Abstract

Underground coal mining causes land subsidence, a large area of cultivated land is destroyed. The Yellow River interlayer filling reclamation technology is the powerful way to restore cultivated land. Understanding the mechanism of action of interlayers in reconstructed soil filled with Yellow River sediments is essential to achieving sustainable land management in the Yellow River regions. Column experiments and Field experiments were conducted to optimum of interlayers in reconstructed soil with Yellow River sediment for restoring subsided coal mined land. Our findings show that the inclusion of interlayers in the sediment reduced water leakage and moisture evaporation, and improved the water-holding capacity of the material in comparison to conventional reconstructed soil profile (Ck2). When the 30 cm thickness of interlayer, putting 2 interlayers in sediment (T6) was the optimal profile with the highest water-holding capacity. In comparison to CK2, the migration rate of wet front decreases by 32.16%, the cumulative evaporation decreases by 16.29%, the volumetric water content of filling layer (θ_{fl}) increases by 121.56%, and the water-holding coefficient (C_{WR}) increases by 59.47%. It is also proved by field experiments. The wheat and maize yields of T6 improved 51.84% and 54.80%, respectively, as compared with CK2, that closer to undisturbed farmland (CK1). This study provides a valuable framework for subsided land reclamation regarding the method of placing interlayers into Yellow River sediment for enhancing water retention and productivity.

KEYWORDS

mining subsidence, land reclamation, soil profile, interlayer, Yellow River sediment

1 INTRODUCTION

Large-scale coal mining causes serious land damage and eco-environmental problems (Hu et al, 2014). So far, about 1.5×10^4 km^2 of land was subsided due to underground coal mining in China, and it is increased with 70 thousand ha per year. Subsidence effects on agricultural land have been documented in Illinois (Guither et al., 1986), in the United Kingdom (Selman 1986), and in Australia (Ham 1987). These effects include soil erosion, disruption of surface drainage, wet or ponded areas, and the reduction in crop yields (Darmody et al., 1989; Darmody et al., 2014). The damage of subsided cropland is a particularly severe problem because of large population in China. By 2020, the total area of destroyed cropland is predicted to reach 3.83×10^3 km^2, thus reducing grain yields by 9.63×10^8 kg, and increasing the number of landless farmers to 1.91×10^6 (Hu et al., 2014). Therefore, restoring damaged cultivated land is extremely important in China.

The filling reclamation technique is the most powerful way to restore large areas of subsided land. The typical land reclamation practice is to fill areas of subsided land with available unconsolidated materials like coal gangue and fly ash (Hu et al., 2015). There are several disadvantages to using these materials, such as potential soil contamination and an insufficient quantity of such materials (Hu et al., 2015; Tang et al., 2018). Sediment from adjacent rivers is often at a low risk of being polluted by heavy metals or other contaminants, and it is readily available (Wang et al., 2016). In USA, for example, Illinois River sediment was successfully used to reclaim a brownfield along the south Chicago lakefront (Darmody et al., 2004). Thus, reclaiming damaged land by using river sediments has broad potential for many countries around the world. In fact, the use of river sediment to reclaim subsided land represents a potentially effective reclamation technology that may also help to solve the problem of river dredging, and in turn “kill two birds with one stone”.

The Yellow River is the fifth longest river in the world. A large number of mining subsided lands are located along the river. The sediment load in the Yellow River is among the world’s largest (Wang et al., 2016). However, Yellow River sediment is coarse-textured, with limited water-holding capacity (Wang et al., 2018). When it is combined with conventional methods of soil reconstruction, in which a layer of soil is directly spread over sediment, the reclaimed soils are characterized by poor soil water holding-capacities and low nutrient contents that are insufficient for plant growth in comparison to native soil (Wang et al., 2014).

Recent studies show that the use of multiple layers of soil of varying grain size is more effective in maximizing a soil’s water-holding capacity (Huang et al., 2011; Huang et al., 2013; Zettl et al., 2015). Hanks et al. (1961) found that the interlayered structure of soil plays an important role in inhibiting and reducing infiltration (Hanks et al., 1961). Li et al. (2012) and Wang et al. (2018) further showed that the position of interlayering within the soil profile affects the degree to which infiltration is reduced. (Li et al., 2012; Wang et al., 2018). Hu et al. (2017) designed multiple-layer soil profiles for reclaiming subsided land with Yellow river sediment in eastern China. In this greenhouse experiment, subsoil interlayers were emplaced into a layer of Yellow River sediment, which resulted in good morphological characteristics of maize (Hu et al., 2017). It might because that the interlayers in Yellow river sediment create favorable hydrological properties resulting in improvement of soil water characteristics. The authors developed a conceptual model for introducing the function of interlayers in Yellow river sediment (Hu et al., 2018). But, the optimum position, thickness and number of interlayers and its effects of the interlayered soil profile on soil quality, particularly with regards to hydrologic processes, has not been fully explored. Therefore, the main objectives of this study were to explore the optimum design of interlayers for reclaiming subsided land with Yellow river sediments.

2 MATERIALS AND METHODS

2.1 Study area

The study area was located at the Qiuji Coal Mine, in Qihe County of Dezhou City, Shandong Province, China, as shown in Figure 1. It lies north of the Yellow River, about 5.2 km away from the Panzhuang Yellow River’s main canal. The climate is a warm temperate continental monsoon with a multiyear average temperature of 14.3 °C and average precipitation of 645.9 mm. The rainfall has obvious seasonality, mostly concentrated in late June to September, accounting for about 76.4% of total precipitation per year. The average annual evaporation is 1700 mm, and the yearly frost-free period is about 210 d. Coal mining process was completed in 2008, and the subsidence had reached a stable state with a subsidence depth of 0.5 to 2.22 meter. The shallow groundwater level is at a depth of 1.0 m during the flood season and about 2.0 m during the non-flood season.

2.2 Laboratory Experiments

This study adopted the column experiments for investigation of infiltration and evaporation based on different soil profiles with different position, thickness and number of interlayers in Yellow river sediment.

2.2.1 Experimental design

Three types of experimental materials were used in the infiltration and evaporation experiments. The topsoil, subsoil and Yellow River sediment were all obtained from study area (Figure 1). Experimental materials were air dried and then sieved through a 2-mm mesh. Their particle size distributions were analyzed using a pipette method. The topsoil, subsoil and Yellow River sediment consisted of a silty-clay loam, clay and loamy sand, respectively (using the USDA textural classification system) (Bormann, 2010). Soil bulk density was measured by the gravimetric method (Table 1).

The experimental soil profiles were 120 cm long and consisted of two control treatments (CK1, CK2) and five treatments with different thickness and number of interlayers in Yellow river sediment (T1–T7) (Figure 2). CK1 consisted of 20 cm of topsoil overlying a continuous layer of subsoil, which represented native farmland soil. CK2 represented the conventional method of reconstructing soil profiles, which consisted of 20 cm of topsoil, followed by 20 cm of subsoil that overlaid 80 cm of sediment. Experiments T1–T7 consisted of various combinations of subsoil interlayers and sediment, all of which were overlain by 20 cm of subsoil and 20 cm of topsoil. Farming within the study area typically consists of rotating wheat and maize crops. The designed soil profiles, characterized by subsoil interlayers that extend from 60–110 cm in depth, was consistent with the root distribution associated with wheat and corn. The experimental treatments were divided into three treatment scenarios. Scenario 1 include T1, T2, T3 with interlayer of varying position. Scenario 2 include T4, T2, T5 with interlayer of varying thickness. Scenario 3 include T5, T6, T7 with different numbers of interlayer.

2.2.2 Experimental process

Experimental setups shown in Figure 3. The cylinder, possessed an inner diameter of 19 cm and a height of 130 cm, was packed with soil and sediment in 5-cm increments and compacted to get the designed dry bulk density (Table 1) (Wang et al., 2014). The surface of each soil layer was corrugated to create roughness before adding the next increment (Ma et al., 2010). During the compacting process, ten soil moisture sensors (ECH$_2$O EC-5) were installed at 10, 30, 45, 55, 65, 75, 85, 95, 105, and 115 cm below the soil surface and programmed to measure the soil water content every 5 min. After standing for 48 h, infiltration was done. The height of the Mariotte bottle was adjusted to supply water to the cylinders, and to keep a constant water head of 3 cm. Changes in water content of the of Mariotte bottle was recorded to calculate cumulative infiltration; the lower position of the wetting front was also recorded. The infiltration experiment ended when the wetting front reached 120 cm (i.e., the bottom of the soil column). Then, each soil column was weighed after the infiltration experiment.

Following the infiltration experiment, each soil column was placed beneath an infrared lamp (250 w). The vertical distance between the lamp and soil surface was maintained at a constant 30 cm. At this time, the evaporation experiment was started. The mean room temperature was 24.5 ± 0.5 ℃. Daily atmospheric evaporation intensity averaged 0.94 cm/day. During the evaporation experiment, the soil columns were weighed every day to calculate cumulative evaporation. Evaporation was completed after 30 days of continuous illumination. The soil profile water content was measured every 30 min by nine soil moisture sensors.

2.3 Field Experiments

2.3.1 Filling Reclamation Process

The field experiment plot of multi-layered soil reconstructed with Yellow river sediments was implemented in July 2015. The process of the filling reclamation (Figure 4) was: 1) Dividing strips for the subside land. The subsided land to be reclaimed was divided into a number of strips depends on the area of subsided land and the mechanical equipment for effective operation radius (7–15m). 2) Stripping the topsoil and subsoil. The topsoil (0–20 cm) and subsoil (20–50 cm) were stripped and stockpiled with excavators respectively.3) Taking and transporting sediments by hydralic pums and pipelines to the subsided land, the concentration of sediments was 1.4 g/cm^3. 4) Dewatering and solidifying sediments. 5) Backfilling the subsoil as interlayer onto the sediment after consolidation of the sediment. 6) Repeat step 3,4,5 following designed soil profile until reached the designed elevation of the land. 7) Backfilling topsoil and subsoil as soil covers onto sediments respectively.

2.3.2 Planting and Sampling

To validate the field planting effect, multi-layered soil profiles T2 and T6, native-farmland soil profiles CK1, and conventional method of reconstructing soil profiles CK2 designed in laboratory experiments were implemented in the plot in 2015. Effect drawing before and after reclamation shown in Figure 5. Local agriculture uses a double-cropping planting structure with winter wheat and summer maize. Wheat was planted during the dates of the 3th and 8th of October and harvested in early June. The planting density of 1.8 to 2.2 million plants per hectare. The seeding depth was approximately 3 cm. Maize was planted during the dates of the 10th and 15th of June and harvested at the End of September. The plant population was between 45 and 70 thousand plants per hectare. The seeding depth was between 3 and 5 cm. Crop straws were returned to the fields after harvesting wheat and maize. During the experiment, the fertilization and irrigation of the experimental field coincides with the native farmland. Wheat and maize yield of different soil profiles was determining after the maize was harvested in 2016.

Soil and Yellow River sediment samples were collected by sampling different profiles. Each soil construction models (CK1, CK2, T2, T6) randomly removed three samples by a ring sampler at 10 cm, 30 cm, 45cm, 65cm, 85cm, and 105 cm depth following harvest maize. The samples were analyzed for organic matter, total nitrogen, available phosphorus and available potassium.

2.4 Model Application and Performance Evaluation

Two widely applied models (Kostiakov model and polynomial function method) were used to the analyze infiltration and evaporation measurements, as follows:

$$I(t)=kt^{n}(k>0,0<a<1) \quad (1)$$

$$E(t)=a x^{2}+bx+c \quad (2)$$

where I and E represent cumulative infiltration and cumulative evaporation (cm), respectively, t is time (min), k and n are empirical estimates, and a, b, and c are evaporation coefficients.

Coefficient of Variation (CV) is a normalized measure of the dispersion of probability distribution, which is defined as the ratio of standard deviation to average value, as follows:

$$CV=\frac{S}{\overline{x}}\times 100\% \quad (3)$$

Water retention coefficient (C_{WR}) was introduced to quantitatively evaluate the soil water-holding capacity, calculated as the soil moisture after evaporation divided by the soil moisture after infiltration. (Xing et al., 2017), as follows:

$$C_{WR}=\frac{M_1}{M_2}\times 100\% \quad (4)$$

where M_1 represent soil moisture after infiltration (cm); M_2 soil moisture after evaporation.

The volumetric water content in filled layer represent the effect of interlayers for water-holding capacity, which was the average volumetric water content of weighted by thickness of each layer.

$$\theta_{fl}=\frac{\theta_1 f_{f1}+\theta_2 f_2+\ldots\theta_n f_n}{n} \quad (5)$$

where θ_n represent water content of every layer (cm^3/cm^3); f_n represent the thickness of every layer (cm); n the number of layers.

The performance of the models was evaluated using R^2, *RRMSE*, and the Nash-Sutcliffe efficiency coefficient (*NSE*). Their mathematical expressions are shown in equations 6–8, respectively:

$$R^2=\left[\sum_{i=1}^{n}(O_i-\overline{O_i})(S_i-\overline{S})\right]^2 / \sum_{i=1}^{n}(O_i-\overline{O_i})^2\sum_{i=1}^{n}(S_i-\overline{S})^2 \quad (6)$$

$$RRMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i-S_i)^2/\overline{O_i}}, \quad (7)$$

$$NSE = 1 - \sum_{i=1}^{n} (S_i - O_i)^2 / \sum_{i=1}^{n} (O_i - \overline{O}_i)^2, \quad (8)$$

where n is the number of samples, S_i is the simulated value of infiltration or evaporation, and O_i is the observed value of infiltration or evaporation.

3 RESULTS

3.1 Iinfiltration

The initial migration of the wetting front through the first 40 cm of material was similar for all treatments (Figure 6) reflecting that the thickness and number of topsoil and subsoil layers in each column was the same to this depth. Differences appeared after 600 min, when the wetting front of all treatments except CK1 moved through the “soil-sediment” interface at slightly staggered times. The rate of downward movement in CK2 was faster than that in the other treatments. It reached the bottom of the column in 4260 min, which is only 68.93% of the time required for CK1. The time required for the wetting front in experiments T1–T7 to reach the bottom of the soil was 4830,5085,5015,4680, 5380, 5630 and 5485 min, respectively. The addition of the various subsoil interlayers to the sediment decreased (improved) the downward rate of movement by 13.38%、19.36%, 17.72%, 9.86%, 26.29%, 32.16%, and 28.76% compared with CK2 (4260 min). The migration time of the wetting front increased gradually with the thickness. However, it initially decreased and then increased with increasing position and number of interlayers. The curves of wetting front showed different flow rates in different layers. Notably, subsoil interlayers in between sediments layers had an important role in slowing down the migration rate of water. Average migration rate of the wetting front (T1–T7) in sediment layers was about 0.023 cm/min, as compared to 0.012cm/min for the subsoil interlayer. This indicates that the migration rate of the wetting front was faster when it entered into the sediment layer, and then it became slower when the wetting front passed from the sediment layer into the subsoil interlayer. Moreover, the change in subsoil interlayer thickness had a stronger influence on wetting front migration time than did the number and position of subsoil layers.

Cumulative infiltration increased gradually with time for the various treatments (Figure 7). During the early stages of the experiments, cumulative infiltration increased rapidly, in part because the water potential gradient was large. The cumulative infiltration of CK1 exhibited a linear relationship with infiltration during the later stages of the experiment; however, the change came earlier in the other treatments. After the 600 min, the cumulative infiltration of CK2 was lowest for a given time. The lower Yellower River sediment layer of CK2 remained unsaturated and possessed the lowest values of infiltration. The wetting front within the sediment may even become unstable and break into narrow wetting columns or “fingers” (Hillel, et al., 1988). The characteristics of soil infiltration are often determined by the pattern of soil layers under conditions of vertical rainfall infiltration (Li et al., 2012). Multi-layered soil profiles (T1–T7) putting interlayers into sediment improved the leakage of soil water "finger" flow, but by different degrees. The cumulative infiltration could be regarded as water-holding capacity of the soil columns during the infiltration process, When the wetting front advancement to the soil columns. At the end of infiltration, the cumulative infiltration for interlayers with a position of 50 cm (T1), 60 cm (T2) and 70 cm (T3) were increased by 14.37%, 18.59%, and 17.55%, respectively, in comparison to CK2 (32.68 cm) (Figure 7a). The cumulative infiltration for subsoil interlayers with a thickness of 10 cm (T4), 20 cm (T2) and 30 cm (T5) were increased by 12.13%, 18.59%, and 25.11%, respectively, in comparison to CK2 (Figure 7b). The cumulative infiltration for one (T5), two (T6), and three (T7) subsoil layers (Figure 7c) increased by 25.11%, 30.92%, and 31.02%, respectively, in comparison to CK2. This indicates that the inclusion of subsoil interlayers in the sediment improved the leakage of water through the soil profile, and enhanced water retention. The effect of the reduced leakage of water gradually increased with the thickness and the number of subsoil interlayers, however, it initially decreased and then increased with increasing position of interlayers.

The *Kostiakov* Model simulated cumulative infiltration (Table 2). For all treatments, the R^2 values for cumulative infiltration were larger than 0.995. The *RRMSE* values were smaller than 0.057, and the *NSE* values were larger than 0.989 and smaller than 1. Therefore, the *Kostiakov* Model effectively simulated the observed values for all treatments.

3.2 Evaporation

Evaporation is one of the most important phases in the water cycle (Wang et al., 2014). Steady state evaporation from soils is not, however, a widespread occurrence (Teng et al., 2019). In general, the evaporation process can be divided into three stages. Figure 8 shows that the effect of interlayers on cumulative evaporation mainly occurred during the second stage. Soil water overcame gravity and moved upward by capillary processes under the action of matrix suction. This upward movement of water provided a constant supply of water to the topsoil that evaporated (Shao et al., 2006). After 30 days, the cumulative evaporation of CK2 was the highest; it was 18.75% higher than measured for CK1 (17.55 cm). Multi-layered soil profiles (T1–T7) putting interlayers into sediment reduced water evaporation. Under different position of interlayer (Figure 8a), the cumulative evaporation for T1, T2 and T3 were decreased by 10.27%, 7.82%, and 6.54%, respectively, in comparison to CK2 (20.84 cm). Under different thickness of interlayer (Figure 8b), the cumulative evaporation for T4, T2 and T5 were decreased by 4.41%, 7.82%, and 9.98%, respectively, in comparison to CK2. Under different number of interlayers (Figure 8c), the cumulative evaporation for T5, T6 and T7 were decreased by 9.98%, 16.29%, and 9.45%, respectively, in comparison to CK2. It shows that cumulative evaporation decreased with the thickness of interlayer. Conversely, cumulative evaporation increased with the depth of interlayer. Compared with the previous two factors, the change of the number of interlayers had the most obvious effect on cumulative evaporation. It initially decreased and then increased with increasing thickness and numbers of interlayers. The matrix suction through multi-layered soil profiles (T1–T7) was discontinuous, therefore reduced moisture evaporation and improved the storage capacity of reclaimed soil with Yellow River sediment. Position, thickness and numbers of interlayers were all effect the evaporation characteristics of reclaimed soil. Therefore, it has great meaningful that changed the position and numbers of interlayers to reduce evaporation under the same total thickness of interlayer.

The polynomial function, $E(t)=ax^2+bx+c$ was used to simulate the cumulative evaporation results (Table 3). For all treatments, simulated cumulative evaporation possessed R^2 values that were larger than 0.994. The *RRMSE* values were smaller than 0.019, and the *NSE* values were larger than 0.987 and smaller than 1. Therefore, the developed polynomial function effectively simulated cumulative evaporation for all treatments.

3.3 Soil moisture contents

The water content of CK1 increased with depth gradually decreasing at the end of infiltration (Figure 9). Following evaporation, the moisture content of the CK1 increased with depth. However, changes in soil moisture distributions in reclaimed soil profiles with Yellow River sediment were discontinuous. There was about 0.46 cm^3/cm^3 of water in subsoil layers, but only about 0.09 cm^3/cm^3 of water in sediment layers after evaporation. The coefficients of variability (CV) were therefore used to describe the influence of interlayers on the variations with depth in moisture content resulting from infiltration and evaporation (Niu et al., 2016). Larger CV values represent a higher degree of variation (Xing et al., 2017). After infiltration, calculated CV values for T1, T2 and T3 (Figure 9a) were 26.71%, 25.98%, 25.32%, respectively. The CV values calculated for moisture contents for T4, T2 and T5 (Figure 9b) were 24.87%, 25.98%, and 24.64%, respectively. The CV values calculated for moisture contents for T5, T6 and T7 (Figure 9c) were 24.64%, 20.21%, and 22.20%, respectively. However, after evaporation, the CV values calculated for moisture were larger for all treatments. Specifically, the CV values for T1, T2 and T3 (Figure 9d) were 67.29%, 68.57%, 68.83% respectively. The CV values for T4, T2 and T5 (Figure 9e) were 63.93%, 68.53%,67.36%, respectively, whereas the values for T5, T6 and T7 (Figure 9f) were 67.36%, 62.82%, and 67.91%, respectively. In summary, soil moisture variations with depth in multilayered soil profiles were discontinuous, and the CV values were increased by evaporation. Moreover, the thickness of the interlayers had a largest influence than others on CV.

During this study, the soil moisture in the vertical profiles at the end of infiltration could be viewed as the initial soil moisture of evaporation. Therefore, the water retention coefficient (C_{WR}) was introduced to quantitatively evaluate the water holding capacity, calculated as the soil moisture after evaporation divided by the soil moisture after infiltration. (Xing et al., 2017). The results of experiments were illustrated in Figure 10. The C_{WR} for CK1 was the highest ($C_{WR} = 0.62$) , CK2 was the lowest and it was only 58.47% of CK1.

Multi-layered soil profiles (T1–T7) putting interlayers into sediment improved the water holding capacity. Under different position of interlayer, the value of C_{WR} for T1, T2 and T3 were increased by 37.93%, 39.22%, and 36.14%, respectively, in comparison to CK2. But there was no significant difference (*P¿0.05*) among T1, T3 and T2. Under different thickness of interlayer, the value of C_{WR} for T4, T2 and T5 were increased by

25.99%, 39.22%, and 49.39%, respectively, in comparison to CK2. That is to say, the value of C_{WR} increased with the thickness of interlayer. Under different number of interlayers, the value of C_{WR} for T5, T6 and T7 were increased by 49.39%, 59.47%, and 54.39%, respectively, in comparison to CK2. But there was no significant difference *(P>0.05)* among T6 and T7. That is to say, when the number of interlayers increased from 2 to 3 layers, the effect of water holding capacity of the reconstructed soil was not significant change. The results show that increasing the thickness of interlayer is a most effective way to improve the water holding capacity of reclaimed soil profile. However, native soil is insufficiently available in most Mining areas and can also be improved water holding capacity of reclaimed soil by changing the number of interlayers. Furthermore, placing two subsoil interlayers between sediment layers (T6) had the largest $C_{WR.}$

3.4 Corn yields

The wheat and maize yields of CK1, CK2, T2 and T6 are showed in Figure 11. Wheat and maize yield of CK1 were the highest, CK2 was the lowest and it was only 63.98% and 62.92% of CK1.Putting interlayers into sediment, wheat and maize yield of the multi-layered soil profiles (T2 and T6) were significantly higher than conventional soil profile CK2. The wheat yields of T2 and T6 improved 32.14% and 51.84%, respectively, as compared with CK2. The maize yields of T2 and T6 improved 34.37% and 54.80%, respectively, as compared with CK2. In addition, there was no significant difference (*P¿0.05*) among T6 and CK1. Therefore, putting interlayers into sediment improved corn yields, and the profile consisting of two interlayers (T6) closer to undisturbed farmland (CK1).

3.5 Nutrients distribution

Major nutrients distribution on field soil profile shown in Table 4. The content of organic matter, total nitrogen and available phosphorus of topsoil in all treatments were no significant difference (*P¿0.05*). But the topsoil content of available potassium in reclaimed soil with Yellow River sediment CK2, T2 and T6 was lower than or the native farmland soil CK1. It showed that available potassium could accumulate in topsoil layers and sediment layers could not strongly adsorb K^+ leaching was mainly from sediment layer, and reclaimed soil with Yellow River sediment was favorable for available potassium leaching. With increasing depth, the organic matter, total nitrogen, available potassium and available phosphorus content in control treatments CK1 and CK2 gradually decreased. However, the nutrients in treatments CK2 were easy loss with water drainage and nutrients content of the sediment layer is obviously lower than that of the soil layer of the same depth. Such us the organic matter, total nitrogen, available potassium and available phosphorus content at 65 cm of CK2 were only 34.81%, 51.35%, 26.79% and 44.64% of CK1. As for multi-layered soil profiles (T2 and T6) putting interlayers into sediment improved the nutrients content in filled layer (40–120 cm). Therefore, the interlayer of soil, as a reservoir in the filling layer, provides essential nutrients for the growth of crops of reclaimed soil.

4 DISCUSSION

For clearly identifying the effect of interlayer on water-holding capacity, the volumetric water content in filled layer (40–120 cm) (θ_{fl}) after 30 days of evaporation may also represent the effect of interlayers for water-holding capacity, which was the average volumetric water content of weighted by thickness of each layer. The results illustrated in Figures 12–14.

Under different position of interlayer (Figure 12), θ_{fl} for T1, T2 and T3 were 0.198, 0.201and 0.204 cm^3/cm^3, which improved by 56.87%, 58.08% and 61.19%, respectively, compared with CK2. There was no significant difference *(P>0.05)* among T1, T2, T3. That is, the change of subsoil interlayer position has no significant effect on the θ_{fl}. However, C_{WR} for T1, T2 and T3 were improved by37.93%, 39.22%, and 36.14%, respectively, compared with CK2. There is a critical position of subsoil interlayer in the sediment, and interlayer has the greatest influence on soil water infiltration and evaporation, and the value of C_{WR} is biggest. Because the unsaturated water conductivity between the subsoil interlayer and Yellow River sediment layer is the biggest difference when the subsoil interlayer on critical position. This study found that the critical position should be around 60 cm under the thickness was the 20 cm (T2). Moreover, the treatment T2 putting interlayers into sediment improved the nutrients content in filled layer (40–120 cm) of CK2. The wheat and maize yields of T2 improved 32.14% and 34.3.7% as compared with CK2.

Under different thickness of interlayer (Figure 13),$\theta_{fl}$for T1, T2 and T3 were 0.162, 0.201and 0.238 cm^3/cm^3, which improved by 27.92%, 57.97% and 87.64%, respectively, compared with CK2. During the infiltration, the migration time of the wetting front increased gradually with the thickness and number of subsoil interlayers. That is the effect of preventing water increased with the interlayer thickness. During the evaporation, the greater the distance of evaporation surface with the thickness of interlayer, and the smaller evaporation intensity. After infiltration and evaporation, the value of C_{WR} have changed. C_{WR} for T4, T2 and T5 were improved by 25.99%, 39.22%, and 49.39%, respectively, compared with CK2. Therefore, the water retention of multi-layered soil profiles increased with thickness of subsoil interlayers.

Under different number of interlayers (Figure 14), θ_{fl} for T3, T4 and T5 were 0.238, 0.281and 0.238 cm^3/cm^3, which improved by 87.64%, 121.30% and 87.64%, respectively, compared with CK2. the C_{WR} for T5, T6 and T7 were improved by 49.39%, 59.47%, and 54.39% respectively, compared with CK2. It indicated that the values of θ_{fl} and C_{WR} were initially increased and then decreased with an increasing number of subsoil interlayers of the same thickness. Moreover, the two subsoil interlayers that were emplaced into the Yellow River sediment layer (T6) possessed the largest water-holding capacity. Moreover, the treatment T6 better than T2, putting two interlayers into sediment better improved the nutrients content in filled layer (40–120 cm) of CK2. The wheat and maize yields of T6 improved 51.84% and 54.80% as compared with CK2.

5 CONCLUSION

Multi-layered soil profiles created by placing subsoil interlayers into sediment is a new strategy to reclaim subsidence land with sediments. Determining the optimal reconstructed soil profile has considerable practical significance for reclaiming subsided land with Yellow River sediment.

The position, thickness and number of interlayers were shown to affect moisture characteristics of the reclaimed soils. The thicker the subsoil interlayer, the better the water-holding capacity of the reconstructed soil profile. However, native soil is insufficiently available to reclaim subsided land in most areas. The water-holding capacity of reconstructed soil profiles can also be improved by changing the position and increasing the number of interlayers. The critical position should be around 60 cm under the thickness was the 20cm (T2) have Water holding capacity. Moreover, it is not the case that the more interlayers put into the sediments resulted in a higher water-holding capacity; instead, the profile consisting of two interlayers (T6) resulted in the maximum water holding capacity of the soil and maize yields closer to undisturbed farmland (CK1). It is also proved by field experiments. The interlayer of soil, as a reservoir in the filling layer, provides essential nutrients for the growth of crops of reclaimed soil, putting interlayers into sediment improved corn yields, and the profile consisting of two interlayers (T6) closer to undisturbed farmland (CK1). The study has important theoretical and practical implications for subsided land reclamation regarding the emplacement of subsoil interlayers in the sediment for enhancing water retention and corn productivity.

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