Experimental research of substrate materials of tailings reservoir reclamation

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Abstract. In order to accelerate the restoration and utilization of mine wasteland, this paper describes an optimization study on substrate materials. The optimization was based on nine well-planned orthogonal experiments (OA9 matrix). The experimental materials were tailings, turfy soil and sawdust, and the experimental plant was festuca arundinacea. Two contrast tests was carried out in the purpose of finding out the most appropriate substrate for plants growth. Based on the results of the range analysis and analysis of variance (ANOVA), conclusion was obtained that the optimized ratio of the substrate materials is $V_{tailings}$: $V_{turfy\ soil}$: $V_{sawdust}$ =3:1:1. The physicochemical properties of the optimized substrate include pH, bulk density, porosity and water-holding capacity, the value is 6.3, 1.0, 59.9% and 32.7% respectively. Festuca arundinacea grew well in this substrate, emergence rate was 62%, survival rate was 52%, aboveground biomass was 19.71g and plant height was 25.54cm.

Introduction

With the sustainable development of economy, the status and role of mining industries have been continuously improved. Mineral resources exploitation has greatly promoted the development of the national economy. Meanwhile, it also leads to serious environmental problems[1]. Mining activities occupy and destroy land resources, and lead to serious soil erosion, which could even lead to serious social problem[2-3]. It is a hard job to restore or regenerate the ecological environment successfully in the mining areas, because the physicochemical properties of tailings vary greatly both among and within tailings ponds[4-5]. Generally speaking, all tailings contain high concentrations of heavy metal, while low concentrations of N, P and organic matter[6]. The ecological environment is seriously destroyed in these mining areas. Traditional restoration measures may destroy the ecological niche which is fragile already[7]. Ecological restoration is a simple and feasible way and is easy to be accepted in engineering. In the process of ecological restoration, the main problem is how to improve and modify the substrate. The term reclamation is used to describe efforts that aim to improve the quality of the land by restoring some pre-disturbance functions. In present times, the studies on substrate materials of ecological reclamation mainly focused on the relationship of vegetation nutrition supply, cultivation technique and the relationship between the substrate utilization, moisture, nutrition and the air. With tailings, turfy soil and sawdust as experimental materials, an orthogonal experiment was carried out in the purpose of finding out the most appropriate substrate for plants growth and providing reference for ecological restoration practices of mining sites.

Experimental details and analytical methods

Substrate materials. Tailings: provided by Hunan east An Xinlong Mining Limited Liability Company. The pH is 6.5, weak acid. Dry density is 1.47 g/cm^2, tested by loose method, specific gravity is 2.72. Turfy soil and sawdust were also used for the experiments.

Experimental plant and Mix substrate materials. Festuca arundinacea, provided by the lawn base of Wuhan, was used for experiments in this research, the purity is 96% and the germination rate is 85%. Festuca arundinacea belongs to gramineae and it can resist to drought and salinity and grows well in the range of pH4.7-9.5.According to substrate materials compositions table, put the sufficiently mixed substrate into flowerpots. Uniformly sowed 1g (thousand-seed weight is 2.52g) festuca arundinacea seeds in every flowerpot, after finishing this, covered substrate about 2cm at the top. Watered the seed until the substrate in the flowerpot was saturated, no fertilizer. Festuca arundinacea seeds were sowed on April 10th and germinated on April 16th, the emergence number tended to be constant after April 25th.

Orthogonal array experimental design. In this research, the experiments were based on an orthogonal array experimental design (OA9 matrix) in which the following three variables were analyzed: tailings (factor A), turfy soil (factor B) and sawdust (factor C). Nine trials were carried out according to the OA9 matrix to complete the optimization process. Every row of orthogonal array represents a substrate composition, which is a specific set of factor levels to be tested. The order of the trails was randomized to avoid any personal of subjective bias. In principle, one column can be assigned to one factor. There are three factors in this study, each with three levels. The extra column here could be used to record the error and indicate the reliability of the experiments, any details could be obtained from Table 1 to Table 9. Data analysis was carried out with the range analysis and analysis of variance (ANOVA) to reflect the optimal conditions and their influence magnitudes[8].

Table 1 levels and factors affecting substrate

level	factors		
	tailings(L)	Turfy soil(L)	Sawdust(L)
1	3	1	1
2	4	2	2
3	5	3	3

Table 2 substrate materials compositions

trial No.	factor		
	A(tailings)L	B(turfy soil) L	C(sawdust) L
1	A_1(3)	B_1(1)	C_1(1)
2	A_1(3)	B_2(2)	C_2(2)
3	A_1(3)	B_3(3)	C_3(3)
4	A_2(4)	B_1(1)	C_2(2)
5	A_2(4)	B_2(2)	C_3(3)
6	A_2(4)	B_3(3)	C_1(1)
7	A_3(5)	B_1(1)	C_3(3)
8	A_3(5)	B_2(2)	C_1(1)
9	A_3(5)	B_3(3)	C_2(2)

Experimental results and analysis

Substrate physicochemical properties. Bulk density was measured by ring-cutting method, porosity value was got from the empirical formula: P%=93.974－32.995D. In this formula, D presents bulk density measured by ring-cutting method and the range of error is ±0.75. Porosity and water-holding capacity were measured by ordinary method and the pH was measured with pH meter.

Table 3 physicochemical properties of substrates

index	trail No.								
	1	2	3	4	5	6	7	8	9
pH	6.3	6.1	5.9	6.3	6.3	6.0	6.5	6.0	5.9
BD	1.0	0.9	0.8	1.0	0.9	0.9	1.02	1.0	1.0
P	59.9	63.5	65.5	58.9	61.9	61.2	60.2	58.3	60.6
WHC	32.7	42.6	54.8	29.8	40.3	42.8	31.0	34.1	36.2

Table 3 shows that substrate are weak acid. The range pH that most plants need varies from 4.0 to 9.0, so all the substrates are suitable for most plants to grow. There is no significant difference among these porosities. There is big difference among the water-holding capacity of the substrates, which is in the range of 24%-54.8%. The significant influence factor is turfy soil, higher turfy soil ratio in the substrate materials compositions makes greater water-holding capacity.

Plant growth observation index analysis.

Table 4 plant index

index	trail No.								
	1	2	3	4	5	6	7	8	9
ER	62	58	54	51	48	45	41	45	43
SR	52	37	30	41	33	29	38	31	24
AB	19.7	12.9	8.6	16.0	10.2	7.9	11.9	9.7	6.6
PH	25.5	23.7	20.2	19.5	14.8	24.1	18.1	23.1	23.8

As is shown in Table 4, the highest values of emergence rate, survival rate, above-ground biomass and plant height are 62%, 52%, 19.7g, 25.5cm respectively. According to intuitive analysis, the optimal substrate is obtained from number 1, that is $A_1B_1C_1$ ($V_{tailings}$: $V_{turfy\ soil}$: $V_{sawdust}$ =3:1:1), followed by substrate number 4 ($V_{tailings}$: $V_{turfy\ soil}$: $V_{sawdust}$ =4:1:2).

Mine tailings represent a source of toxic pollutants, mainly heavy metals[9], which have deadly impacts on plant growth. Therefore higher tailings substrate inhabited plant growing normally, especially survival rate, aboveground biomass and plant height. Because the seeds germinate mainly rely on organic matters, appropriate temperature, moisture and oxygen.

Range analysis. There are two important parameters in the range analysis: K_{ij} and R_j. K_{ij} is the sum of the evaluation indexes of all of the levels (i=1, 2, 3) in each factor (j=A, B, C). R_j, which is used for evaluating the importance of the factors, is defined as the range between the maximum and minimum value of $\overline{K_{ij}}$[10].

Table 5 range analysis data

item	ER			SR			AB			PH		
	A	B	C	A	B	C	A	B	C	A	B	C
$\overline{K_1}$	58	51	51	40	44	37	13.	15.8	12.4	23.1	21.0	24.2
$\overline{K_2}$	48	50	51	34	34	34	11.4	11.0	11.9	19.5	20.5	22.3
$\overline{K_3}$	43	47	48	31	28	34	9.4	7.7	10.2	21.7	22.7	17.7
R	15	4	3	9	16	3	4.1	8.1	2.1	3.6	2.1	6.5
OL	A_1	B_1	C_1	A_1	B_1	C_1	A_1	B_1	C_1	A_1	B_3	C_1

Table 5 shows that the factors have a different effect on emergence rate, the factors' levels of significance are as follows: A > B = C, which means that turfy soil and sawdust have the same significant influence on emergence rate, while the most significant influence factor is tailings. The factor B has the highest influence on survival rate and above-ground biomass, followed by factor A, and factor C has the lowest influence on the two indexes. Factor C has the highest effect on plant height, followed by factor A, and factor B has the lowest influence on plant height.

Analysis of variance (ANOVA). The ANOVA results for plant growth are shown in Table 6-9. As mentioned above, MS_j was compared with MS_e before the calculation of the F_j to increase the reliability of the F-test. If the variance MS_j is less than twofold that of the MS_e, this means that the factor effect of sawdust is very small. To increase the reliability of this statistical method (ANOVA), the sum of squared deviation (SS_j), degree of freedom (df_j) and the variance (MS_j) should be added to the sum of squared deviation (SS_e), degree of freedom (df_e) and the variance for the experimental error (MS_e) factors respectively, and the factor effect should be regarded as the experimental error. As for the inspection level, α=0.05, α=0.1,the critical value can be found in the distribution table of the F-value: $F_{0.05}$ (2, 2) = 19.0, $F_{0.1}$ (2, 2) = 9.0. In Table 6, it is clear that F_A > $F_{0.05}$ (2, 2), F_B < $F_{0.1}$

(2, 2), $F_C < F_{0.1}$ (2, 2). When comparing F_j and Fα, the F value obtained in ANOVA was higher than the listed F_α, this shows that the tailings is the prominent factor affecting emergence rate. In Table 7, it is clear that $F_{0.1}$ (2, 2) < F_A< $F_{0.05}$ (2, 2), F_B > $F_{0.05}$ (2, 2), F_C < $F_{0.1}$ (2, 2), this means that tailings and turfy soil are the prominent factors affecting the survival rate. In Table 8, it is clear that $F_{0.1}$ (2, 2) < F_A < $F_{0.05}$ (2, 2), F_B > $F_{0.05}$ (2, 2), F_C < $F_{0.1}$ (2, 2), this shows that tailings and turfy soil are the prominent factors affecting the above-ground biomass. In Table 9, it is clear that F_A < $F_{0.1}$ (2, 2), F_B < $F_{0.1}$ (2, 2), F_C > $F_{0.05}$ (2, 2), this means that sawdust is the prominent factor affecting the plant height. It can be deduced that the most important contribution to the plant growth is factor A (tailings), followed by factor B (turfy soil), and lastly, factor C (sawdust).

Table 6 analysis of variance for emergence rate

sources	*SS*	*DF*	*MS*	*F*
A	350.1	2	175.0	25.3
B	26.1	2	13.0	1.8
C	18.1	2	9.0	1.3
random error	13.8	2	6.9	
sum	408.1	8		

Table 7 analysis of variance for survival rate

sources	*SS*	*DF*	*MS*	*F*
A	114.7	2	57.3	13.3
B	392.0	2	196.0	45.4
C	24.6	2	12.3	2.8
random error	8.6	2	4.31	
sum	539.9	8		

Table 8 analysis of variance for above-ground biomass

sources	*SS*	*DF*	*MS*	*F*
A	28.0	2	14.0	11.0
B	100.4	2	50.2	39.5
C	7.7	2	3.8	3.0
random error	2.5	2	1.2	
sum	138.6	8		

Table 9 analysis of variance of plant height

sources	*SS*	*DF*	*MS*	*F*
A	20.3	2	10.1	7.8
B	7.7	2	3.8	3.0
C	66.3	2	33.1	25.7
random error	2.5	2	1.2	
sum	96.8	8		

Conclusions

A sufficient amount of trufy soil is required for plant growth, but an excessive amount of turfy soil make plant have a low emergence rate and survival rate. Although the physicochemical properties of the rest substrates can basically meet the demands of plant growth, the optimal substrate material ratio is $V_{tailings}$: $V_{turfy\ soil}$: $V_{sawdust}$ =3:1:1 obtained through analysis and ANOVA analysis. The order of significant influence of all the factors on plant growth is turfy soil, followed by sawdust and the last is tailings.

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