate of spinach declined, which might be due to the increase of ion concentration in the soil, which thus affected osmotic pressure. From the perspective of spinach growth, the total weights and leaf areas of spinach plants applied with bioorganic fertilizer at different rates were all higher than those of the CK. The total weight of spinach plants increased linearly with

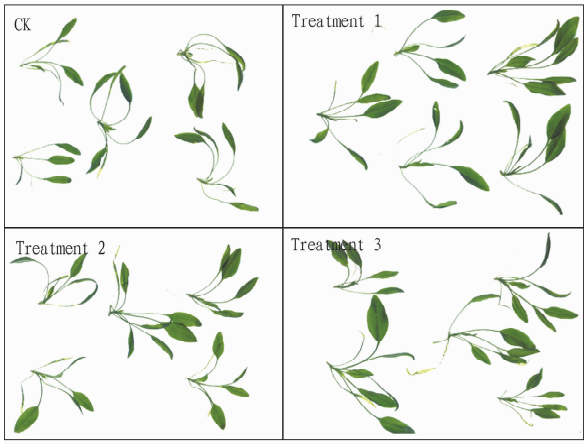

Fig. 1 Morphology of spinach leaves in treatments with different application rates of bioorganic fertilizers

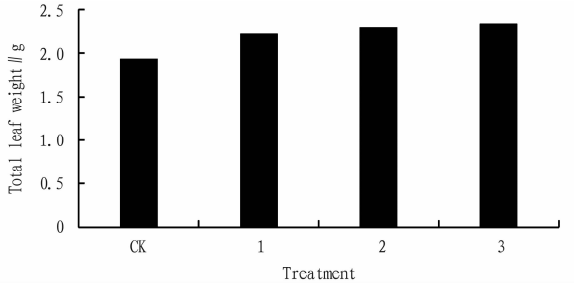

Fig. 2 Effects of different application rates of organic fertilizer on total leaf weight of spinach plant

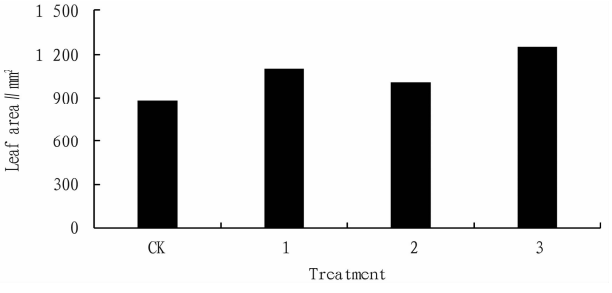

Fig. 3 Effects of different application rates of organic fertilizer on leaf area of spinach plants

the application rate of bioorganic fertilizer increasing among treatments, while the leaf area fluctuated with the increase of bioorganic fertilizer concentration among various treatments. The average root volumes and average diameters of treatments applied with bioorganic fertilizer at different rates were all higher than those in the CK, but the average root length showed a different trend. The average root length was higher in the CK than in various bioorganic fertilizer treatments in the early growth period, but the differences of various treatments from the CK gradually decreased in the middle period, and in the later period, the root length of spinach treated with organic fertilizer gradually exceeded the CK. The study on the effects of bioorganic fertilizer at different application rates on spinach leaf area, root growth and other indexes provides data support and a theoretical basis for the promotion and application of bioorganic fertilizer, as well as a reference basis for promoting fertilizer reduction and efficiency improvement.

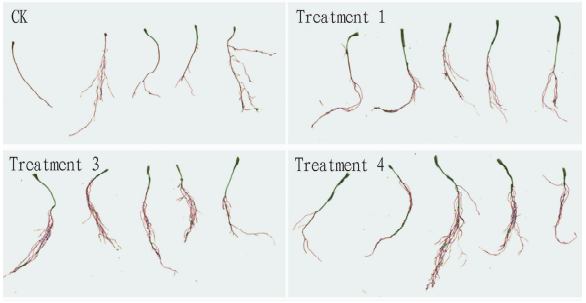

Fig. 4 Treatment of spinach root morphology with different application rates of bioorganic fertilizer

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