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Experimental Study on the Preparation of Improved Soil Substrate from Coal Gangue

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Abstract. With the continuous development of China's industry, the disorderly discharge and accumulation of coal gangue in mining areas have become a key ecological problem, which not only occupies a large amount of land, but also causes various pollution phenomena. Therefore, the comprehensive utilization of coal gangue has become a research hotspot in the field of environmental governance. In this paper, by mixing coal gangue and fly ash with straw in different ratios to prepare compound soil substrate and growing lettuce, the effects of different ratios of the three wastes and coal gangue particle sizes on crop growth were analyzed by measuring cotyledon area, plant height and other indexes. The experimental results showed that the best proportion of soil matrix improvement was 42.9% coal gangue, 7.1% fly ash, 10% straw and 40% soil, where the coal gangue particle size proportion was 20% fine particles, 20% medium particles and 60% coarse particles. This experiment mixed coal gangue with typical solid wastes, which will, to a certain extent, solve the problem of solid waste dumping and resource scarcity in China and provide a scientific reference for the comprehensive utilization of the three wastes and the repair of soil in mining areas.

1 Introduction

In the process of the continuous promotion of the national coal market policy, the coal consumption of China, the largest coal producer and consumer in the world, keeps increasing, reaching 3.68 billion tons in 2018, accounting for 50.2% of the world coal consumption [1]. Coal gangue is an associated resource produced in the process of coal production and processing. According to statistics, coal gangue storage occupies an area of about 106hm2 in China, and nearly 4 billion tons of the storage makes coal gangue one of the most important solid waste in China [2]. Due to the wide distribution area, high probability of environmental pollution and long duration [3], the open-air stacking of coal gangue will not only cause soil, air and groundwater pollution, but also induce landslides and debris flows, thus causing adverse effects on the natural landscape and ecological environment of the mining area.

At present, coal gangue treatment technology is mainly divided into ground and underground treatment technology. The research and utilization of coal gangue ground treatment technology mainly focuses on coal gangue power generation, road paving, production of building materials, production of chemical raw materials and agricultural application [4]. Shen, H.S., He, W.H. [5] et al. used coal gangue instead of concrete coarse aggregates to carry out the compressive strength test of coal gangue-based concrete and underground hardening tests, which verified the good effect of coal gangue-based concrete in underground hardening projects. Gu, L.Y. [6] et al. prepared porous ceramics with good compressive strength by using Huainan gangue and fly ash as raw materials, soda as sintering agent and sawdust as the pore-forming agent. Jin B. [7], et al. used sludge, gangue and shale as materials to prepare sintered brick, and the results showed that the strength of sintered bricks could reach to grade MU15 with 10% sludge, 40% gangue and 50% shale. Wang, Y.K. [8], et al. used coal gangue and bauxite to prepare Mullite-based ceramsite and prepare Fe/C/Mullite-based ceramics composite absorbing material by wet chemical synthesis technology. Ling, C.Y., Zhang, R. [9] et al. designed the experimental process of preparing polymeric aluminum ferric silicate PEASS from coal gangue, and discovered that the PFASS flocculant from coal gangue had the best effect on oil-field sewage after comparing with other flocculants. So, it is significant to adopt reasonable green and low-carbon technology to recycle solid waste, reduce ecological environmental pollution and achieve sustainable development. However, the processing technology of coal gangue is often limited by the input cost and the benefits generated, and some utilization directions have practical technical bottlenecks [10]. Therefore, developing a green and low-carbon comprehensive treatment method of coal gangue with low cost, simple operation, good effect has excellent economic and social benefit.

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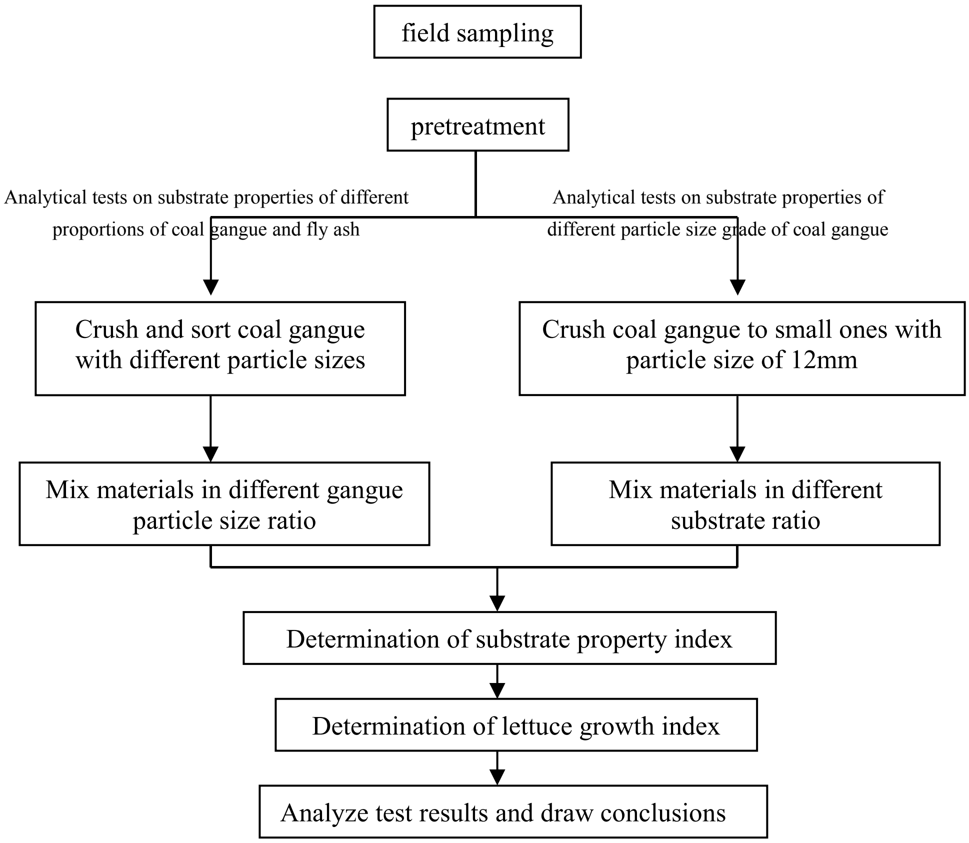
2 Materials and Methods

2.1 Experimental procedure



2.2 Experimental materials

The experiment used gangue, fly ash, straw and soil as the base materials to prepare the composite substrate. The coal gangue was taken from Xiaonan Mine coal gangue mountain of Tiefa Coal Group in Diaobingshan, Liaoning, and the fly ash was taken from Datang Power Plant of Tiefa Group; the corn straw and soil were taken from the farmland of Liuhuangdi Village in Diaobingshan, Liaoning near the coal gangue mountain.

American Dasusheng Lettuce seeds were selected as the test crop. The American Dasusheng lettuce grows fast, with a fertility period of about 45 days, high adaption and strong cold-endurance, and it can be produced annually, making it an ideal variety for protected cultivation and open-field planting in spring and autumn.

2.3 Experimental design

Simulated potted plants were chosen in the experiment. In order to avoid the problems of the low temperature and insufficient light when planting seedlings in laboratory, the experimental site was set in Gaoli greenhouse in Yuhong District, Shenyang.

A pot of 330 mm in length, 230 mm in width and 100 mm in depth was used for the simulation. Lettuce seeds were first placed in a gauze-laid Petri dish, and then placed in a biochemical and thermostatic incubator at 20°C for hydroponic germination after adding a small amount of ultrapure water. After 2 days, 20 germinated seeds were evenly sown in pots containing seven different substrates, and three replicate groups were set for each substrate, covered with about 1-2 cm thickness of substrate and watered thoroughly.

In this experiment, the basic physicochemical properties of the raw material of the substrate were firstly analyzed by conventional agrochemical analysis, and the heavy metal contents in coal gangue and fly ash were measured. The results are showed in Table1 below. The results showed that the heavy metal contents of the raw materials used were in accordance with the agricultural land requirements

Table 1. Basic physicochemical properties of substrate materials and heavy metal content

Raw materials	Coal gangue	Fly ash	Corn straw	soil
pH	8.60	9.42	5.12	8.16
Soil moisture（%）	4.30	0.06	10.62	31.85
Organic matter（g/kg）	71.31	24.24	153.22	69.18
Total N（mg/kg）	759.34	677.81	1408.11	830.91
Alkali-hydrolyzed N（mg/kg）	50.97	25.42	94.80	63.04
Total P（mg/kg）	1787.75	1020.76	7661.05	1322.51
Available P（mg/kg）	13.09	90.48	331.83	78.11
Total K（mg/kg）	630.80	938.96	1072.80	708.24
Available K（mg/kg）	193.97	110.55	3070.85	187.59
Hg（mg/kg）	0.92	0.12		
As（mg/kg）	0.06	0.11		
Pb（mg/kg）	46.68	5.85		
Cd（mg/kg）	0.58	0.21		
Cr（mg/kg）	54.16	30.14		

2.3.1 Analytical tests on substrate properties of different proportions of coal gangue and fly ash

Crush large coal gangue to small ones with particle size of 12mm, crush corn straw to 1mm-5mm, sift soil through a 10 mesh sieve and remove the plant residues, stones and other debris contained in the raw material. Mix the gangue without particle gradation and fly ash in the ratio of 2:1, 3:1, 4:1, 6;1, 8:1, 1:0 with a fixed amount of straw (10%) and soil (40%) to prepare mixed substrates, and record the six different substrates as R1-R6 (where R1 is 33.3% gangue, 16.7% fly ash; R2 is 37.5% gangue, 12.5% fly ash; R3 for 40.0% coal gangue, 10.0% fly ash; R4 for 42.9% coal gangue, 7.1% fly ash; R5 for 44.4% coal gangue, 5.6% fly ash; R6 for 50% coal gangue, 0% fly ash). And set up the farmland soil near the gangue mountain for the control group CK.

2.3.2 Analytical tests on substrate properties of different particle size grade of coal gangue

The coal gangue in the study area is predominantly blocky with particle size larger than 6mm, and the largest particle size is even up to 50-70mm. So planting in such a soil structure is bound to be unsuccessful. Thus it must be crushed first, and then sorted if necessary in response to the requirement of the soil substrate structure where crops grow.

Crush and sort coal gangue by using sieves of different apertures. Then set gangue with particle size less than 3mm as fine particles, 3-6mm as medium particles, greater than 6mm as coarse particles. Fine particles, medium particles, coarse particles of gangue is used as topsoil in the ratio of 8:1:1, 1:1:1, 2:1:2, 2:2:1, 1:3:1, 1:1:3, just to ensure that the total weight of the pots remain unchanged. Record the six different substrates as M1-M6 (where M1 is 80.0% fine particles, 10.0% medium particles, 10.0% coarse particles; M2 is 33.3% fine particles, 33.3% medium particles, 33.3% coarse particles; M3 is 40.0% fine particles, 20.0% medium particles, 40.0% coarse particles; M4 is 40.0% fine particles, 40.0% medium particles, 20.0% coarse particles; M5 is 20.0% fine particles, 60.0% medium particles, 20.0% coarse particles; M6 is 20.0% fine particles, 20.0% medium particles, 60.0% coarse particles). Well mix gangue, fly ash, straw (in the ratio of 4:1:1) and 1kg of quantitative soil as soil substrate, and then conduct potted plant simulation tests. And set up unsorted gangue substrate for the control group CM.

2.4 Analysis method

2.4.1 Determination of substrate property index

Soil physicochemical indicators are related to important properties such as soil nutrients, buffering and water and fertility retention, thus determining soil fertility and soil productivity, So the determination of several physicochemical indicators is important for exploring soil production performance. Take the mixed substrate in pots respectively before and after planting lettuce and put it in two sealed bags. Then label and well store for the determination of pH, organic matter, alkali-hydrolyzed nitrogen, available phosphorus and available potassium in the mixed substrates. The pH was determined directly by pH meter, organic matter by potassium dichromate volumetric method and external heating, alkali-hydrolyzed nitrogen by alkali-hydrolyzed reduction diffusing method, available phosphorus by sodium bicarbonate extraction and molybdenum-antimony resistance colorimetry, and available potassium by ammonium acetate extraction with flame photometer method.

Contents of gangue, fly ash, straw and soil in the mixed substrate were quantitative except for the particle size of gangue, and the nutrient content of the substrate and other chemical characteristics only had slight changes, but the composition of the soil particle size would make a greater difference on the texture and structure and other physical characteristics, thus affecting the growth of crops. Therefore, analytical tests on substrate properties of different particle size grade of coal gangue focused on the determination of physical properties, such as soil bulk density, porosity, and moisture, which reflected the properties of each substrate of different particle grade. In this experiment, soil bulk density was determined by cutting ring method, and soil porosity and moisture were measured based on soil bulk density.

2.4.2 Determination of lettuce growth index

The number of days required for lettuce cotyledons to emerge, for full lettuce seedlings, and the emergence rate of lettuce were recorded during the first two weeks after planting. Select three lettuce plants of each pot as samples. Count the number of leaves per plant. Measure the height and stem thickness (bottom root of the stem) of the plant. Select five leaves of each sample and measure the leaf area with a leaf area meter. Then measure the fresh and dry weights of each lettuce sample with an electronic balance. Finally, the samples were sterilized in an oven at 105°C for 5 min, dried at a constant temperature of 80°C to a constant weight, and weighed with an electronic balance for the dry weight, and take the average value.

3 Results ＆ discussion

3.1 Analysis results of the substrate properties of different ratios of coal gangue and fly ash

3.1.1 The results of the determination of the physicochemical properties of the substrates

The results of the determination of the physicochemical properties of the substrates are shown in Table 2 below.

Table 2. Substrate property indexes in different ratios of coal gangue and fly ash

Group number	pH	Organic matter（g/kg）	Alkali-hydrolyzed N（mg/kg）	Available P（mg/kg）	Available K（mg/kg）
R1	8.18±0.14	66.75±0.81	65.90±1.05	89.29±0.98	420.53±3.22
R2	8.02±0.25	69.71±0.69	67.42±0.93	86.30±1.57	426.06±4.35
R3	7.88±0.16	72.84±0.62	68.38±0.75	84.48±1.34	431.31±3.90
R4	7.67±0.09	75.97±0.58	72.41±0.83	81.35±1.09	438.94±5.86
R5	7.43±0.19	76.09±0.74	73.94±0.76	78.26±0.87	443.25±3.94
R6	7.26±0.20	78.65±0.53	76.15±0.54	76.97±0.96	450.08±6.01
CK	8.16±0.11	69.18±1.03	63.04±0.66	78.11±1.31	187.59±2.06

The results showed that in the experiment of soil substrate with different ratios of coal gangue and fly ash, with the increase of the proportion of coal gangue, the pH value of the substrate was gradually decreasing, which was due to the reduction of the content of alkaline material-fly ash; compared with the second national soil census grading standards, soil acidity and alkalinity gradually tended to neutral, the pH of R1-R4 were between 7.5-8.5, which was weakly alkaline, the PH of the substrate in R5 and R6 groups was less than 7.5 and neutral.

For organic matter content, in addition to R1 group whose content was less than the control group, the rest of the groups were greater than the control group content, and with the proportion of coal gangue increasing, soil organic matter content also gradually increased, and R6 group content reached a maximum of 78.65g/kg.

Alkali-hydrolyzed nitrogen and available potassium in the substrate increased with the gangue content. But compared the alkaline-hydrolyzed nitrogen content of the substrate and the farmland soil near the gangue mountain, the amount didn’t increase much; Conversely, the available potassium content could reach more than twice that of the control soil group. And the available phosphorus in the substrate decreased while the gangue content increased. According to the second national soil survey and relevant standards, the main nutrient content

of the substrates with different gangue and fly ash different ratio mechanism all reached the first standard (organic matter > 40g/kg, available nitrogen > 0.2mg/kg, available phosphorus > 40mg/kg, available potassium > 200mg/kg). Overall, the contents of organic matter, alkaline-hydrolyzed nitrogen, available phosphorus and available potassium in the compounding substrate were significantly higher than the control group, except for individual groups, which reached the fertility level of fertile soil. Moreover, the value of compounded organic matter reduced on an alkaline basis, which was beneficial to plant growth, so it was completely feasible to grow crops with compounded substrates.

3.1.2 The results of the determination of the growth indexes and biomass of lettuce

The results of the determination of the growth indexes and biomass of lettuce at 40 d in different ratios of coal gangue and fly ash are showed in Figure 1 below.

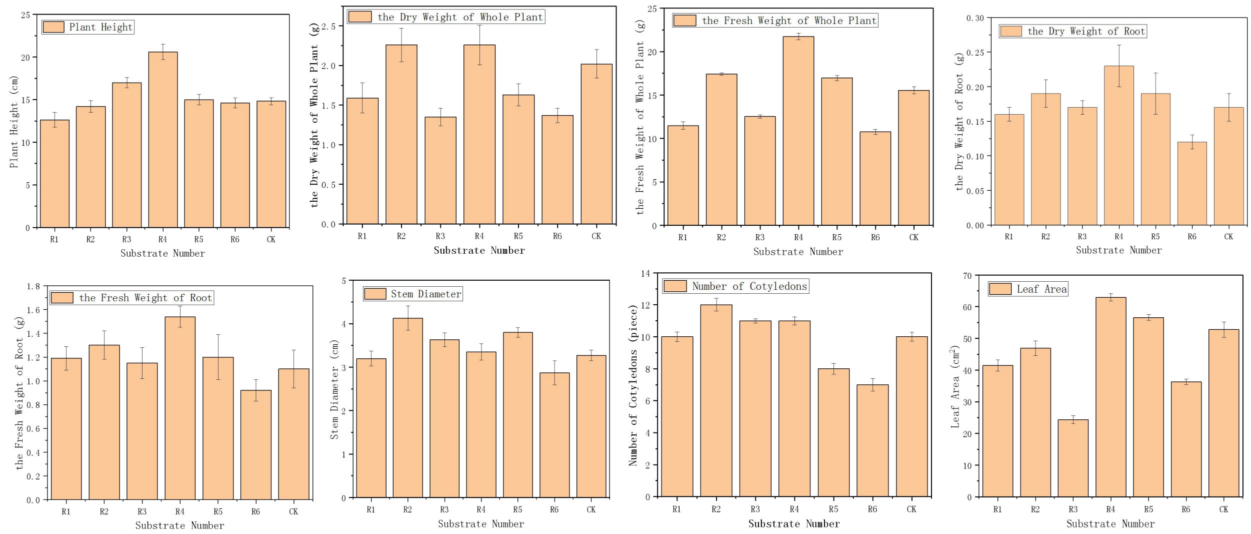


Fig. 1. Growth indexes and biomass of lettuce at 40 d in different ratios of coal gangue and fly ash

By measuring the plant height, stem thickness, leaf area and number of cotyledons of lettuce planted with different content of gangue, it could be seen that with the increase of the proportion of gangue, the stem thickness and leaf area showed two peaks, respectively at R2 and R4(the stem thickness peaked at 4.13cm at R2 and 3.80cm at R4; the leaf area peaked at 46.90cm2 at R2 and 62.90cm2 at R4), and exceeded the control group; the plant height showed one peak at R4 group, reaching 20.60 cm, and exceeded the control group; the number of cotyledons reached a maximum of 12 pieces at R2, and R2, R3, as well as R4 all exceeded the control group. The combined analysis showed that R2 and R4 were more favorable for lettuce growth. To draw further conclusions, parameters such as fresh weight and dry weight of the plants need to be analyzed.

From the results of the determination of the fresh and dry weights of the whole lettuce plant, we could draw conclusions that the fresh and dry weights of the whole plant and roots showed two peaks at R2 and R4(the fresh weight of the whole plant peaked at 17.43g at R2 and 21.74g at R4; the dry weight of the whole plant peaked at 2.26g at R2 and R4,; the root fresh weight peaked for the first time at 1.3g at R2 and reached a maximum of 1.54g at R4; the root dry weight peaked for the first time at 0.19g at R2 and reached a maximum of 0.23g at R4) with the increase of gangue content in the substrate, and R2 and R4 were higher than the control group; for the dry weights of the whole lettuce plant and roots, the values were lower than the control group except for R2 and R4; the growth indexes of R4 group were all the maximum, which indicated that the substrate ratio of R4 group can be best for the lettuce growth.

3.2 Analysis results of the substrate properties of different ratios of coal gangue particle sizes

3.2.1 The results of the determination of the physicochemical properties of the substrates

The physical properties such as substrate capacity, porosity and water holding capacity were measured in this group of tests. The soil capacity and water holding capacity were determined by cutting ring method, and the soil porosity was measured according to the soil capacity. The results are shown in the Table3 below.

Table 3. substrate property indexes in different ratios of gangue particle size

Group number	Soil bulk density （g/cm3）	Field water-holding capacity（%）	Total porosity（%）	Water-holding porosity（%）	Aeration porosity（%）	Air-water ratio
M1	1.46±0.03	32.51±0.96	38.44±0.93	57.91±1.46	18.31±0.81	0.31±0.02
M2	1.28±0.02	24.90±0.73	44.85±1.09	45.06±0.99	43.43±1.19	0.97±0.06
M3	1.21±0.05	26.25±0.83	47.47±1.52	36.30±1.94	42.52±0.98	1.17±0.05
M4	1.30±0.03	27.52±0.87	42.60±0.80	44.21±1.51	39.35±1.37	0.89±0.04
M5	1.23±0.01	23.94±0.91	46.21±1.62	43.15±1.24	44.86±1.41	1.04±0.03
M6	1.15±0.06	22.82±1.14	49.34±1.43	40.95±1.03	56.98±1.16	1.39±0.07
CM	0.97±0.02	22.03±0.95	64.90±0.97	22.48±0.62	58.06±1.26	2.58±0.04

The experimental results showed that the greater the particle size grade of gangue in the substrate, the smaller the bulk density, the smaller field water holding capacity, the larger the field porosity, the larger the air-water ratio, thus the better aeration, the poorer water holding capacity. Conversely, the smaller the particles, the larger the soil bulk density, the larger the field water holding capacity, the smaller the total porosity, the smaller the air-water ratio, thus the better water holding capacity, the poorer aeration.

3.2.2 The results of the determination of the growth indexes and biomass of lettuce

The results of the determination of the growth indexes and biomass of lettuce at 40 d in different ratios of coal gangue and fly ash are showed in Figure 2 below.

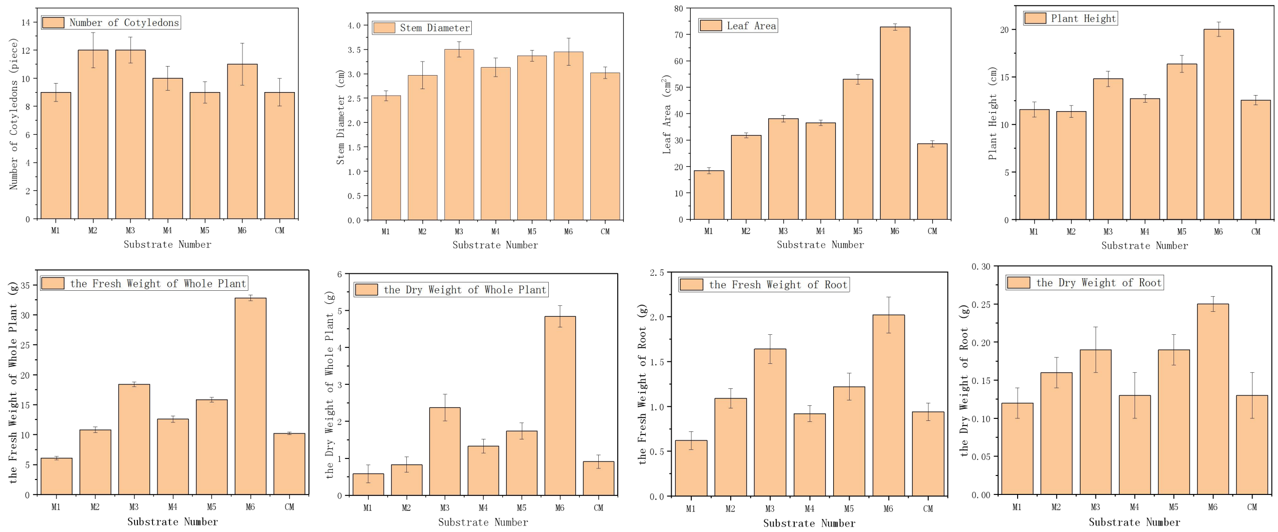


Fig. 2. Growth indexes and biomass of lettuce at 40 d in different particle size ratios

The plant height, stem thickness, leaf area and number of cotyledons of lettuce planted with different particle size compound substrates of coal gangue were measured, and it was found that with the increase of the proportion of coal gangue, the stem thickness, plant height and leaf area showed two peaks at M3 and M6 respectively(the stem thickness peaked at 3.5cm at M3 and 3.45cm at M6; the plant height peaked at14.80cm at M3 and 20.00cm at M6; the leaf area peaked at 38.10cm2 at M3 and 72.80cm2 at M6), and M3 and M6 were higher than the control group, and the plant height and leaf area values of M6 group were significantly higher than the other groups, 20.00 cm and 72.80 cm2 respectively. The number of cotyledons reached the maximum at M2, M3 and M6, and all of them exceeded the control group.

From the determination of the fresh and dry weights of the whole plant and roots, we could draw conclusions that the fresh and dry weights of the whole plant and roots showed two peaks at M3 and M6(the fresh weight of the whole plant peaked at 18.4g at M3 and 32.82g at M6; the dry weight of the whole plant reached a peak of 2.37g at M3 and a maximum of 4.84g at M6; the root fresh weight peaked for the first time at 1.64g at M3 and reached a maximum of 1.64g at M6; the root dry weight peaked for the first time at 0.19g at M3 and reached a maximum of 0.25g at M6), and both M3 and M6 are higher than the control group; the fresh and dry weights of the whole plant and roots were the minimum in the M1 group and the maximum in the M6 group. It indicates that the gangue particle size ratio of M6 group can be best for the growth of lettuce.

4 Conclusions

Lettuce was grown in soil substrates in different ratios of coal gangue, fly ash and in different particle size ratios. Then analyze and evaluate two aspects: the basic physicochemical properties of the substrate and the growth quality of lettuce. Finally select the best ratio for the preparation of improved soil substrate. The main conclusions are as follows:

(1) The alkali-hydrolyzed nitrogen and available potassium content in the substrate in different ratios of coal gangue and fly ash increased with the increase of the proportion of coal gangue, while pH and available phosphorus content decreased; the greater the particle size grade of gangue in the substrate, the smaller the bulk density, the smaller field water holding capacity, the larger the field porosity, the larger the air-water ratio, thus the better aeration, the poorer water holding capacity.

(2) It was feasible to improve the soil substrate of coal gangue mountain by compounding the gangue soil substrate from the different ratios of coal gangue and fly ash as well as the different particle size gradation of coal gangue in two aspects. Lettuce grew better in compounded substrates with the appropriate proportion of gangue and fly ash as well as the gangue particle size than the corresponding control group, and the substrate properties were also better. So the compounded substrate developed in this experiment could improve gangue soil substrate effectively to varying degrees, and was more conducive to lettuce growth.

(3) The test results showed that the best ratio of gangue and fly ash is 6:1; and the best ratio of gangue particle grade is 1:1:3(fine particles: medium particles: coarse particles). Thus we could draw a conclusion that the best ratio of the improved soil substrate of the mine gangue mountain is 42.9% gangue, 7.1% fly ash, 10% straw, 40% soil, where the gangue particle size ratio was 20% fine particles, 20% medium particles, 60% coarse particles .

Acknowledgments

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