Analysis on the Difference of Reconstructed Soil Moisture Content in a Grassland Open-Pit Mining Area of China

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Abstract: To reveal the variability of different reconstructed soil ratios and different vegetation growth grades on the water holding capacity of recon-structured soil, the most suitable ratio of reconstructed soil materials was explored. Taking the inner dump of Shengli mining area in Inner Mongolia of China as the research area, the reconstructed soil of reclaimed land was investigated and sampled. One-way analysis of variance was used to analyze the difference of the moisture content of the reconstructed soil, and the reasons for the difference were discussed. The results showed that: (1) Among the different soil reconstructions, soil moisture content was higher when soil reconstructions were rock and soil stripping material: coal gangue: fly ash = 3:4:3. The soil moisture content of un-reclaimed land was mostly at a high level when the soil reconstruction method was rock and soil stripping material; and the soil moisture content was not at the highest level when the vegetation growth grade was higher. This indicates that it was not the case that the better the vegetation growth condition was, the higher the soil moisture content was. (2) In the case where the soil reconstruction method was rock and soil stripping material: coal gangue: fly ash = 3:4:3, the soil moisture content of the reclaimed land decreased with the reduction of tillage frequency when the vegetation growth condition was optimal (vegetation growth grade was 4). (3) In the case where the soil reconstruction method was rock and soil stripping material: coal gangue: fly ash = 3:4:3, when the vegetation growth condition was better (vegetation growth grade was 3 and 4), the soil moisture content of the reclaimed land was highest when it was tilled once every 15 days. It was also found in combination with other soil reconstruction methods that it was not always the case that the higher the frequency of tillage, the higher the soil moisture content. The study of coal gangue, fly ash and rocky soil stripping as topsoil substitute materials with their different ratios on reconstructed soil provides support for the reclamation work in topsoil scarce mines and provides technical reference for the ecological restoration project of grassland open-pit mines in the same climate zone.

Keywords: land reclamation; ecological restoration; topsoil substitute materials; soil moisture content; grassland mining area

1. Introduction

Coal resources have always been in the main position in global energy, and the degree of global mining of coal resources has been gradually increasing in recent years [1]. The total global coal production in 2019 was 8.129 billion t, up 0.50% compared with 2018 [2]. China is the largest coal producer and consumer in the world, accounting for 47.30% of the total global coal production in 2019 [2]. Open-pit coal mining is the main mining method in the world, and the proportion of open-pit coal mining in several other major coal mining countries (USA, Russia, India, etc.) except China is basically above 50%. Some countries reach more than 90%, and the proportion of open-pit coal mining in China has also increased from 4% to 15% [3,4]. While the large-scale mining of open-pit coal mines
meets the needs of China’s economic construction, it also causes many ecological and social problems [5–7]. China’s National 12th Five-Year Plan states that it will promote the development of diversified and clean energy sources, vigorously develop a circular economy, enable the effective reduction and resource utilization of solid waste from industrial and mining enterprises, reduce and control pollutant emissions, reduce resource waste, increase the proportion of non-fossil energy consumption in primary energy, and create an environmentally friendly and resource-saving society [8].

Soil reconstruction is the core of land reclamation [9], and the quality of reconstructed soil directly determines the state of land reclamation. Topsoil is the primary choice in the process of soil reconstruction [10], but natural factors such as poorly developed soil in mining areas, and human factors such as mining activities, have led to serious problems of topsoil scarcity in many mining areas [11–13]. In topsoil-scarce mining areas, the selection of topsoil substitute materials is the key to the soil reconstruction process. Topsoil substitute materials effectively solve the problem of topsoil scarcity in the soil reconstruction process, and at the same time realize the resource utilization of solid waste in mining areas [3]. Mining has caused a series of ecological and environmental problems such as vegetation destruction, land degradation, and water and soil erosion in mining areas, and effective measures for ecological restoration are urgently needed. The basis of ecological restoration is soil, and the key is soil water, which restricts the function and evolution of the ecosystem and is related to the success or failure of ecological restoration [14]. Soil water is an extremely dilute solution that plays an important role in the formation and maturation of soil (such as the weathering of minerals, the synthesis and decomposition of organic matter). It is directly available for crop uptake and utilization on the one hand, and influences other fertility factors and tilth, such as root conditions, nutrient supply, aeration, and the level of ground temperature, while the water required during the life of the crop is almost entirely drawn from the soil [15].

Coal gangue is the solid waste with hard texture and low carbon content produced along with the coal mining and coal washing process. China’s coal production is large, but the utilization rate of coal gangue is low, and a large amount of coal gangue is piled up nearby to form a coal gangue mountain. The large amount of toxic heavy metals contained in the coal gangue can pose a serious threat to soil and groundwater [16], and its spontaneous combustion produces a large number of harmful gases and dust that seriously affect air quality [15,17,18]. Coal gangue has more large pores, which provides easy flow channels for moisture and gases, but also causes poor water-holding properties, which will affect the supply of groundwater to soil moisture for a long time, and then affect the growth of plants [19–21]. China is a large coal-burning country with high fly ash production and high ecological and environmental pressure. The utilization of fly ash not only helps to reduce environmental pollution but also promotes the improvement of soil fertility [15]. Fly ash has a small particle size, a high clay particle content, and excellent water absorption and water holding capacity, which can be used as a topsoil substitute material in the reclamation process of open-pit mines [22]. The mixture of coal gangue-fly ash as the topsoil substitute material, on the one hand, compared with the simple fly ash filling mode, this mode due to the presence of coal gangue greatly increases the water permeability and air permeability of reconstructed soil, avoiding the excessive moisture content and poor air permeability caused by fly ash filling; on the other hand, compared with the simple coal gangue filling mode, this mode can effectively increase the moisture content of reconstructed soil surface due to the poor permeability of fly ash, and at the same time make up for the defect of poor water supply to the surface soil by groundwater in the gangue filling mode, which provides normal water for plant roots [14]. It has been shown that fly ash mixed with coal gangue in a certain proportion can provide good field water holding capacity for the soil, and fly ash mixed with coal gangue as reconstructed soil has a greater improvement on soil moisture content [23]. Meanwhile, the use of coal gangue for soil profile reconstruction effectively promotes the intensive use of land and the sustainable development of the ecological environment [14]. Current research shows
that coal gangue can be used as a filling material for soil reconstruction applied in the ecological restoration of mining areas, but influenced by coal gangue material ratios, etc. This paper investigates the differences in moisture content of different reconstructed soils in the context of different soil tillage number and different vegetation growth grades.

In this study, based on the fact that solid waste from mining areas can be used as topsoil substitute materials, the differences in moisture content of reconstructed soil under different ratios of topsoil substitute materials are studied in combination with different soil tillage number and different vegetation growth grades, and the optimal ratio of topsoil substitute materials for mining areas is obtained, which is conducive to the improvement of vegetation growth in topsoil-scarce mining areas and provides technical support for the land reclamation work in mining areas at home and abroad in the future. In this paper, we selected the reclaimed land of reconstructed soil of NERC’s Beidian Shengli open-pit coal mine in Inner Mongolia, China, where topsoil is scarce and the climate is arid, and explored the differences in moisture content of reconstructed soil under different ratios of topsoil substitute materials and different vegetation growth grades, and discussed the reasons for the differences. This study aims to provide a theoretical reference for land reclamation in topsoil-scarce mining areas and a practical reference for the selection of the optimal ratio of topsoil substitute materials for soil reconstruction in mining areas.

2. Overview of the Study Area

The No.1 open-pit coal mine of Beidian Victory Mine is located in the northeastern part of Inner Mongolia Plateau, deep inland, in the northwest of Xilinhot City, Xilingole League, Inner Mongolia, within the Yillet Sumu, geographically located at 43°57′–44°14′ N, 115°30′–116°26′ E, as shown in Figure 1. The surface is 6.84 km long from east to west and 5.43 km wide from north to south, with a coal-bearing area of 37.14 km²; a geological reserve of 1934.43 t, a mineable geological reserve of 1854.79 t, and an average stripping rate of 2.59 m³·t⁻¹. The entire mine area is relatively flat terrain and belongs to the temperate semi-arid continental monsoon climate zone, with an average annual temperature of 1.7 °C, annual precipitation of 294.74 mm and average annual evaporation of 1794.40 mm, which is a typical grassland zonal vegetation-type area. At present, the soil type of this mine area mainly consists of chestnut soil, meadow chestnut soil and meadow soil. In some areas, sandy and gravelly chestnut soil is formed due to grassland degradation, and the vegetation coverage rate is low, forming an ecologically fragile grassland area with strong erosion. In 2019, effective land reclamation and vegetation reconstruction were carried out in the soil area of the inner dump reconstruction in the mining area. The natural plant composition consists of Stipa krylovii Roshev, Stipa grandis P.A. Smirn., Cleistogenes squarrosa (Trin.) Keng, Artemisia frigida Willd., Leymus chinensis (Trin.) Tzvel., Agropyron cristatum (L.) Gaertn., Caragana sinica (Buc'hoz) Rehder, etc. The pioneer vegetation of artificial reclamation and revegetation was Medicago sativa L.
Figure 1. Overview of the study area.

3. Materials and Methods

Three different reconstruction methods were used to reconstruct the soil in the inner dump in the mine. The first: the surface layer of 50 cm rocky soil stripping, below all natural accumulation of mining stripping. The second is a mixture of rocky soil stripping and coal gangue with a surface layer of 50 cm and a ratio of 2:3, below all natural accumulation of mining stripping. The third is a mixture of rocky soil stripping, coal gangue and fly ash with a surface layer of 50 cm, with a ratio of 3:4:3, below all natural accumulation of mining stripping. Each reconstruction method constitutes a small field block, and three small fields formed by three different reconstruction methods constitute a large field block, totaling four large fields.

The background values of reconstructed soil materials are shown in Table 1 below. The soil chemical properties of the test samples were determined via The Beijing Research Center for Agricultural Standards and Testing, where the organic matter content was determined by a volumetric method of K₂Cr₂O₇ heating using an electric sand bath [24]. The total nitrogen content was determined using an automatic nitrogen analyzer [25], the available phosphorus content was determined by the Olsen method [26], the available potassium content was extracted by a CH₃COONH₄ solution and determined by a flame photometer [27]. Soil texture classification was performed according to the American classification standard, i.e. [28], the three vertices of the equilateral triangle represent 100% sand (particle size > 0.05–2 mm), silty (particle size 0.002–0.05 mm) and clay (particle size < 0.002 mm), respectively.
Table 1. Reconstruction of soil material background values.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Organic Matter (g·kg⁻¹)</th>
<th>Total Nitrogen (g·kg⁻¹)</th>
<th>Available Phosphorus (mg·kg⁻¹)</th>
<th>Available Potassium (mg·kg⁻¹)</th>
<th>Texture/Particle Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil</td>
<td>35.4 ± 7.4</td>
<td>2.0 ± 0.5</td>
<td>5.30 ± 2.17</td>
<td>133.00 ± 54.30</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Coal gangue</td>
<td>43.9 ± 34.0</td>
<td>0.7 ± 0.4</td>
<td>2.63 ± 1.01</td>
<td>145.83 ± 92.83</td>
<td>2–5 cm</td>
</tr>
<tr>
<td>Fly ash</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rock and soil stripping material</td>
<td>18.8 ± 5.1</td>
<td>0.9 ± 0.3</td>
<td>1.83 ± 0.86</td>
<td>50.97 ± 15.43</td>
<td>Sandy clay loam</td>
</tr>
</tbody>
</table>

Note: fly ash is a by-product of coal combustion. After combustion, it mostly retains some chemical elements, such as Si, Al, etc., and the nutritional elements are mainly trace elements, such as As, Mn, etc.

3.1. Sample Collection and Processing

Sample plots were surveyed and sampled (ring knife method) in August 2019 for four large fields and un-reclaimed land in the reclaimed area of the inner dump after reclamation that year (located in the northern part of the test field for this sampling, which consisted mainly of rock and soil stripping material from mining and was used as a control sample plot). The maturation treatments for the four large plots were as follows: Plot 1 was tilled once every 15 days, tilled for one year and planted with Medicago sativa L., and at the end of the year the Medicago sativa L. was tilled into the soil and replanted with Medicago sativa L. for one year. Plot 2 was tilled once every 30 days, tilled for one year and planted with Medicago sativa L., and at the end of the year the Medicago sativa L. was tilled into the soil and replanted with Medicago sativa L. for one year. Plot 3 was tilled once every 60 days, tilled for one year and planted with Medicago sativa L., and at the end of the year the Medicago sativa L. was tilled into the soil and replanted with Medicago sativa L. for one year. Plot 4 was tilled and planted with Medicago sativa L. in the same year, and at the end of the year, the Medicago sativa L. was tilled to the soil and replanted with Medicago sativa L. for one year. The sample area at the time of sampling was one year after the tillage treatment and planted with Medicago sativa L., and the Medicago sativa L. had grown out by then. The vertical sections of the soil reconstruction program and the maturation treatment for the four large plots are shown in the figure below. In order to make the selected points in the sample plots represent different levels of vegetation recovery, a qualitative grading of vegetation growth was carried out in the sampled plots, and the actual qualitative grading was carried out in three different reconstructed plots, considering the variability of the overall level of vegetation recovery in different reconstructed plots. In each small field plot, 12 sample points were set on the representative plots based on the line transect method, and the vegetation restoration level was defined as 1, 2, 3, and 4 grades from excellent to poor according to the vegetation growth, and 3 soil sample points were set under each grade with a sampling depth of 20 cm, and the soil samples collected from the 3 sample points were mixed. The plan view of the study area is shown in Figure 2A, where each small field block has an area of approximately 15,180 m². The vertical section of soil reconstruction scheme and maturation treatments of field is shown in Figure 2B.
3.2. Data Determination

Soil moisture content was determined by the drying method.

Soil moisture content calculation formula:

\[ X = \frac{m_1 - m_2}{m_2} \times 100 \]

where: \( X \) is the soil moisture content (%); \( m_1 \) is the mass of wet soil sample (g); \( m_2 \) is the mass of dry soil sample (g).

3.3. Data Analysis

The experimental data were analyzed by one-way ANOVA (\( p < 0.05 \)) when the data met the normality test and the data were chi-squared in SPSS 22.0 (IBM SPSS Statistics, Chicago, IL, USA), otherwise the non-parametric test was applied for analysis. The data were calculated using the mean values of three replicate tests.

The first small field block of the first large field of the reclaimed land was denoted as 1-1, the second small field block of the first large field of the reclaimed land was denoted as 1-2, and so on for naming different fields of the reclaimed land.

4. Results

4.1. Differences in the Soil Moisture Content under Different Soil Reconstruction Ways

When the vegetation growth grade is 1, the difference of soil moisture content under different soil reconstruction methods is shown in Figure 3. When tilled once in 15 days, the soil moisture content of un-reclaimed land was the highest at 12.29%, and there was no significant difference between it and reclaimed land 1-1, 1-2 and 1-3 (Figure 3A). When tilled once in 30 days, the soil moisture content of reclaimed land 2-3 was the highest at 14.16%, which was significantly higher than that of reclaimed land 2-2, with a higher percentage of 113.69%; there was no significant difference between reclaimed land 2-3 and un-reclaimed land, but reclaimed land 2-3 was 15.19% higher than un-reclaimed land (Figure 3B). When tilled once in 60 days, the soil moisture content of reclaimed land 3-3 was the highest at 13.15%, but there was no significant difference between reclaimed land 3-1, 3-2 and un-reclaimed land (Figure 3C). When planted Medicago sativa L. in the same year after tillage treatment, the soil moisture content of reclaimed land 4-3 was the highest at 15.36%, which was significantly higher than that of reclaimed land 4-2, with a higher percentage of 64.56%; there was no significant difference between reclaimed land 4-3 and un-reclaimed land, but reclaimed land 4-3 was 24.96% higher than that of un-reclaimed land (Figure 3D).

In summary, under the vegetation growth grade of 1, when the soil reconstruction was rock and soil stripping material: coal gangue: fly ash = 3:4:3, the soil moisture content of reconstructed soil was mostly at a higher level under different tillage treatments.
Figure 3. Difference of soil moisture content under different soil reconstruction modes when vegetation growth grade is 1. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting *Medicago sativa* L. in the same year after tillage treatment. Un-reclaimed land is replaced by “un”, the same as below. Different letters indicate significant difference.

When the vegetation growth grade is 2, the difference of soil moisture content under different soil reconstruction methods is shown in Figure 4. When tilled once in 15 days, the soil moisture content of un-reclaimed land was the highest at 12.29%, followed by reclaimed land 1-3 at 11.97%, with no significant difference among the plots (Figure 4A). When tilled once in 30 days, the soil moisture content of reclaimed land 2-2 was the highest at 13.12%, followed by reclaimed land 2-3 at 12.90%, with no significant difference among the plots (Figure 4B). When tilled once in 60 days, the soil moisture content of un-reclaimed land was the highest, and there was no significant difference among the plots (Figure 4C). The soil moisture content of the un-reclaimed land was the highest when planted *Medicago sativa* L. in the same year after tillage treatment, which was significantly higher than that of the reclaimed land 4-2, with a percentage of 38.48%; there was no significant difference between the un-reclaimed land and the reclaimed land 4-1 and 4-3 (Figure 4D).

In summary, the soil moisture content of un-reclaimed land was mostly higher than that of reclaimed land under different reconstructions when the vegetation growth grade was 2.
Figure 4. Difference in soil moisture content under different soil reconstruction modes when vegetation growth grade is 2. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting *Medicago sativa* L. in the same year after tillage treatment. Different letters indicate significant difference.

When the vegetation growth grade is 3, the difference in soil moisture content under different soil reconstruction methods is shown in Figure 5. When tilled once in 15 days, the soil moisture content of reclaimed land 1-3 was the highest at 17.59%, which was significantly higher than that of reclaimed land 1-2, with a higher percentage of 261.06%; there was no significant difference between reclaimed land 1-3 and unreclaimed land, but it was 43.12% higher than that of unreclaimed land (Figure 5A). When tilled once in 30 days, the soil moisture content of reclaimed land 2-3 was the highest at 13.39%, which was not significantly different from any other sample plots, but reclaimed land 2-3 was 8.95% higher than un-reclaimed land (Figure 5B). When tilled once in 60 days, the soil moisture content of reclaimed land 3-3 was the highest at 14.40%, and there was no significant difference between it and reclaimed land 3-1, 3-2 and un-reclaimed land, but its soil moisture content was 17.15% higher than that of un-reclaimed land (Figure 5C). The soil moisture content of reclaimed land 4-2 had the highest soil moisture content of 14.96% when *Medicago sativa* L. was planted in the same year after tillage treatment, and there was no significant difference between it and reclaimed land 4-1, 4-3 and un-reclaimed land, but its soil moisture content was 21.71% higher than that of un-reclaimed land (Figure 5D).

In summary, under the vegetation growth grade of 3, when the soil reconstruction method was rock and soil stripping material: coal gangue: fly ash = 3:4:3, the soil moisture content of reconstructed soil was mostly at a higher level under different tillage treatments.
When the vegetation growth grade is 4, the difference in soil moisture content under different soil reconstruction methods is shown in Figure 6. When tilled once in 15 days, the soil moisture content of reclaimed land 1-3 was the highest at 15.11%, which was 22.93% higher than that of un-reclaimed land (Figure 6A). When tilled once in 30 days or 60 days, the soil moisture content of un-reclaimed land was highest, followed by reclaimed land with soil reconstruction of rock and soil stripping material: coal gangue: fly ash = 3:4:3, and there was no significant difference among the plots (Figure 6B,C). When *Medicago sativa* L. was planted in the same year after tillage treatment, the soil moisture content of reclaimed land 4-2 was the highest at 14.09%, which was 14.65% higher than that of un-reclaimed land (Figure 6D).

In summary, under the vegetation growth grade of 4, the soil moisture content of the reconstructed soil was mostly at a high level under different tillage treatments when the soil reconstruction was rock and soil stripping material: coal gangue: fly ash = 3:4:3.

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**Figure 5.** Difference in soil moisture content under different soil reconstruction modes when vegetation growth grade is 3. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting *Medicago sativa* L. in the same year after tillage treatment. Different letters indicate significant difference.

**Figure 6.** Difference in soil moisture content under different soil reconstruction modes when vegetation growth grade is 4. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting *Medicago sativa* L. in the same year after tillage treatment. Different letters indicate significant difference.
4.2. Differences in the Soil Moisture Content under Different Vegetation Growth Grades

When the soil reconstruction method is rock and soil stripping material, the difference of soil moisture content under different soil reconstruction methods is shown in Figure 7. When tilled once in 15 days, the soil moisture content of the un-reclaimed land was highest at 12.29%, which was significantly higher than the soil moisture content when the vegetation growth grade was 4, with a higher percentage of 62.41% (Figure 7A). When tilled once in 30 days, the soil moisture content of the un-reclaimed area was the highest, which was significantly higher than the soil moisture content when the vegetation growth grade was 3, with a higher percentage of 95.36% (Figure 7B). When tilled once in 60 days, the soil moisture content of the vegetation growth grade 1 was the highest at 12.78%, it was not significantly different from that of the vegetation growth grade 2, 3, 4 and the un-reclaimed area (Figure 7C). The soil moisture content of the un-reclaimed land was the highest when Medicago sativa L. was planted in the same year after tillage treatment, and was significantly higher than that of the vegetation growth grade 4, with a higher percentage of 125.22% (Figure 7D).

In summary, the soil moisture content of the un-reclaimed land was mostly at a higher level when the soil reconstruction method was rock and soil stripping material; and the soil moisture content was not at the highest level when the vegetation growth grade was higher. This indicates that it was not the case that the higher the soil moisture content was, the better the vegetation growth condition was.

![Figure 7](image1.png)

**Figure 7.** Difference in soil moisture content under different vegetation growth grades when soil reconstruction method is rock and soil stripping material. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting Medicago sativa L. in the same year after tillage treatment. Different letters indicate significant difference.

The variability of soil moisture content at different vegetation growth grades when the soil reconfiguration method is rock and soil stripping material: coal gangue = 2:3 is shown in Figure 8. When tilled once in 15 days, the soil moisture content at vegetation growth grade 4 was the highest at 12.68%, and there was no significant difference among the plots (Figure 8A). When tilled once in 30 days, the soil moisture content at vegetation growth grade 2 was the highest at 13.12%, which was significantly higher than that at vegetation growth grade 1, with a higher percentage of 98.00% (Figure 8B). When tilled once in 60 days, the soil moisture content at vegetation growth grade 3 was highest at 13.46%, but there was no significant difference between the plots (Figure 8C). The soil
moisture content at vegetation growth grade 3 was the highest at 14.96% when Medicago sativa L. was planted in the same year after tillage treatment, and there was no significant difference between the plots (Figure 8D).

![Figure 8](image-url)

Figure 8. Difference in soil moisture content under different vegetation growth grades when the soil reconstruction method is rock and soil stripping material: coal gangue = 2:3. (A) tilling once in 15 days, (B) tilling once in 30 days, (C) tilling once in 60 days, and (D) planting Medicago sativa L. in the same year after tillage treatment. Different letters indicate significant difference.

When the soil reconstruction method is rock and soil stripping material: coal gangue: fly ash = 3:4:3, the variability of soil moisture content under different vegetation growth grades is shown in Figure 9. When tilled once in 15 days, the soil moisture content at vegetation growth grade 3 was the highest at 17.59%, and there was no significant difference between the vegetation growth grade was 1, 2, 4 and the un-reclaimed land, but it was 43.12% higher than the un-reclaimed land (Figure 9A). When tilled once in 30 days, the soil moisture content at vegetation growth grade 1 was the highest at 14.16%, and there was no significant difference between the vegetation growth grade was 2, 3, 4 and uncultivated land, but it was 15.19% higher than un-reclaimed land (Figure 9B). When tilled once in 60 days, soil moisture content at vegetation growth grade 3 was the highest at 14.40%, which was significantly higher than vegetation growth grade 2, with a higher percentage of 64.93% (Figure 9C). When Medicago sativa L. was planted in the same year after tillage treatment, the highest soil moisture content was 15.36% at vegetation growth grade 1, which was significantly higher than that of vegetation growth grade 2, 3 and 4, with a percentage of 42.94%, 53.73% and 35.34%, respectively (Figure 9D).
4.3. Differences in the Soil Moisture Content under Different Tillage Number

When the soil reconstruction method is rock and soil stripping material, the variability of soil moisture content of reconstructed soil under different tillage number is shown in Figure 10. When the vegetation growth grade was 1, 2 and 3, there was no significant difference in the soil moisture content under different tillage number, and the soil moisture content of the reconstructed soil is mostly lower than that of the un-reclaimed land (Figure 10A, 10B and 10C). When the vegetation growth grade was 4, the soil moisture content of the un-reclaimed land was the highest at 12.29%, followed by the large field block 2, which soil moisture content was 10.47%, both of which were significantly higher than that of large field block 4, with higher proportions of 125.22% and 91.81%, respectively (Figure 10D).

Figure 10. Difference in soil moisture content under different ripening treatment methods when the soil reconstruction method is rock and soil stripping material. (A) vegetation growth grade 1, (B) vegetation growth grade 2, (C) vegetation growth grade 3, and (D) vegetation growth grade 4. Different letters indicate significant difference.

When the soil reconstruction method is rock and soil stripping material: coal gangue = 2:3, the variability of soil moisture content of reconstructed soil under different tillage number is shown in Figure 11. When the vegetation growth grade was 1, 2 and 4, there was no significant difference in soil moisture content under different tillage number.
(Figure 11A, 11B and 11D). When the vegetation growth grade was 3, the soil moisture content of field block 4 was the highest, 14.96%, which was significantly higher than that of field block 1, with a higher percentage of 207.19% (Figure 11C). When the vegetation growth grade was 4, the highest soil moisture content was 14.09% in field block 4 (Figure 11D).

In summary, the soil moisture content of the reclaimed land decreased with the decrease of tillage frequency when the vegetation growth condition was optimal (vegetation growth grade of 4) under the soil reconstruction method of rock and soil stripping material: coal gangue = 2:3.

![Graphs showing soil moisture content](image)

**Figure 11.** Difference in soil moisture content under different tillage number when the soil reconstruction method is rock and soil stripping material: coal gangue = 2:3. (A) vegetation growth grade 1, (B) vegetation growth grade 2, (C) vegetation growth grade 3, and (D) vegetation growth grade 4. Different letters indicate significant difference.

When the soil reconstruction method is rock and soil stripping material: coal gangue: fly ash = 3:4:3, the variability of reconstructed soil moisture content under different tillage number is shown in Figure 12. When the vegetation growth grade was 2, 3 and 4, there was no significant difference in soil moisture content under different tillage number, but the soil moisture content of large field block 1 was the highest when the vegetation growth grade was 3 and 4 (Figure 12B, 12C and 12D). When the vegetation growth grade was 1, soil moisture content was highest in large field block 4 with 15.36%, which was significantly higher than that in large field block 1 with a percentage of 54.06% (Figure 12A).

In summary, in the case of the soil reconstruction method of rock and soil stripping material: coal gangue: fly ash = 3:4:3, when the vegetation growth condition was better (vegetation growth grade is 3 and 4), the soil moisture content of the reclaimed land was the highest when it was tilled once in 15 days. It was also found in combination with other soil reconstruction methods that it was not always the case that the higher the frequency of tillage, the higher the soil moisture content.
Figure 12. Difference in soil moisture content under different tillage number when soil reconstruction method is rock and soil stripping material: coal gangue: fly ash = 3:4:3. (A) vegetation growth grade 1, (B) vegetation growth grade 2, (C) vegetation growth grade 3, and (D) vegetation growth grade 4. Different letters indicate significant difference.

All the results of the above analysis were collated and summarized, and the main results are shown in Table 2.

Table 2. Effect of different tillage number on soil moisture content for the same soil reconstitution methods (when vegetation growth grade is 4). Different letters indicate significant difference.

<table>
<thead>
<tr>
<th>Soil Moisture Content (%)</th>
<th>Rocky Soil Stripping</th>
<th>Rocky Soil Stripping: Coal Gangue = 2:3</th>
<th>Rocky Soil Stripping: Coal Gangue: Fly Ash = 3:4:3</th>
<th>Unreclaimed Land</th>
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</tr>
<tr>
<td>Tilling once in 15 days</td>
<td>7.57 ± 4.03 ab</td>
<td>12.68 ± 4.92 a</td>
<td>15.11 ± 7.58 a</td>
<td>12.29</td>
</tr>
<tr>
<td>Tilling once in 30 days</td>
<td>10.47 ± 2.91 a</td>
<td>10.02 ± 3.52 a</td>
<td>11.86 ± 1.08 a</td>
<td>12.29</td>
</tr>
<tr>
<td>Tilling once in 60 days</td>
<td>9.67 ± 0.93 ab</td>
<td>9.47 ± 1.87 a</td>
<td>10.43 ± 2.01 a</td>
<td>12.29</td>
</tr>
<tr>
<td>Planting Medicago sativa L. in the same year after tillage treatment</td>
<td>5.46 ± 3.19 b</td>
<td>14.09 ± 4.78 a</td>
<td>11.35 ± 1.69 a</td>
<td>12.29</td>
</tr>
<tr>
<td>Unreclaimed land</td>
<td>12.29 ± 0.85 a</td>
<td>12.29 ± 0.85 a</td>
<td>12.29 ± 0.85 a</td>
<td>12.29</td>
</tr>
<tr>
<td>Average value</td>
<td>9.09</td>
<td>11.71</td>
<td>12.21</td>
<td>12.29</td>
</tr>
</tbody>
</table>

5. Discussion

5.1. Analysis of the Effect of Different Reconstructions on Soil Moisture Content

The mechanism of the effect of coal gangue, fly ash and rock and soil stripping material on soil moisture content is shown in Figure 13. Lima M T et al. [29] showed that the mine dump can be vegetated and their study found that the soil moisture content of the mine dump is similar to that of the native forest fragment. Among the different soil reconstructions, soil moisture content is higher when soil reconstructions are rock and soil stripping material: coal gangue: fly ash = 3:4:3. This has a certain relationship with the characteristics of coal gangue and fly ash itself. The moisture content of coal gangue is low. Although it can maintain a certain amount of moisture, due to the characteristics of larger particles, relatively more large pore content, high ground temperature and easy evaporation, the soil reconstructed by coal gangue has poor water and fertilizer retention capacity and high permeability, which cannot realize the effective supply of groundwater to the
surface soil, and is prone to vertical erosion (nutrient leaching loss and moisture permeation loss), which is detrimental to plant growth [15,23,30]. Fly ash has a rich pore space and a huge specific surface area with small bulk density, and its incorporation into soil can effectively improve soil structure and aeration and permeability properties, resulting in better water absorption and water holding properties [31]. While the SiO2 and Al2O3 contained in fly ash will hydrate with water, which can effectively restrain soil clay composite and reduce the percentage content of clay capillary pores, making its water absorption and holding properties significantly better than those of soil and coal gangue [32-34]. Feng et al. [35] showed that the composition of fly ash particles is mainly sand and coarse powder particles, and their bulk density is only 1/2 to 1/3 of that of soil, which can be used as an improver for clayey acidic soil. It was also found that the addition of fly ash to soils can increase soil moisture content and enhance soil infiltration, thus reducing surface runoff [36,37].

The incorporation of fly ash can increase the saturated moisture content of coal gangue [38]. Some researchers have studied the reclamation of soil with fly ash and coal gangue, and found that the profile of fly ash mixed with coal gangue is more consistent with the moisture content of the soil-filled profile and has more consistent hydraulic properties with soil after mixed filling [36,39]. The mixture of fly ash and coal gangue can change the pore structure of coal gangue and reduce the gas conductivity of coal gangue, and the mixed fly ash to improve the structure of coal gangue can provide a guarantee for the reasonable use of coal gangue, which is important for the optimization of reconstructed soil structure [28].

For the rock and soil-stripping material present in the reconstructed soil, its initial water and fertilizer retention capacity is poor, and its physical structure and moisture content are not conducive to plant growth, but its nutrients are basically suitable for plant growth. With the weathering of rock and soil stripping material, its texture becomes finer and their moisture content increases, which can basically satisfy the water required for vegetation growth [37].

![Diagram](image_url)

**Figure 13.** Mechanism of the effect of coal gangue, fly ash and rock and soil stripping material on soil moisture content.

### 5.2. Analysis of the Effect of Different Tillage Methods and Vegetation Growth Grades on Soil Moisture Content

This study finds that it is not always the case that the higher the frequency of tillage the higher the soil moisture content. Tillage activities change the properties of the surface
soil such as bulk density, organic matter, and non-capillary porosity, which in turn affect the infiltration rate, and the bulk density of reconstructed soil changes when tillage frequency varies. When tillage frequency is low, soil compaction is high, which in turn results in low water infiltration rates [40]. When tillage frequency is high, the reconstructed soil bulk density becomes smaller, which can directly affect the soil fertility. The lower soil bulk density facilitates the circulation of water and air in the soil, improves the infiltration rate of water in the soil, increases the moisture content of the soil profile, and plays a role in water retention [41,42]. However, frequent tillage activities can loosen the topsoil pore structure and lead to serious water loss. Frequent tillage activities will cause the topsoil structure to be destroyed, the soil fines to increase, and the organic matter content to decrease, resulting in poor cementation ability between soil particles, loose texture, and large porosity, which allows water to easily pass through the upper layer of loose soil affecting the soil’s water and soil conservation ability. With the increase of tillage frequency, the content of soil macroaggregates significantly decreases and the content of water-stable macroaggregates also significantly decreases, the erosion resistance of topsoil gradually becomes worse, and the quality of soil gradually decreases, so the tillage frequency of reconstructed soil need not be too high [43].

Vegetation growth conditions are also not better with higher soil moisture content. This may be related to the microtopography and reconstructed soil structure existing in the dump, when small gullies exist in the dump, there may be waterlogging during rainfall, and the soil capacity is expressed as platform > gentle slope > steep slope on different microtopography [44]. Some studies have shown that in practical applications, using only fly ash to fill the land is likely to cause waterlogging on the surface, resulting in poor soil permeability and affecting vegetation growth conditions. Therefore, vegetation growth conditions are not necessarily optimal when the soil moisture content is at its highest [45,46].

5.3. Limitation Analysis of Reconstructed Soil Material Ratios

When using coal gangue for soil reconstruction, the soil moisture content will be affected by the slope position, and the runoff effect of precipitation leads to a gradual increase in water from the top to the bottom of the slope [47]. In a dry climate, the soil after fly ash reconstruction has a strong moisture content, but this strong moisture content also brings certain limitations. When too much fly ash is applied, the moisture content of the whole reclaimed soil profile may be close to the saturated moisture content all year round, which will stunt the growth of plants, and this limitation may exist even in dry years [48]. Therefore, in the process of reconstructed soil leveling in the mine area, it should avoid the existence of gullies as much as possible and adequately plough and level the reclaimed land; at the same time, the content of fly ash should not be too much in the process of reconstructing topsoil-scarce mine soils; otherwise, it may lead to adverse changes in soil pH, increase soil salinity, increase trace element concentrations to toxic levels, and cause nutrient imbalance, etc. [49,50] Fly ash and coal gangue mixed in a certain proportion has the best effect on the improvement of soil field capacity. There are a large number of heavy metal elements in coal gangue, such as Si, Al, Fe, S, Ca, Mg and so on. Due to the high permeability of coal gangue, it is easy to leach heavy metals, and using coal gangue as a filling reclamation substrate will cause groundwater pollution. Therefore, permeability is an important factor to be considered when evaluating the suitability of the substrate as part of the reconstructed soil. Incorporating fly ash to reduce the permeability of the mixture can reduce the leaching of heavy metals from coal gangue, thus reducing groundwater pollution [28].

6. Conclusions

(1) Among the different soil reconstructions, soil moisture content was higher when soil reconstructions were rock and soil stripping material: coal gangue: fly ash = 3:4:3.
(2) The soil moisture content of un-reclaimed land was mostly at a high level when the soil reconstruction method was rock and soil stripping material; and the soil moisture content was not at the highest level when the vegetation growth grade was higher. This indicates that it was not the case that the better the vegetation growth condition was, the higher the soil moisture content was.

(3) In the case where the soil reconstruction method was rock and soil stripping material: coal gangue = 2:3, the soil moisture content of the reclaimed land decreased with the reduction of tillage frequency when the vegetation growth condition was optimal (vegetation growth grade was 4). In the case where the soil reconstruction method was rock and soil stripping material: coal gangue: fly ash = 3:4:3, when the vegetation growth condition was better (vegetation growth grade was 3 and 4), the soil moisture content of the reclaimed land was highest when it was tilled once every 15 days. It was also found in combination with other soil reconstruction methods that it was not always the case that the higher the frequency of tillage, the higher the soil moisture content.

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References


44. Yang, Y.P. Study on Site Classification and Characteristics of Coal Mining Bases in Lingwu Mining Area. Master’s Thesis, Inner Mongolia Agricultural University, Hohhot, China, 2014.


