Abstract: The cultivated land area per capita in China is relatively small compared to the world average. However, most of the coal output is coming from underground mining, resulting in land subsidence and the destruction of existing cultivated land. The Yellow River is known as a ground-suspended river due to its large sediment concentration. Using unpolluted Yellow River sediment to reclaim the coal mine subsidence not only solves the problem of sediment deposition, but also solves the problem of shortage of filling material. Some experimental studies revealed low soil productivity as a result of thin soil cover. To ensure crop growth and production in land reconstructed with Yellow River sediments, determining the optimal thickness of soil cover over the sediment is extremely important. There were four experimental treatments and one control treatment. Each treatment was repeated three times. The control treatment was an original soil profile with 30 cm topsoil plus 110 cm subsoil. The four experimental treatments with different thickness of soil covers had the same thickness of topsoil (30 cm) and Yellow River sediments (60 cm), and different thickness of subsoil, which were 10, 30, 40, and 50 cm, respectively. Thus, the total thicknesses of soil cover (topsoil plus subsoil) were 40 cm, 60 cm, 70 cm, and 80 cm, respectively. The topsoil, subsoil, and Yellow River sediments were collected from Liangshan County. The soil type is fluvo-aquic. Maize (Zea mays L.) is the main crop in Liangshan County. A greenhouse experiment was conducted to investigate the growth of maize. The results showed that (1) the peroxidase (POD) activity, superoxide dismutase (SOD) activity, and malondialdehyde (MDA) content of maize leaf decreased with an increasing thickness of soil, while soluble protein (SP) and leaf relative water content (RWC) increased. (2) The dry biomasses of the shoot and root system in T70 and T80 were not significantly different from those in the control (3) Increased soil thickness is conducive to the storage of more water and available nutrients. Considering the time and cost of reconstruction, 70 cm is the optimal thickness of soil cover on Yellow River sediment to ensure maize growth.

Keywords: land reclamation; soil profile; river sediments; maize growth

1. Introduction

Cultivated land is a precious resource. Under the circumstance of a surging global population, cultivated land is a key to address food security by supporting agriculture [1]. Along with urbanization, cultivated land plays a more significant role in environmental sustainability and living quality satisfaction [2]. Researchers have recognized the growing gap between population growth and the rapid shrinkage of land resources [3,4]. In order to alleviate the pressure of farmland loss,
the government has implemented a variety of arable land protection plans. However, Chinese arable land is still decreasing due to various factors. For example, underground coal mining leads to mining subsidence, resulting in large areas of land damage. The estimated subsided land is over 1.5 million hectares, i.e., every 10,000 tons of coal extracted from the ground may result in approximately 0.2 to 0.33 hectares of subsided land [5]. The subsidence area is expected to expand by $7 \times 10^4$ hectares annually [5]. In eastern China, deep subsidence results in waterlogging because of a high underground water level, which has meant that a considerable amount of farmland has lost the capacity for cultivation [6]. The farmland cannot be cultivated, which means that farmers lose their livelihood. These changes have resulted in social instability and have seriously hindered the sustainable development of local communities and economies [7]. Therefore, it is imperative to reclaim farmland damaged due to coal mining subsidence.

Previous studies have explored the technology for reclaiming subsidence land affected by coal mining. These technologies include digging deep with mechanical equipment to fill shallow areas and filling reclamation with solid mine waste such as coal gangue and fly ash or lake mud [5,8,9]. The recovery rate of farmland using the technique of digging deep to fill shallow areas is low [8], and the shortage of [10,11] and potential pollution problems associated with filling materials [12–14] are very serious. Thus, previous reclamation methods do not effectively address the contradiction between huge population and farmland shortage.

The Yellow River is one of the highest sediment content rivers in the world [15,16]. To ensure the safety of the lower reaches of the Yellow River, the government invests substantial sums of money every year to dredge the river, and large areas of land are occupied by the dredged sediment [6]. Both sides will benefit if the dredged sediment from the Yellow River could be reasonably disposed of and the shortage of filling materials for subsidence land could be address. One hundred and twenty-five thousand CNY (approximately $18,200 USD) is required to reclaim 1 hectare of cultivated land with Yellow River sediment. After reclamation, the economic and ecological benefits are enormous. First, farmland provides essential food and other biological products. Second, the area of cultivated land can be converted into the index of construction land area in China. One hectare of arable land is worth hundreds of thousands of dollars. Third, cultivated land improves the harsh ecological environment of coal mining subsidence. Therefore, the reclamation of mining subsidence land with Yellow River sediment is important for economically and ecologically sustainable development.

Reclaiming subsided land with Yellow River sediment is a new reclamation technology to restore farmland in China. At present, there are few related studies. Wang et al. [6] analyzed the feasibility of using Yellow River sediment as the filling material for reclamation of mining subsidence land. According to the existing research [6], the Yellow River sediment is a sandy soil, and the soil profiles reconstructed with Yellow River sediment have poor capacity to retain water. To improve the capacity to retain water of the reconstructed soil profiles, stored subsoil and topsoil were spread over the sediment layer after filling. Hu et al. [17] performed an experimental field study on filling mining subsidence land with Yellow River sediment in Jining City; the results show that the estimated wheat yield of the reclaimed farmland was only one half of that of the control farmland due to the soil thickness being only 40 cm. Soil thickness is a critical factor in determining reclamation success or failure due to its effect on soil quality and productivity [18].

The thickness of covering soil is also important because thin coverage is not sufficient to support plant growth and thick coverage significantly increases the cost of reclamation engineering. Despite having the knowledge and experience of filling subsided land with Yellow River sediment, the existing study lacks quantitative data on the influence of soil thickness on crop production. The objective of this study was to determine the optimum cover thickness that not only meets the requirements for crop growth, but also reduces the cost of reclamation.
2. Materials and Methods

2.1. Study Area

The experiment was performed in a greenhouse at the Institute of Land Reclamation and Ecological Restoration, China University of Mining and Technology (Beijing). The topsoil, subsoil, and Yellow River sediments were taken from the study area, where land damage due to coal mining, farmland shortage, and dredging of Yellow River sediments were all serious problems. The study area was located in Liangshan County, Jining City, Shandong Province, China (Figure 1). In 2016, the GDP of Liangshan County was 26.504 billion CNY (approximately $3.859 billion USD) and the resident population was 749,800 [19]. The county has a total land area of 96,100 hectares [19], which mainly consists of plains and belongs to the Huangpan alluvial plain, with mostly flat terrain. The soil type is fluvo-aquic. The cultivated land is 64,000 hectares and the cultivated land per capita is approximately 0.085 hectares, which is far lower than the world average of 0.28 hectares [20]. Local agriculture uses a double-cropping planting structure with winter wheat and summer maize. Liangshan County is rich in mineral resources, including approximately 1 billion tons of coal reserves. All coal output is coming from underground mining, leading to a lot of farmland damage due to mining subsidence.

![Figure 1. Sample site of soil and Yellow River sediment.](image)

2.2. Experimental Design

A column experiment with different soil covers on Yellow River sediments was designed for selecting the optimum thickness of soil cover in a greenhouse. There were four experimental treatments with different soil covers and one control treatment in this experiment (Figure 2). Each treatment was repeated three times. The control treatment was an original soil profile with 30 cm topsoil plus 110 cm subsoil. The four experimental treatments had the same thicknesses of topsoil (30 cm) and Yellow River sediments (60 cm), and different thicknesses of subsoil, which were 10, 30, 40, and 50 cm, respectively. Thus, the total thicknesses of soil cover (topsoil plus subsoil) were 40 cm, 60 cm, 70 cm, and 80 cm, respectively. The total thickness of soil cover over Yellow River sediment was the primary variable in this study. Therefore, we use the total thickness of soil cover as the name of experimental treatments.
was 250 mL, and the irrigation frequency was low in the early growth stage and high in the later growth stage to ensure that the maize plants would not wither.

The soil cover thickness was optimized based on leaf peroxidase (POD) activity, superoxide dismutase (SOD) activity, malondialdehyde (MDA) content, soluble protein (SP) content, leaf relative water content (RWC), maize biomass, and soil properties. Leaf POD activity, SOD activity, MDA content, SP content, and RWC were tested at five stages of maize growth: at the seedling stage, elongation stage, big trumpet stage, heading stage, and flowering stage. After harvest, the maize dry biomass of the shoot and root systems were measured. The physical and chemical properties of the soil at different depths were tested. Soil properties included available nitrogen (AN), available phosphorus (AP), available potassium (AK), organic matter (OM), pH, electrical conductivity (EC), and soil water content (SWC).

Fertilizer with 7.2 g of urea (N: 46%) and 3.5 g of potassium dihydrogen phosphate (P$_2$O$_5$: 52%; K$_2$O: 34%) was applied in the topsoil (0–20 cm) of each reconstructed soil column. Accelerated germination of maize seeds was carried out in a thermostatic chamber at 35 °C. Then, two seeds were planted in each reconstructed soil column. At the seedling stage, two maize seedlings were retained; then, at the elongation stage, only one was retained. The amount of irrigated water applied each time was 250 mL, and the irrigation frequency was low in the early growth stage and high in the later growth stage to ensure that the maize plants would not wither.

### 2.3. Experimental Materials

Columns used in the experiment were polyvinyl chloride (PVC) pipes, with an inner diameter of 16 cm and a height ranging from 100 to 140 cm. Glass cement was used to attach a plastic plate to the bottom of each pipe, and three small drainage holes were drilled into each plastic plate with a drilling machine.

The topsoil, subsoil, and Yellow River sediment used in the study were collected from Liangshan County (Figure 1). The Yellow River sediment was collected from the Chenhai Yellow River diversion gate in Liangshan County. The topsoil and subsoil were collected from normal farmland. Before sampling, the surface litter was removed. Topsoil samples were obtained at a depth of 0 to 30 cm in a farmland soil profile. The subsoil samples were taken below 30 cm of the soil profile.

The soil and sediment were air-dried to a constant mass water content at approximately 30 °C and sieved (<2 mm). Physical and chemical properties of the soils and sediment are presented in Table 1.

![Figure 2](image-url) Five reconstructed soil profiles with different thicknesses of covering soil.

As maize is a main crop in Liangshan County, we used maize as the experimental plant for exploring the effectiveness of different thickness of soil covers in this test. The soil cover thickness was optimized based on leaf peroxidase (POD) activity, superoxide dismutase (SOD) activity, malondialdehyde (MDA) content, soluble protein (SP) content, leaf relative water content (RWC), maize biomass, and soil properties. Leaf POD activity, SOD activity, MDA content, SP content, and RWC were tested at five stages of maize growth: at the seedling stage, elongation stage, big trumpet stage, heading stage, and flowering stage. After harvest, the maize dry biomass of the shoot and root systems were measured. The physical and chemical properties of the soil at different depths were tested. Soil properties included available nitrogen (AN), available phosphorus (AP), available potassium (AK), organic matter (OM), pH, electrical conductivity (EC), and soil water content (SWC).

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The soil and sediment were air-dried to a constant mass water content at approximately 30 °C and sieved (<2 mm). Physical and chemical properties of the soils and sediment are presented in Table 1.
Table 1. Original properties of topsoil, subsoil, and Yellow River sediment.

| Properties               | Topsoil          | Subsoil          | Yellow River Sediment |
|--------------------------|------------------|------------------|-----------------------|
| pH value                 | 8.53 ± 0.12      | 9.10 ± 0.12      | 8.77 ± 0.22           |
| Electrical conductivity  | 104.67 ± 6.25    | 154.77 ± 16.60   | 48.27 ± 6.34          |
| Soil organic matter      | 24.81 ± 1.17     | 14.64 ± 0.90     | 4.09 ± 0.12           |
| Total nitrogen           | 960.00 ± 50.99   | 520.00 ± 32.66   | 10.33 ± 7.76          |
| Total phosphorus         | 1119.05 ± 33.30  | 702.94 ± 24.98   | 228.97 ± 19.65        |
| Total potassium          | 18.87 ± 0.08     | 18.35 ± 0.31     | 17.64 ± 0.04          |
| Available nitrogen       | 36.33 ± 1.09     | 16.04 ± 0.41     | 4.96 ± 0.41           |
| Available phosphorus     | 9.08 ± 1.40      | 8.03 ± 0.45      | 5.43 ± 0.24           |
| Available potassium      | 118.41 ± 5.62    | 59.56 ± 2.59     | 20.48 ± 0.32          |

Note: Soil texture was tested with a Malvern Mastersizer 2000 laser diffraction particle size analyzer, and determined according to the U.S.D.A. System of Textural Classification. Values are means ± standard deviations of three samples.

2.4. Analytical Methods

Leaf POD activity was measured using the guaiacol method [21–23]. Leaf SOD activity was measured using the nitroblue tetrazolium (NBT) photochemical reduction method [22,24]. Leaf MDA content was measured using the thiobarbituric acid method [24]. Leaf SP content was measured according to the Coomassie brilliant blue G-250 method [23]. Leaf RWC was calculated according to the following equation [25]. RWC (%) = (leaf fresh weight − leaf dry weight)/(leaf saturated weight − leaf dry weight) × 100.

At the end of the experiment, all maize plants in every treatment were sampled. The fresh plants were dried in an oven at 105 °C for 30 min to stop plant respiration and then dried at 75 °C for several days until they reached a constant dry weight [26]. Soil AN was measured using the alkali-hydrolyzed diffusing method [26]. AP content was determined according to a molybdenum antimony colorimetric method [27]. AK content was determined with a flame photometer [28]. OM content was determined according to a potassium dichromate volumetric method [29]. The soil pH value was measured with a glass electrode pH meter [30]; EC was measured with a conductivity meter [31] and SWC was measured according to the oven-drying technique [32,33].

One-Way ANOVA (p < 0.05) was used to analyze the significant differences among treatments at the same stage of maize growth for POD activity, SOD activity, MDA content, SP content, and RWC. The same method was used to analyze the significant differences among treatments at the same depth for each soil property. All of the analyses were performed using SPSS 19.0 statistical software. OriginPro 2016 was used to draw figures.

3. Results

3.1. Leaf Antioxidant Activities, MDA Content, SP Content, and Leaf RWC

Both leaf POD and SOD activity decreased with increasing thickness of covering soil, respectively (Table 2). In addition, POD and SOD first increased and then decreased during maize growth. In the same stage of the experiment, the control had lower POD activity than all the other experimental treatments (T40, T60, T70, and T80). Compared with the other experimental treatments, T40 had the greatest POD activity and T80 had the lowest activity in the same experimental stage. The same trend was found for SOD activity. The leaf POD activity in T40 and T60 was significantly higher than that in T70, T80, and the control, and the leaf POD activity in T70 and T80 was significantly higher than that in the control at seedling stage of maize. The leaf POD activity in T40, T60, and T70 was significantly higher than that in T80 and the control, and the leaf POD activity in T80 was significantly higher than that in the control at elongation stage. The leaf SOD activity in T40, T60, and T70 was significantly higher than that in T80 and the control at the elongation stage. The leaf SOD activity in T40 was significantly higher than that in the control at the flowering stage. The results revealed that 40 cm of covering soil was not a suitable thickness, and its water holding capacity was not enough to support maize growth.
Table 2. Leaf antioxidant activities, malondialdehyde (MDA) content, soluble protein (SP) content, and leaf relative water content (RWC) at five stages of maize growth.

| Stages of Maize Growth | Treatment | POD (U·g⁻¹ FW min⁻¹) | SOD (U·g⁻¹ FW) | MDA (nmol·g⁻¹ FW) | SP (mg·g⁻¹ FW) | RWC (%) |
|------------------------|-----------|------------------------|----------------|-------------------|----------------|---------|
| Seedling stage         | T40       | 4900.00 ± 313.09 a      | 285.71 ± 24.03 a | 9.82 ± 2.11 a     | 30.43 ± 1.90 c | 90.16 ± 2.57 a |
|                        | T60       | 4800.00 ± 328.11 a      | 275.13 ± 26.98 a | 6.15 ± 1.06 ab    | 35.85 ± 2.22 bc | 90.53 ± 2.23 a |
|                        | T70       | 3866.67 ± 226.62 b     | 243.39 ± 19.93 a | 5.86 ± 1.53 ab    | 33.55 ± 2.62 abc | 90.77 ± 2.63 a |
|                        | T80       | 3400.00 ± 275.32 b     | 232.8 ± 23.13 a  | 6.23 ± 1.04 ab    | 38.48 ± 1.99 ab | 90.63 ± 2.72 a |
|                        | Control   | 1977.78 ± 283.28 c     | 232.8 ± 20.89 a  | 4.46 ± 1.31 b     | 41.28 ± 1.99 a  | 90.80 ± 2.25 a |
| Elongation stage       | T40       | 6977.78 ± 346.77 a     | 385.19 ± 19.58 a | 36.30 ± 2.05 a    | 33.71 ± 2.06 b  | 88.00 ± 1.73 b |
|                        | T60       | 6577.78 ± 794.58 a     | 355.56 ± 18.14 a | 35.26 ± 2.26 a    | 38.46 ± 2.06 ab | 89.19 ± 2.00 ab |
|                        | T70       | 6466.67 ± 306.72 a     | 362.96 ± 10.48 a | 18.57 ± 2.33 bc   | 42.94 ± 1.31 ab | 89.12 ± 3.61 ab |
|                        | T80       | 5244.44 ± 436.60 b     | 296.3 ± 20.95 b  | 13.31 ± 3.66 c    | 40.83 ± 3.95 ab | 90.75 ± 1.73 ab |
|                        | Control   | 3133.33 ± 306.72 c     | 266.67 ± 18.14 b | 20.76 ± 2.34 b    | 44.26 ± 2.96 a  | 94.22 ± 1.5 a  |
| Big trumpet stage      | T40       | 9866.67 ± 568.30 a     | 469.14 ± 34.92 a | 60.67 ± 4.72 a    | 47.63 ± 5.50 b  | 86.68 ± 3.12 a |
|                        | T60       | 8933.33 ± 633.04 a     | 444.44 ± 30.24 a | 56.58 ± 2.85 ab   | 50.2 ± 3.66 ab  | 87.07 ± 2.18 a |
|                        | T70       | 9166.67 ± 381.03 a     | 395.06 ± 46.19 a | 56.88 ± 3.77 ab   | 58.09 ± 2.2 ab  | 89.95 ± 2.65 a |
|                        | T80       | 8333.33 ± 707.63 a     | 419.75 ± 34.92 a | 54.82 ± 4.83 ab   | 55.69 ± 3.25 ab | 89.88 ± 3.61 a |
|                        | Control   | 8266.67 ± 406.43 a     | 395.06 ± 37.84 a | 47.40 ± 2.27 b    | 60.57 ± 2.07 a  | 91.38 ± 3.91 a |
| Heading stage          | T40       | 129.33 ± 1114.55 a     | 539.68 ± 34.29 a | 48.94 ± 3.28 a    | 57.22 ± 2.83 b  | 91.38 ± 4.36 a |
|                        | T60       | 119.33 ± 942.81 a      | 529.1 ± 30.23 a  | 52.85 ± 1.94 a    | 59.35 ± 2.13 ab | 90.35 ± 1.73 a |
|                        | T70       | 11500.00 ± 649.41 a    | 539.68 ± 22.45 a | 47.38 ± 3.92 a    | 64.28 ± 2.90 ab | 91.38 ± 1.32 a |
|                        | T80       | 11333.33 ± 905.95 a    | 518.52 ± 22.41 a | 44.81 ± 3.53 a    | 64.77 ± 1.84 ab | 89.08 ± 1.00 a |
|                        | Control   | 10766.67 ± 691.93 a    | 465.61 ± 36.29 a | 31.47 ± 4.08 b    | 66.25 ± 3.04 a  | 93.64 ± 1.73 a |
| Flowering stage        | T40       | 6933.33 ± 587.10 a     | 433.86 ± 28.7 a  | 46.73 ± 3.34 a    | 62.05 ± 3.12 b  | 79.13 ± 3.09 b |
|                        | T60       | 6733.33 ± 637.70 a     | 423.28 ± 41.56 ab| 39.85 ± 3.03 ab   | 66.73 ± 3.40 ab | 82.57 ± 2.00 ab |
|                        | T70       | 6266.67 ± 354.16 a     | 359.79 ± 14.97 ab| 40.42 ± 2.18 ab   | 70.89 ± 3.00 ab | 85.96 ± 2.50 a |
|                        | T80       | 6000.00 ± 434.05 a     | 380.95 ± 27.35 ab| 36.94 ± 3.32 b    | 68.51 ± 3.26 ab | 87.88 ± 2.00 a |
|                        | Control   | 5800.00 ± 362.43 a     | 338.62 ± 23.76 b | 20.37 ± 2.53 c    | 73.86 ± 2.94 a  | 86.07 ± 2.65 a |

Note: POD, leaf peroxidase; SOD, superoxide dismutase; MDA, leaf malondialdehyde; SP, soluble protein; RWC, leaf relative water content. Values are means ± standard deviations of three samples. Different letters in the same column of the same stage indicate a significant difference at the 0.05 level.
Leaf MDA content decreased with increasing thickness of covering soil (Table 2). In addition, leaf MDA content first increased and then decreased during maize growth. The leaf MDA content in T40 was significantly higher than that in the control during the whole experimental period.

The leaf SP contents of maize in different experimental periods are shown in Table 2. The leaf SP content in T40 was the lowest, and that in the control was the highest among the different reconstructed soil profiles at seedling stage, and the same trend was found at elongation stage, big trumpet stage, heading stage, and flowering stage. The leaf SP content in T40 was significantly lower than that in T80 and the control, and the leaf SP content in T60 was significantly lower than that in the control at seedling stage. The leaf SP content in T40 was significantly lower than that in the control at elongation stage, and the same trend was found at big trumpet stage, heading stage and flowering stage. Leaf SP content increased with increasing thickness of soil spread over sediment and increased during the growth period.

The leaf RWC of maize at different experimental stages in five reconstructed soil profiles (T40, T60, T70, T80, and the control) is shown in Table 2. The leaf RWC in the control was the highest, but there were no significant differences among the different reconstructed soil profiles at seedling stage, and the same trend was found at big trumpet stage and heading stage. The leaf RWC in the control was the highest, and the leaf RWC in T40 was significantly lower than that in the control, while there were no significant differences among T60, T70, T80, and the control at elongation stage. The leaf RWC in T80 was the highest; the leaf RWC in T40 was significantly lower than that in T70, T80, and the control; and there were no significant differences among T60, T70, T80, and the control at flowering stage. The RWC of leaves increased with an increase in the thickness of soil spread over sediment due to the differences in water stress.

3.2. Dry Biomass and Root-Shoot Ratio of Maize

The dry biomass of both the shoot system and the root system roughly increased with increasing thickness of soil spread over sediment (Figure 3). The highest dry biomass of the shoot system was obtained in the control, while T80 had the maximum dry biomass of the root system. T40 and T60 had significantly lower dry biomasses of the shoot and root system than the control; furthermore, the dry biomasses in T70 and T80 were not significantly different from those in the control, and the root-shoot ratio in T60 was not significantly different from that in the control.

Figure 3. Dry biomass and root-shoot ratio of maize in different reconstructed soil profiles after the experiment. Different letters among columns indicate significant differences at the 0.05 level.
### Table 3. Soil physical and chemical properties at five soil depths.

| Depth | Treatment | AN (mg·kg⁻¹)   | AP (mg·kg⁻¹)   | AK (mg·kg⁻¹)   | OM (g·kg⁻¹)   | PH  | EC (µS·cm⁻¹) | SWC (%) |
|-------|-----------|----------------|----------------|----------------|----------------|-----|--------------|---------|
| 5 cm  | T40       | 29.06 ± 1.88 b | 8.73 ± 0.40 c  | 90.00 ± 3.92 b | 10.32 ± 0.37 b | 8.03 ± 0.06 a | 145.00 ± 5.20 b | 13.73 ± 0.57 b |
|       | T60       | 33.13 ± 2.89 a | 9.82 ± 0.53 b  | 113.00 ± 5.20 a| 10.71 ± 0.78 b | 8.02 ± 0.06 a  | 152.00 ± 6.00 ab | 14.23 ± 0.32 b  |
|       | T70       | 34.63 ± 1.12 a | 10.23 ± 0.49 b | 121.00 ± 10.15 a| 11.48 ± 0.54 ab| 8.01 ± 0.03 a  | 160.00 ± 4.58 a  | 15.68 ± 0.62 a  |
|       | T80       | 35.27 ± 0.75 a | 10.76 ± 0.52 b | 123.00 ± 11.53 a| 12.00 ± 0.85 ab| 8.01 ± 0.01 a  | 165.00 ± 6.56 a  | 15.86 ± 0.33 a  |
|       | Control   | 35.35 ± 1.42 a | 11.96 ± 0.62 a | 124.00 ± 9.85 a | 12.71 ± 0.78 a | 7.99 ± 0.06 a  | 154.00 ± 7.00 ab | 15.95 ± 0.59 a  |
| 35 cm | T40       | 28.00 ± 1.57 b | 8.81 ± 0.59 b  | 128.00 ± 11.79 a| 8.50 ± 0.43 b  | 8.06 ± 0.04 a  | 182.67 ± 4.16 b  | 14.64 ± 0.62 b  |
|       | T60       | 35.75 ± 1.31 a | 9.32 ± 0.5 b   | 118.00 ± 7.21 a | 8.49 ± 0.48 b  | 8.06 ± 0.07 a  | 185.00 ± 5.29 b  | 15.16 ± 0.34 ab |
|       | T70       | 37.75 ± 1.10 a | 9.60 ± 0.46 b  | 120.00 ± 8.54 a | 9.63 ± 0.62 ab | 8.04 ± 0.02 a  | 194.00 ± 3.00 a  | 16.17 ± 0.80 a  |
|       | T80       | 37.50 ± 2.42 a | 11.13 ± 0.47 a | 118.00 ± 5.57 a | 9.74 ± 0.59 ab | 8.03 ± 0.03 a  | 196.00 ± 2.65 a  | 16.50 ± 0.61 a  |
|       | Control   | 38.50 ± 1.08 a | 10.98 ± 0.31 a | 118.00 ± 9.54 a | 10.14 ± 0.69 a | 7.99 ± 0.03 a  | 194.00 ± 1.73 a  | 16.07 ± 0.38 a  |
| 45 cm | T40       | 7.00 ± 0.64 b  | 5.47 ± 0.50 b  | 54.00 ± 4.58 b  | 2.76 ± 0.05 c  | 8.2 ± 0.05 a   | 66.00 ± 1.73 c   | 7.00 ± 0.51 b   |
|       | T60       | 35.75 ± 1.31 a | 8.85 ± 0.44 a  | 121.00 ± 12.53 a| 8.10 ± 0.13 b  | 8.05 ± 0.04 b  | 197.00 ± 9.54 b  | 15.55 ± 0.56 a  |
|       | T70       | 35.11 ± 1.51 a | 9.18 ± 0.41 a  | 119.00 ± 6.24 a | 8.72 ± 0.38 ab | 8.03 ± 0.01 b  | 214.00 ± 9.17 b  | 16.17 ± 0.77 a  |
|       | T80       | 36.02 ± 1.28 a | 10.07 ± 0.62 a | 127.00 ± 9.00 a | 9.37 ± 0.45 a  | 8.00 ± 0.03 b  | 223.00 ± 9.17 a  | 16.67 ± 0.44 a  |
|       | Control   | 36.49 ± 1.94 a | 9.54 ± 0.78 a  | 135.00 ± 5.29 a | 9.22 ± 0.88 a  | 8.01 ± 0.03 b  | 217.00 ± 1.73 a  | 16.11 ± 0.35 a  |
| 65 cm | T40       | 6.30 ± 0.26 c  | 5.41 ± 0.42 b  | 55.00 ± 2.65 c  | 2.37 ± 0.23 b  | 8.20 ± 0.03 b  | 72.00 ± 3.00 c   | 7.28 ± 0.44 b   |
|       | T60       | 6.49 ± 0.24 c  | 5.83 ± 0.38 b  | 53.00 ± 3.61 c  | 3.10 ± 0.13 b  | 8.21 ± 0.03 a  | 68.00 ± 4.36 c   | 6.10 ± 0.23 c   |
|       | T70       | 35.50 ± 1.47 a | 8.92 ± 0.52 a  | 138.00 ± 7.94 a | 7.87 ± 0.42 a  | 8.09 ± 0.03 a  | 210.00 ± 4.58 b  | 16.33 ± 0.50 a  |
|       | T80       | 33.80 ± 1.83 ab| 9.09 ± 0.64 a  | 122.00 ± 8.54 b | 8.53 ± 1.07 a  | 8.04 ± 0.05 a  | 214.00 ± 2.00 b  | 16.21 ± 0.79 a  |
|       | Control   | 32.76 ± 1.14 a | 9.20 ± 0.62 a  | 131.00 ± 7.21 a | 8.85 ± 1.13 a  | 8.02 ± 0.08 a  | 232.00 ± 6.24 a  | 16.24 ± 0.32 a  |
| 90 cm | T40       | 8.75 ± 0.76 c  | 5.85 ± 0.46 b  | 54.00 ± 4.58 c  | 2.14 ± 0.09 c  | 8.24 ± 0.04 a  | 89.00 ± 4.36 c   | 6.39 ± 0.17 b   |
|       | T60       | 11.90 ± 0.95 b | 4.03 ± 0.44 c  | 59.00 ± 4.58 bc | 2.30 ± 0.18 c  | 8.22 ± 0.05 a  | 96.00 ± 1.73 bc  | 6.02 ± 0.29 bc  |
|       | T70       | 13.00 ± 0.62 a | 5.11 ± 0.44 b  | 53.00 ± 3.61 c  | 3.09 ± 0.19 b  | 8.21 ± 0.03 a  | 95.00 ± 5.29 bc  | 5.57 ± 0.38 c   |
|       | T80       | 13.50 ± 1.07 b | 5.46 ± 0.40 b  | 66.00 ± 4.00 b  | 2.86 ± 0.20 b  | 8.20 ± 0.04 a  | 101.00 ± 1.00 b  | 5.63 ± 0.43 c   |
|       | Control   | 36.35 ± 2.19 a | 7.97 ± 0.80 a  | 131.00 ± 7.21 a | 7.93 ± 0.14 a  | 8.05 ± 0.06 b  | 321.00 ± 26.3 a  | 16.68 ± 0.28 a  |

Note: AN, available nitrogen; AP, available phosphorus; AK, available potassium; OM, organic matter; EC, electrical conductivity; SWC, soil water content. Values are means ± standard deviations of three soil samples. Different letters in the same column of the same depth indicate a significant difference at the 0.05 level.
3.3. Soil Physical and Chemical Properties

After the maize was harvested, the soil columns were cut longitudinally. Soil samples were collected at five different depths to determine soil physical and chemical properties (Table 3). The depth refers to the distance between sampling points and surface soil. The surface soil water content (at 5 cm depth) increased with increased soil thickness. At the depth of 65 cm, the water content of T70 was higher than that of T80 and the control.

At the depth of 5 cm, the pH value of T80 was the same as that of T70, less than that of T60, and the pH value of T60 was less than that of T40 (Table 3). With the increased thickness of the covering soil, the soil pH value decreased at 5 cm depth, and the same trend was found at a depth of 90 cm. The EC of T40, T60, T70, and T80 was increased in turn at 5 cm depth, and the same trend was found at 35 cm and 65 cm. Because of the high pH and low EC of the Yellow River sediment, a greater thickness of covering soil is conducive to controlling the pH value and EC.

At the depth of 5 cm, the AN content of T40, T60, T70, and T80 was increased in turn, and the same trend was found for AP, AK, and OM content (Table 3). The contents of AN, AP, AK, and OM in surface soil (0–5 cm) increased with the increased soil thickness. At the depth of 65 cm, the AN and AK contents of T70 were higher than those of the control and the AN content of T80 was higher than that of the control. The increased soil thickness is conducive to maintaining the contents of AN, AP, AK, and OM. AN and AK accumulated in the soil layer above the sediment layer, and even the contents of AN and AK in T70 and T80 treatments were higher than those in the control treatment.

4. Discussion

The different thicknesses of soil covering the sediment layer had different water holding capacities under the same irrigation conditions, leading to differences in water stress that affected crop growth, which would result in differences in crop production and oxidative stress [34]. With the antioxidant defense system [35], the crop plants could protect themselves from oxidative stress [36].

Observations that POD and SOD activities increased or were maintained under water stress have been reported by many studies [34,37,38]. Under the same irrigation conditions, different thicknesses of soil spread over sediment had different water storage capacities, leading to varying degrees of water stress that affected maize growth, which would have resulted in differences in maize growth and oxidative stress [34]. With the antioxidant defense system [35,39], maize could protect itself from oxidative stress [36]. The leaf POD and SOD activities first increased and then decreased during maize growth, the same trend has been reported by Ge et al. [40]. The activities of SOD and POD tended to decrease with the increase in thickness of covering soil. The covering soil treatment of 40 cm had the highest POD and SOD activities in the experimental stages, while the control had the lowest. Drought conditions can increase the activities of SOD and POD [34]. This phenomenon shows that 40 cm of covering soil was not an ideal thickness, and its water holding capacity was not enough to support maize growth. The POD activity in the control was significantly lower than that in the other treatments at seedling stage and elongation stage ($p < 0.05$), and the significant difference disappeared at big trumpet stage. The SOD activity in the control was not significantly different from that in T60 and T70 in some stages ($p < 0.05$). Thus, based on SOD and POD activities, the covering soil thickness of 60 cm, 70 cm, or 80 cm was the most suitable thickness.

The accumulation of ROS (reactive oxygen species) increased the MDA content [34]. MDA is the final product of lipid peroxidation and indicates oxidative damage [37,41]. Other research found that the generation of ROS increased with water stress and then resulted in an increase in MDA content [34,37,40]. The leaf MDA contents of maize first increased and then decreased during maize growth. The control and T80 had the lowest MDA contents during the period of growth, and the MDA content in T70 and T80 was close to that in the control in some stages ($p < 0.05$). Thus, based on MDA, the most suitable thickness of covering soil was 70 cm or 80 cm.
The SP content of leaves has been shown to decrease with increasing drought stress [40]. High amounts of SP can maintain a relatively low osmotic potential in plant cells, mitigating the damage caused by water stress [41]. All the leaf SP contents of maize increased with an increase in growth stage. SP content increased with the increase in thickness of covering soil, and 40 cm of covering soil had the lowest content. The SP content in the control was not significantly different from that in T80 in all stages and not significantly different from that in T70 in some stages (p < 0.05). Based on SP, the most suitable thickness of covering soil was 70 cm or 80 cm.

Leaf RWC decreased gradually with an increase in water deficit [42]. Leaf RWC was significantly reduced under water stress, but it significantly increased during recovery [43]. Leaf RWC increased gradually with an increase in thickness of covering soil. There was no significant difference between the leaf RWC of T80 and that of the control, and the same trend was found for T70 and T60. Based on leaf RWC, a covering soil thickness of 60 cm, 70 cm, or 80 cm was optimal.

According to the dry biomass of maize plants at the flowering stage, the control had the highest dry biomass, while the dry biomass of the root system in T40 was significantly lower than that in the control and the other experimental treatments. This phenomenon might have occurred because 40 cm of covering soil was not enough to hold sufficient water for maize growth, causing an overaccumulation of ROS, poor growth performance of the crop [34], cell death, and loss of biomass. However, the dry biomass of the root system in T70 and T80 was close to that in the control and significantly higher than that in T60 (p < 0.05). Based on dry biomass of maize plants, the covering soil thickness of 70 cm or 80 cm was optimal.

According to soil physical and chemical properties, the soil above of the interface between soil and sediment helps to store water and nutrients. For example, at a depth of 65 cm, the water content, AN, and AK of T70 was higher than that of T80 and the control. The sediment layer has a temporary impediment to water infiltration and plays a role of water storage [44]. The increased soil thickness is conducive to maintaining the contents of AN, AP, AK, OM, and soil water content in the surface soil layer.

In summary, a thickness of 70 cm is the thinnest soil thickness that can ensure the normal growth of maize. Because local soil resources are in a state of shortage, the cost of transporting soil from other places is expensive. The best covering thickness is 70 cm based on the principle that lesser soil thickness is financially optimal.

5. Conclusions

Yellow River sediment is a good material for restoring farmland. As it has a small amount of silt and clay it has a poor capacity to hold water, which leads to the low yield of crops. Thus, the key is soil cover. Different thicknesses of soil cover on Yellow River sediment resulted in different water contents of soil columns, which either directly or indirectly influence plant growth. Research on the optimal thickness of soil cover is necessary not only for the verification of the efficacy of filling reclamation with sediment, but also for the wide application of this reclamation method in eastern China. With an increase in the thickness of soil cover, leaf POD and SOD activity and MDA content of maize leaf decreased, while SP and leaf RWC increased. Increased soil thickness is conducive to the storage of more water and available nutrients. The dry biomasses of the shoot and root system in T70 and T80 were not significantly different from those of the control treatment, while T40 and T60 were significantly lower than those of the control treatment. Based on the results of this research, and considering the cost of reconstruction, a total soil cover of 70 cm was the optimal soil thickness for maize growth.

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