Research Article
Reclaiming Subsidized Land: An Evaluation of Coal Gangue Interlayers

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Rehabilitation of areas impacted by subsidence following coal mining is a pressing need in eastern China, especially where availability of suitable soil material is limited. A field experiment was established to evaluate performance of varying layered combinations of soil and coal gangue materials as measured by maize (Zea mays L.) growth and yield. Two control treatments and eight experimental treatments were constructed. All treatments had a 30 cm surface layer of topsoil. CK1 consisted of native soil material. CK2 consisted of 50 cm gangue covered by topsoil and 40 cm subsoil. Group 1 treatments (T1–T3) had a 15 cm layer of subsoil immediately below the topsoil, underlain, respectively, by progressively thicker gangue layers (20, 30, and 40 cm) overlying another 15 cm subsoil layer, in turn underlain by gangue. Group 2 treatments (T4–T7) consisted of 40 cm subsoil. T4-T5 followed the same pattern as Group 1 except that the lower subsoil layer was 25 cm thick. T6-T7 differed from T4-T5 by having 25 cm upper and 15 cm lower subsoil layers between different thicknesses of gangue. Group 3 (T8) consisted of three 10 cm layer of subsoil separating 2 gangue layers and gangue layer below. Key plant performance indicators, biomass and yield, were significantly better under CK1-2 than in the other treatments (T1–T8). Below the topsoil pH and total salt content were higher and water content was less in T1–T8 than in CK1-2, reflecting the influence of gangue in 30–70 cm zone in these treatments. The nutrient content (TN, AN, TP, OP, TK, AK, and OM) of topsoil in experimental treatments was lower than or similar to that of the control treatments. Results indicate that minimizing the adverse impacts of gangue requires a combined top-subsoil cover of at least 70 cm.

1. Introduction

Fossil fuels have been the basis of energy production all over the world and 85% of the energy consumption is met by fossil fuels nowadays [1, 2]. Coal, as one of the most important fossil fuels, accounts for the majority of electricity generation in many countries [3]. Even in the year 2018, coal was responsible for 38% of total global electricity generation [4]. In China, more than 90% of coal resources come from underground coal mining and these methods can cause surface collapse and ecological and environmental damage [5]. Subsided land in China occupies about 1.35 million ha and is increasing at an annual rate of 70,000 ha/year [6]. The subsidence area will reach 2.19 million ha by 2030 in China according to the current projections for coal production and anticipated subsidence. The destruction or degradation has caused serious shortage of cultivated land in the mining areas, and the socioeconomic and ecological environments of the mining areas have also been adversely affected. The rate of mining subsidence reclamation is only about 35% at present [7]. Therefore, reclamation of subsidence caused by coal mining has become an urgent problem to be solved in China.

Meanwhile, a lot of gangue is produced during coal mining and accounts for about 10–15% of total coal production [8]. Gangue is composed of carbon-bearing rocks...
and rocks discharged from coal mines in the process of well construction, excavation, coal mining, and coal washing [9]. It refers to the aggregation of solid waste discharged during coal mine construction and production [10]. Accumulation of gangue in China has reached 3.8 billion tons and is increasing at an annual rate of 200 million tons [11]. Gangue stockpiles occupy large land areas and also pollute the atmosphere, water, and soil and even endanger human health [12, 13]. A large amount of technology development has been invested in the utilization of gangue, but the utilization rate is less than 15% [11]. Due to the shortage of soil resources in coal mining subsidence areas, gangue is usually used as substrate for soil profile reconstruction and for ecological and environmental restoration in coal mine subsidence areas [14, 15]. Gangue is inherently infertile and has very limited water holding capacity due to its large porosity and lack of plant available nutrients [16].

Up to now, soil construction on land reclaimed with gangue consists of placing local soil over gangue [17–19]. All these studies focused on the effects of different thicknesses of soil cover over gangue substrate on crop growth. These results showed that the crop yield was close to that of local farmland when the soil cover thickness was greater than 70 cm. Some studies showed that the interlayered profiles can improve the water and fertilizer retention of soil profiles [20–23]. In order to solve the problems of the poor water and fertilizer conservation of coal gangue and the scarcity of soil resources in coal mining area, we proposed evaluating interlayered profiles, in which the thickness of overlying soil in some sections is less than that of 70 cm. We hypothesised that plant growth in interlayered profiles is better than that of the traditional placement of local soils over gangue.

The objective of this study is to compare plant performance of the traditional method using local soil placed over gangue with the varying interlayered combinations of soil and gangue materials as measured by maize (*Zea mays L.*) growth and yield. Finally, a new soil profile is determined, which is suitable for crop growth and can also save soils.

2. Materials and Methods

2.1. Experimental Field Design. The experimental site was located in Tianji town, Panji district (32°49′ and 116°48′), Huainan City, and Anhui Province (Figure 1). This area is located in the transitional zone of the subtropical and warm temperate zone. Annual rainfall is 937.2 mm and yearly average temperature is 15.3°C per year. The average frost-free period is 223.7 days per year [24]. Due to abundant sunshine, abundant heat, moderate precipitation, and long frost-free period, it is suitable for rice, wheat, corn, and other grain crops [25].

The experiment plots were constructed using soil and gangue from the adjacent coal mining subsided area in January 2018 under conditions when the groundwater level was high. The gangue used in this experiment was selected from the coal seam. The gangue is dense, large in size (10 mm–50 mm), and largely devoid of plant available nutrients. The soil is lime concretion black soil. It belongs to the vertosols according to the China Soil Taxonomy [25], US Soil Taxonomy [26], and World Reference Base for Soil Resources [27]. The lime concretion black soil is a semi-aqueous soil formed under swamp vegetation on fluvial and lacustrine sediments under warm temperate and semihumid climate conditions [28]. The dominant clay mineral is montmorillonite, which is characterized by heavy texture, low organic matter content, and a large shrink–swell capacity, and is prone to desiccation and waterlogging [29]. Selected soil and gangue properties are shown in Table 1. Gangue trace element content is shown in Table 2. The experiment plots consisted of various combinations of interlayered gangue and soil. Ten different interlayer soil profiles were designed (Figure 2). There are two control treatments (CK1 and CK2) and 8 more experimental treatments (T1, T2, T3, T4, T5, T6, T7, and T8). Each treatment was replicated three times. All treatments had a 30 cm surface layer of topsoil. CK1 was filled with native soil (120 cm) and CK2 consisted of gangue (50 cm) covered by 70 cm soil (30 cm topsoil and 40 cm subsoil), which represents a traditional reclaimed soil profile in this region. Treatments T1–T8 had various combinations of soil and gangue layers as shown in Figure 1. According to the subsoils’ thickness, position, and number of the interlayers, T1–T8 can be divided into 3 Groups. Group 1 composed of T1, T2, and T3. In Group 1, thickness of the subsoil is 30 cm and each interlayer is 15 cm thick, located in the upper, middle, and lower layers, respectively. Group 2 consisted of T4, T5, T6, and T7. In Group 2, the subsoil thickness is 40 cm and the thickness of interlayers is 25 cm, 25 cm, 15 cm, and 15 cm, respectively. The interlayers are located in the middle layer, lower layer, lower layer, and middle layer, respectively. In Group 3 (T8), total subsoil thickness is 30 cm. There are two gangue interlayers separating three 10 cm layers of subsoil; they are, respectively, located in the upper layer and lower layer. These combinations were based on the orthogonal experimental design and chosen from all the schemes. The experiment consisted of 30 rectangular plots (each plot with 6 m × 7 m = 42 m²) and all plots were randomly arranged (Figure 3). A 0.5 m wide buffer area was set between plots. The experimental field was surrounded by 1 m wide soil buffer area after it was constructed. Excavating machinery was used to level soil and gangue and to compact gangue during plot construction (Figure 4).

Maize (*Zea mays L.*) was sown on 4 April 2018, with plant spacing of 30 cm and row spacing of 50 cm, and planting density was about 68400 plants per ha. Maize was harvested on 24 June 2018. Experiment field management followed practices used by local farmers.

2.2. Soil, Gangue, Plant Sampling, and Measurements. Soil and gangue samples were collected by sampling the profile at 0–10 cm, 20–30 cm, 40–50 cm, 60–70 cm, 80–90 cm, and 100–110 cm depth intervals following harvest. Three samples were randomly removed by a ring sampler (5 cm ID × 5 cm height) at the same increments used previously for analyzing the soil water content. The method of Chen et al. [32] was used to determine field moisture content of gangue. This involved extracting gangue samples from soil pits at
designated locations and weighing them in the field \((M_1)\). Subsequently, the samples were oven-dried at 100°C in the laboratory until the quality of the samples does not change and then were weighed again \((M_2)\) [33]. The gangue water content was estimated by computing \((M_1 - M_2)/M_2\).

Meanwhile, the soil and gangue incremental samples were mixed and then stored in insulated and tied plastic bags to prevent moisture loss and brought back to the laboratory promptly and stored at 4°C until chemical analyses were conducted [34]. Soil and gangue were air-dried for 15 d at room temperature, sieved through a 1 mm screen, and mixed, and soil and gangue were tested for pH, available phosphorus, alkali-hydrolysable nitrogen, available potassium, and electrical conductivity. The remaining air-dried soil and gangue were ground to pass through a 0.25 mm sieve to determine total nitrogen, total phosphorous, total potassium, and organic matter. The methods used to measure these element contents were the protocols of US EPA methods 9045D [35], LY/T 1233-1999 [36], DB13/T 843-2007 [37], LY/T 1236-1999 [38], HJ 802-2016 [39], NY/T 1121.6-2006 [40], LY/T 1228-1999 [41], LY/T 1232-1999 [42], and LY/T 1234-1999 [43].

**Table 1: Selected chemical and physical properties of topsoil, subsoil, and coal gangue.**

| Properties          | Texture | Sand (%) | Silk (%) | Clay (%) | Total potassium (g/kg) | Total nitrogen (g/kg) | Total phosphorus (g/kg) | Organic matter (g/kg) | Available phosphorus (mg/kg) | Alkali-hydrolysable nitrogen (mg/kg) | Available potassium (mg/kg) | pH  |
|---------------------|---------|----------|----------|----------|------------------------|-----------------------|------------------------|-------------------------|----------------------------|--------------------------------|----------------------------|-----|
| Topsoil             |         | 8.35     | 73.98    | 17.67    | 12.56                  | 0.71                  | 0.16                   | 6.99                    | 0.88                       | 27.93                          | 241.1                      | 7.62|
| Subsoil             |         | 9.11     | 74.14    | 16.75    | 13.21                  | 0.60                  | 0.15                   | 5.08                    | 1.46                       | 46.31                          | 247.28                     | 7.67|
| Coal gangue         | Gravel  | 8.47     | 1.25     | 82.71    | 0.42                   | 0.16                  | 6.99                   | 0.88                    | 27.93                      | 241.1                          | 7.62                      |     |

**Table 2: Coal gangue trace elements.**

| Trace elements content in coal gangue | S (%) | Cr (mg/kg) | Cu (mg/kg) | Zn (mg/kg) | As (mg/kg) | Pb (mg/kg) | Hg (mg/kg) | Cd (mg/kg) | Ni (mg/kg) |
|--------------------------------------|-------|------------|------------|------------|------------|------------|------------|------------|------------|
| The average background of soil in Huainan [30] |       | 64.93      | 24.6       | 80.81      | 10.45      | 30.47      | 0.02       | 0.06       | 25.74      |
| Soil environment quality standard value in China [31] |       | 350        | 100        | 300        | 20         | 350        | 1.0        | 1.0        | 60         |

The methods used to measure these element contents were the protocols of US EPA methods 9045D [35], LY/T 1233-1999 [36], DB13/T 843-2007 [37], LY/T 1236-1999 [38], HJ 802-2016 [39], NY/T 1121.6-2006 [40], LY/T 1228-1999 [41], LY/T 1232-1999 [42], and LY/T 1234-1999 [43].
Plant height, stem diameter, chlorophyll, and leaf areas of maize were measured at seedling, jointing, and tasseling stages (on the 30th, 51st, and 73rd day, respectively). Dry biomass and yield were measured after maize matured. At maize seeding stage, 3 plants with similar growth were selected in each plot and labeled as samples for later monitoring of maize growth. Plant height was measured as the distance from the surface of soil to the upper most extended lead tip of the plant [44]. Plant stem diameter was measured by using a vernier caliper at the first node above ground level [45]. Leaf chlorophyll was measured using a SPAD-502 chlorophyll meter [46]. Leaf area was measured following the method of Maddonni et al., which is based on multiplying 0.75 times leaf length by leaf width [47]. Dry shoot biomass samples were oven-dried for 24 h at 80°C and then weighed. Yield was measured according to Circular of the General Office of the Ministry of Agriculture, China, on issuing the Measures for the Examination and Acceptance of the Establishment of the National Grain Yield for High Yield [48].

2.3. Statistical Analysis. The data were analyzed by one-way analysis of variance (ANOVA) to detect differences between treatments. Treatment differences were shown using the SNK (S) test at the significance level of $P < 0.05$ by the SPSS.
19.0 system. The standard deviation (SD) of each treatment was analyzed by SPSS19.0 program.

3. Results

In order to analyze the effect of different soil profiles on the growth of maize, maize growth (plant height, stem diameter, chlorophyll content, and leaf areas) at different stages (seedling, jointing, and tasseling stage) and biomass, yield, soil water content, and nutrients after harvest were analyzed. The following results from the study were obtained.

3.1. Plant Height, Stem Diameter, Chlorophyll Content, and Leaf Areas. The planting height, stem diameter, chlorophyll, and leaf areas of different treatments at seedling stage, jointing stage, and tasseling stage are shown in Figure 5(a). It can be seen that the differences of each treatment at jointing and tasseling stages were significant ($P < 0.05$) but there was a nonsignificant difference of maize growth among the different treatments at seedling stage. Maize growth in T8 was the poorest during the experiment period. Notably, at jointing and tasseling stages, there was significantly better maize growth between other treatments and T8. Maize growth in CK1 was similar to that in CK2. This indicated that a 70 cm cover of soil above a coal gangue layer was superior for maize growth compared with other treatments.

3.2. Dry Biomass and Corn Yield. The characteristics of above-ground dry biomass and yield in different experimental treatments were similar (Figure 6). There were significant differences of biomass or yield between control treatments (CK1 and CK2) and experimental treatments (T1–T8). The biomass and yield of the control treatments were significantly higher than those of the experimental treatments. The average biomass and yield of the control treatments were 1.30 times and 1.43 times higher than those of the experimental treatments, respectively. The biomass and yield values of CK1 were 220.70 g and 8739.15 kg/ha, respectively, followed by CK2. The biomass and yield values of CK2 were 207.27 g and 8239.60 kg/ha, respectively. There was no significant difference of biomass or yield between CK1 and CK2. The biomass and yield of CK2 were 1.25 times and 1.45 times higher than those of Group 1, respectively. The biomass and yield of CK2 were 1.23 times and 1.31 times higher than those of Group 2, respectively. The biomass and yield of CK2 were 1.38 times and 1.58 times higher than those of Group 3, respectively. The difference of biomass and yield between Group 2 and CK2 was the smallest, followed by Group 1, and the difference between Group 3 and CK2 was the largest. Due to the fact that biomass and yield of CK2 were obviously higher than those of the experimental treatments, CK2 can be adopted when lime concretion black soil and gangue were used as filling materials.

3.3. Soil and Coal Gangue Attributes

3.3.1. Water Content. Soil and coal gangue water content in different interlayered soil profiles are shown in Figure 7. With depth increase, water content of soil or gangue increased. There was no significant difference of topsoil (0–30 cm) water content between control experiments and Group 1 and Group 2. However, the difference of topsoil water content between control experiments and Group 3 was significant. At the same depth, the soil water content was significantly higher than that of gangue. This indicated coal gangue has poor water holding capacity creating a hydrological discontinuity. The water content of interlayered soil was higher than or similar to that of CK1 or CK2. This indicated that gangue has poor water holding capacity and the interlayer has larger water holding capacity.

3.3.2. Acidity Alkalinity (pH), Electrical Conductivity (Eh), and Total Salt Content. There was a significant difference of pH value at topsoil (0–10 cm) among T8 (Group 3) and control treatments (Table 3). With depth increase, water content of soil or gangue increased. There was no significant difference of topsoil (0–30 cm) water content between control experiments and Group 1 and Group 2. However, the difference of topsoil water content between control experiments and Group 3 was significant. At the same depth, the soil water content was significantly higher than that of gangue. This indicated coal gangue has poor water holding capacity creating a hydrological discontinuity. The water content of interlayered soil was higher than or similar to that of CK1 or CK2. This indicated that gangue has poor water holding capacity and the interlayer has larger water holding capacity.
Figure 5: Planting height, stem diameter, chlorophyll, and leaf areas of different treatments at seedling, jointing, tasseling, and mature stages.

Figure 6: Dry biomass and corn yield of different treatments at mature stages.
total soil salt content in the topsoil (0–10 cm) among T8 and control treatments. There were no significant differences of these three indices topsoils among all experimental treatments (T1–T8). At the same depth, the pH value, Eh value, and total soil salt content at the interlayer position were higher than or similar to those of CK1 and CK2. Values of pH, Eh, and total salt content of gangue were significantly higher than those of soil, which were 1.15 times, 1.40 times, and 1.44 times those in soil, respectively. Some measures should be taken to reduce the values of pH, Eh, and total soil salt content of gangue and interlayered soil.

3.3.3. Total and Available Nutrients. The content of total nitrogen, available nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, and organic matter of topsoil in all experimental treatments was lower than or similar to the control treatments (Tables 4–7). But the content of these total and available nutrients of the interlayers in all experimental treatments was higher than or the same as the control treatments. The available nitrogen, total phosphorus, available phosphorus, and total potassium contents of soil were larger than those of gangue, except that the total nitrogen, available potassium, and organic matter contents of soil were lower than those of gangue. Due to the high carbon content in gangue, the nitrogen and organic matter content in gangue were very high. However, nitrogen and organic matter in gangue are not readily available to plants.

4. Discussion

4.1. Distribution Characteristics of Filling Material Water Content and Nutrients in Layered Soil Profile. The texture, bulk density, and organic matter content of the filling material will affect the hydraulic properties [34, 50]. When the wetting front passes through the fine soil-coarse soil interface, due to the large porosity and small suction of the coarse soil, the wetting front stops at the interface causing a hydrological discontinuity [51], and the water content of the upper soil increased. When the gangue is located in the middle layer of soil profile, its presence inhibits the process of soil water infiltration and correspondingly increases the moisture of the upper soil [52]. However, the soil in this study area is the lime concretion black soil that has a large silt content and limited water infiltration [53], making it difficult for water to pass through the 40–70 cm soil layer. Therefore, there was no significant difference of the surface soil water content among the control group, Group 1, and Group 2. There were significant differences in topsoil water content between T8 and the other soil profiles. This can be explained by the proximity of the gangue (40 cm) to the soil surface in T8, which impedes downward movement of water at the interface of the hydrological discontinuity between the
Table 3: Acidity alkalinity, electrical conductivity (Ec), and total soil salt content.

| Treatment   | pH 0–10cm | pH 20–30cm | pH 40–50cm | pH 60–70cm | pH 80–90cm | pH 100–110cm |
|-------------|-----------|------------|------------|------------|------------|--------------|
| CK1         | 7.40±0.09c| 7.32±0.11a| 7.60±0.33c| 7.59±0.26b| 7.57±0.12b| 7.55±0.14d  |
| CK2         | 7.42±0.01abc| 7.37±0.16a| 7.58±0.25c| 7.68±0.00b| 8.92±0.26a| 8.94±0.08ab |
| T1          | 7.53±0.19abc| 7.61±0.18a| 9.00±0.44a| 7.70±0.18b| 8.87±0.14a| 9.14±0.13a  |
| T2          | 7.58±0.05abc| 7.61±0.22a| 8.02±0.29bc| 8.44±0.26a| 7.50±0.10b| 8.00±0.10c  |
| T3          | 7.67±0.05ab| 7.68±0.13a| 8.25±0.28abc| 8.61±0.37a| 7.48±0.06b| 8.84±0.31ab |
| T4          | 7.47±0.03abc| 7.56±0.10a| 8.19±0.35abc| 7.60±0.04b| 7.69±0.10b| 8.69±0.13ab |
| T5          | 7.44±0.02abc| 7.45±0.15a| 8.57±0.28ab| 8.80±0.10a| 7.71±0.20b| 8.77±0.14ab |
| T6          | 7.43±0.05abc| 7.45±0.11a| 7.41±0.11c| 8.90±0.27a| 7.56±0.06b| 8.61±0.12b  |
| T7          | 7.46±0.01abc| 7.39±0.16a| 7.49±0.16c| 8.53±0.19a| 7.86±0.04b| 8.93±0.07ab |
| T8          | 7.68±0.06a   | 7.71±0.08a| 8.95±0.04a| 8.77±0.15a| 7.62±0.12b| 9.11±0.01a  |

Table 4: Total and available nitrogen of interlayered soil profiles.

| Treatment  | TN (g/kg) 0–10cm | TN (g/kg) 20–30cm | TN (g/kg) 40–50cm | TN (g/kg) 60–70cm | TN (g/kg) 80–90cm | TN (g/kg) 100–110cm |
|------------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| CK1        | 0.56±0.03a       | 0.50±0.06a        | 0.43±0.02b        | 0.43±0.02b        | 0.38±0.05d        | 0.44±0.37e        |
| CK2        | 0.53±0.03a       | 0.49±0.05a        | 0.41±0.02b        | 0.45±0.04b        | 1.26±0.03a        | 1.28±0.03bc       |
| T1         | 0.44±0.03b       | 0.34±0.02b        | 1.25±0.09a        | 0.47±0.01b        | 1.18±0.01b        | 1.26±0.02bc       |
| T2         | 0.43±0.02b       | 0.33±0.04b        | 1.13±0.08a        | 1.13±0.08a        | 0.40±0.03d        | 1.20±0.05bcd      |
| T3         | 0.41±0.01b       | 0.34±0.05b        | 1.33±0.13a        | 1.41±0.27a        | 0.43±0.02d        | 1.32±0.08ab       |
| T4         | 0.44±0.02b       | 0.35±0.05b        | 1.24±0.05a        | 0.47±0.16b        | 0.58±0.04c        | 1.14±0.05cd       |
| T5         | 0.45±0.01b       | 0.35±0.05b        | 1.32±0.09a        | 1.26±0.07a        | 0.54±0.02c        | 1.40±0.02a        |
| T6         | 0.45±0.04b       | 0.36±0.04b        | 0.41±0.02b        | 1.22±0.01a        | 0.55±0.06c        | 1.15±0.07cd       |
| T7         | 0.46±0.01b       | 0.37±0.04b        | 0.38±0.02b        | 1.36±0.01a        | 0.55±0.05c        | 1.03±0.05d        |
| T8         | 0.40±0.03b       | 0.32±0.04b        | 1.36±0.19a        | 1.26±0.03a        | 0.40±0.03d        | 1.18±0.01bcd      |

Table 5: Total and available nitrogen of interlayered soil profiles.

| Treatment  | AN (mg/kg) 0–10cm | AN (mg/kg) 20–30cm | AN (mg/kg) 40–50cm | AN (mg/kg) 60–70cm | AN (mg/kg) 80–90cm | AN (mg/kg) 100–110cm |
|------------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| CK1        | 25.19±0.98a      | 21.85±1.38a       | 18.89±0.44a       | 15.16±0.38b       | 14.52±0.12a       | 13.55±1.41a       |
| CK2        | 24.96±1.31a      | 21.27±1.55a       | 18.29±0.77a       | 14.09±0.25b       | 9.94±0.38b        | 10.30±0.06b       |
| T1         | 21.24±1.50b      | 17.61±0.24bc      | 10.63±0.95c       | 14.73±0.69b       | 9.96±0.40b        | 8.69±0.11bc       |
| T2         | 19.96±1.56b      | 15.74±0.16bc      | 10.40±0.60c       | 9.97±0.20c        | 15.53±1.32a       | 9.53±0.27bc       |
| T3         | 19.33±0.25b      | 15.79±0.02bc      | 10.48±0.50c       | 9.81±0.80c        | 14.68±0.78a       | 10.25±0.57bc      |
| T4         | 20.06±0.41b      | 18.09±0.72bc      | 10.35±0.50c       | 16.35±0.28a       | 15.52±0.54a       | 8.14±0.33c        |
| T5         | 21.94±0.55b      | 15.92±0.60bc      | 10.63±0.59c       | 9.78±0.69c        | 15.91±0.60a       | 9.40±0.39bc       |
| T6         | 21.32±0.91b      | 17.51±0.35bc      | 15.53±1.58bc      | 9.71±0.42c        | 15.27±0.20a       | 10.25±0.67bc      |
| T7         | 21.94±1.16b      | 17.64±0.87bc      | 15.43±0.35b       | 9.79±0.54c        | 15.22±0.81a       | 10.09±0.28bc      |
| T8         | 19.06±0.13b      | 15.12±0.48c       | 10.16±0.42c       | 9.80±0.39c        | 14.66±0.94a       | 9.35±0.24bc       |

Upper soil layer and the gangue. The soil water content and nutrients in the interlayer were higher than those in the control group at the same depth. This is due to the fine texture and suction of lime concretion black soil and the coarse texture and poor suction of the lower gangue, which leads to water and nutrients being ponded in the upper soils.
The gangue is coarse-textured, low in plant available nutrients, and high in pH value, which is not conducive to the growth and development of plant root. The root system mainly absorbed water from the upper soil, which may explain the lower subsoil water content of T8. Gangue has the characteristics of large particle size, small suction, and poor water holding capacity [54]. So the water content of gangue was obviously lower than that of soil layer. Water movement and solute transport in soil are interconnected and affected. Therefore, the distribution characteristics of nutrients content in different soil profiles were similar to those of soil water content.

### 4.2. The Effects of Filling Material Properties on the Corn Root Distribution

The growth of maize roots directly affects the growth of shoots. Only when the root system is well-developed can the needs of above-ground growth be fully satisfied [55]. In addition to the water and nutrient conditions, due to the different physical and chemical properties of different soils, the changes of soil mechanical strength, bulk density, temperature heat, air permeability, fertilizer and water retention, and other factors are also different, which will affect the growth of maize roots [56]. Water and fertilizer in soil are more abundant than in gangue, so it can be expected that corn roots will favor soil over gangue as a
Table 7: Organic matter of soil and coal gangue of interlayered soil profiles.

| Treatment | 0–10 cm | 20–30 cm | 40–50 cm | 60–70 cm | 80–90 cm | 100–110 cm |
|-----------|---------|----------|----------|----------|----------|------------|
| CK1       | 6.26 ± 0.05a | 5.96 ± 0.30a | 5.53 ± 0.43f | 3.36 ± 0.43c | 3.41 ± 0.29b | 3.40 ± 0.28f |
| CK2       | 6.13 ± 0.23a | 5.85 ± 0.40a | 5.51 ± 0.02f | 4.63 ± 0.38e | 96.99 ± 1.76a | 70.38 ± 4.64e |
| T1        | 5.07 ± 0.07b | 4.26 ± 0.18b | 77.34 ± 3.40d | 3.77 ± 0.17c | 97.81 ± 4.78a | 83.42 ± 2.88c |
| T2        | 4.83 ± 0.28b | 4.20 ± 0.21b | 71.29 ± 0.38e | 79.36 ± 3.55d | 3.72 ± 0.08b | 67.72 ± 3.47e |
| T3        | 4.76 ± 0.54b | 4.08 ± 0.26b | 80.05 ± 1.85d | 117.31 ± 3.24a | 3.66 ± 0.05b | 91.21 ± 1.24b |
| T4        | 4.99 ± 0.13b | 4.29 ± 0.12b | 107.45 ± 1.33c | 5.09 ± 0.58b | 4.38 ± 0.23b | 74.85 ± 1.37c |
| T5        | 5.18 ± 0.46b | 4.36 ± 0.62b | 138.23 ± 1.24a | 107.34 ± 5.24b | 3.92 ± 0.41b | 106.95 ± 2.11a |
| T6        | 5.28 ± 0.17b | 4.32 ± 0.13b | 4.45 ± 0.26f | 93.11 ± 2.41c | 4.12 ± 0.64b | 102.17 ± 2.04a |
| T7        | 5.32 ± 0.58b | 4.37 ± 0.21b | 4.12 ± 0.08f | 106.44 ± 3.42b | 4.01 ± 0.47b | 76.74 ± 3.27d |
| T8        | 4.65 ± 0.27b | 3.94 ± 0.66b | 120.20 ± 3.26b | 106.41 ± 2.87b | 3.56 ± 0.33b | 71.73 ± 0.94d |

growth medium. In the early stage of maize growth, 85%–90% of roots were distributed in the soil layer above 40 cm [57]. So there was no significant difference among the control groups and treatments during the seedling stage. However, with the prolongation of growth period, the roots of quantity of deep soil continued to increase. It has been demonstrated that 93.85% of maize roots are distributed above 60 cm in lime concretion black soil during maize maturation [58]. Because the thickness of surface soil in the control group was more than 70 cm, the biomass and yield were significantly higher than those in the treatments. Guo et al. [59] carried out a field experiment using 30 cm topsoil and a subsoil composed of a 1:1 mix local subsoil and saprophytic topsoil overlying gangue. The combined thickness of soil in the treatments overlying gangue was 30 cm, 50 cm, 70 cm, and 100 cm, respectively. The experiment was conducted in the coal gangue filling and reclamation subsidence areas in Kailuan Coal Mine in Tangshan City, Hebei Province. Tangshan City is located in the east part of the North China Plain. The climate of Tangshan City is warm, semihumid, monsoon, and continental with four distinct seasons. The average annual temperature in Tangshan is 10°C–11.3°C. The average annual rainfall in Tangshan is 620 mm–750 mm. Rainfall is mainly concentrated from July to August [60]. The results showed that the maize yield in the soil profile with 70 cm soil thickness was not significantly different from that of the control treatment. Liu et al. [61] investigated land reclamation area in the coal mining subsidence area of Huainan City in Anhui Province. Treatments consisted of the following soil thicknesses over gangue: 40 cm, 60 cm, 75 cm, and 90 cm. The results indicated that the soil productivity of the 75 cm soil thickness and 90 cm soil thickness treatments was similar to that of the control treatments. But the soil productivity of the 40 cm and 60 cm soil thickness treatments was significantly lower than that of the control treatments. The results of this study also showed that there was no significant difference in corn yield between a soil thickness of 70 cm (CK2) and the control treatment (CK1), but the maize yield of CK2 was significantly higher than that of T1–T8. This result is consistent with the other studies referenced above and suggests that, under these climatic conditions, a soil profile with a thickness of 70 cm (CK2) is optimal for use as a cover over gangue for filling subsided areas.

4.3. The Potential Pollution from the Application of Gangue.
Gangue can be used as filling and reclaiming materials if the trace elements in gangue will not pollute the soil, groundwater, and surrounding environment. Studies show that trace elements (Cr, Pb, Hg, As, Cu, Se, etc.) in gangue vary greatly from several times to dozens of times in different areas of China, and not all trace elements in gangue exceed the national or local standards [62–64]. In order to ensure the safety of gangue for agricultural use, the standards for pollution control on the storage and disposal site for general industrial solid wastes and environmental quality standard for soils should be observed when reclaiming subsidence areas with gangue [65, 66].

5. Conclusions
The differences in plant height, stem diameter, chlorophyll, and leaf areas of different treatments increased in significance as the growth period extended, especially in the tasselling stage. Maize growth of the control groups was significantly better than T8. But the differences of maize growth among the treatments groups are not significant. The biomass and yield of the control groups were significantly better than the experimental treatments. The biomass of CK1 and CK2 was 220.70 g and 207.27 g, respectively. The yields of CK1 and CK2 were 8739.15 kg/ha and 8239.60 kg/ha, respectively. The water and nutrient contents of topsoil in the control group were higher or similar to those of the experimental treatments. But there were no significant differences of biomass, yield, subsoil water content, and nutrients between CK1 and CK2. Results indicated minimizing the adverse impacts of gangue requires a combined top-subsoil cover of at least 70 cm. This result is consistent with other studies conducted in the same area of China.

In the future, repeated measurements of maize growth and yield are recommended to gauge how the various treatments respond to weather variation. For example, significant changes in soil hydrology could impact transport of soluble salts within profiles that might hinder plant growth.

Data Availability
Data used to support the findings of this study are included within the article.
Conflicts of Interest
The authors declare that they have no conflicts of interest.

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