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Soil Quality Change after Reclaiming Subsidence Land with Yellow River Sediments

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Abstract: With continuous population growth and decreasing cultivated land area, China's food security is greatly threatened. Additionally, coal mining in China is primarily underground mining, which causes land subsidence and destroys existing cultivated land. This effect aggravates the contradiction between a growing population and a shrinking area of cultivated land. The purpose of this study was to introduce a method of filling reclamation with Yellow River sediments to restore farmland and realize the sustainable utilization of cultivated land. The properties of the soil and crop yields in reclaimed farmland were assessed. This study examined farmland reclaimed with Yellow River sediments at an experimental site located in Jining City, Shandong Province, China. Filling reclamation procedures with Yellow River sediments were applied. The reclaimed farmland (RF) and unaltered farmland (CK) were continuously monitored for three years, and the soil was sampled six times. A total of 180 soil samples were collected from RF and CK. The soil properties were measured at three depths: 0–20 cm, 20–50 cm, and 50–80 cm. Crop yields were monitored regularly. The results indicate that filling reclamation with Yellow River sediments is an effective method for restoring farmland. The RF and CK soils were weakly alkaline, non-saline soils. The RF soil was suitable for the growth of local crops. With an increasing number of farming years, both the quality of cultivated land and crop yields have increased. Therefore, filling reclamation with Yellow River sediments is an effective way to realize the sustainable utilization of cultivated land.

Keywords: land reclamation; farmland; mining; Yellow River sediments; crop yield; sustainability

1. Introduction

China has a large population and relatively scarce cultivated land resources. The cultivated land per capita is approximately 0.1 ha, which is far lower than the world average of 0.28 ha [1]. This results in a significant imbalance between the availability and demand of cultivated lands [2]. Nevertheless, due to the rapid increase of the population in China, the imbalance has been further aggravated, significantly undermining the improvement of social equity and environmental sustainability [3,4]. Although the government has adopted a series of measures to protect cultivated land, farmland has been decreasing for various reasons. Coal mining is mostly underground mining in China, which inevitably damages the land through subsidence [5,6]. By 2017, the area of coal mining subsidence was 2×10^6 ha, of which 60% was cultivated land or other agricultural land in China [7]. Because the mining area in eastern China is an important grain-producing area and coal-production base with a high water level, land subsidence causes water accumulation in a large area and leads to the loss of cultivability of a large area of productive, cultivated land [8,9]. The mining subsidence area is increasing at a rate of 70,000 ha per year [10], and the loss of arable land because of subsidence will continue to increase. This trend exacerbates the above contradiction. Therefore, reclaiming the arable land damaged by coal mining subsidence is imperative.

Previous studies have discussed technologies for reclaiming land degraded by coal mining subsidence. These technologies include deep-digging and filling reclamation areas with solid mine waste, such as coal gangue and fly ash or lake mud. Deep-digging means digging to extensive depths with mechanical equipment to fill shallow areas. Coal gangue, fly ash, and other industrial waste have been basically recycled in mining areas, used to generate electricity due to their calorific value, or made into multi-purpose building materials due to their physical properties [11,12]. However, there is not enough coal gangue or fly ash available for use as filling material. The clay content of lake mud is relatively high, resulting in high water content, poor permeability, and slow seepage of reclaimed soil. The muddy layer is thick, which easily forms a marsh. The time required for drainage and consolidation is relatively long. The recovery rate of farmland using the technique of digging deep to fill shallow areas is low. The technique of filling reclamation with coal gangue and fly ash involves the risks of inadequate filling materials and potential pollution [13,14]. The consolidation and drainage time for filling reclamation with lake mud [15] is too long, and the land cannot be cultivated until two to three years after reclamation. Previous reclamation methods cannot effectively address the dual challenges of a large population but scarce land resources.

The sediment load in the Yellow River is among the world's largest [16]. The Yellow River has a total length of 5464 km, and its drainage area is approximately 75×10^4 km^2. It is the fifth longest river in the world. Because the middle reaches flow through the Loess Plateau, where vegetation has been seriously destroyed and the soil is loose, sediment flows into the Yellow River due to erosion induced by rain. The Yellow River is famous for its high sediment content and produces 16 million tons of sediment annually [17]. The accumulation of sediment causes the downstream to become a ground-suspended river. To ensure the safety of the lower reaches of the Yellow River, the government invests a large amount of money every year in dredging, and the dredged sediments occupy a large amount of land. Filling reclamation engineering projects using sediments from the Yellow River can prevent the sediments from occupying land and address the shortage of filling materials for coal mining subsidence. For coal mines along the Yellow River, using Yellow River sediments to fill and reclaim coal mining subsidence land holds considerable promise. The results of a previous study [18] showed that Cd and Hg were not detected in Yellow River sediments. The contents of heavy metals such as Cr, Cu, Zn, Pb, Ni and As did not exceed the second and third standard values of the soil environmental quality standards of China [19]; thus, Yellow River sediments are not a source of pollution. Hu et al. [20] proposed the idea of a filling reclamation process with Yellow River sediments and verified the feasibility of using Yellow River sediments as a filling material.

Reclaiming subsidence land with Yellow River sediments appears to be a promising method for restoring farmland [21]. However, the soil properties and crop yields after reclamation are still unclear, especially over the course of several years. In this study, reclaimed farmland (RF) and unaltered farmland (CK) were continuously monitored for three years, the soil was sampled six times, and 180 soil samples were collected. Additionally, crop yields were monitored regularly. The objectives of this study are as follows: (1) to introduce a new filling material (Yellow River sediments), which can be used to restore the cultivated land lost due to coal mining subsidence and to describe the associated filling reclamation process, and (2) to assess the soil properties and crop yields after reclamation.

2. Materials and Methods

2.1. Experimental Site

The experimental site is located west of Pengnali Village, Dalukou Town, Liangshan County, Jining City, Shandong Province, China (Figure 1). The region has a semi-humid continental climate with an annual average temperature of 13.5 °C and an annual precipitation of 601 mm [22]. The experimental site was a coal mining subsidence area with a maximum collapse depth of 1.5 m and an area of approximately 48.67 ha. The experimental site was approximately 7 km away from the Yellow River. We chose this site to test the filling reclamation process with Yellow River sediments.

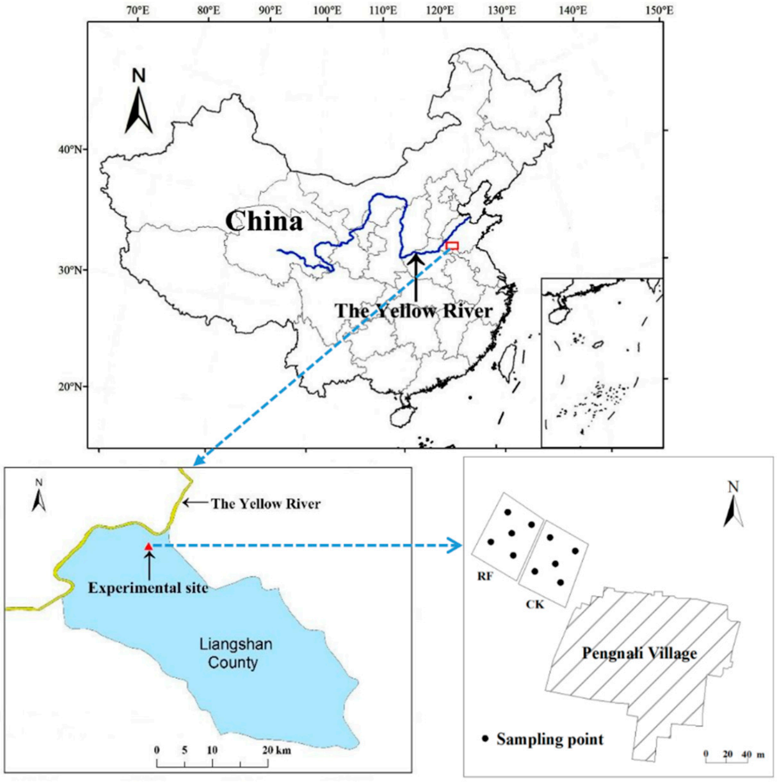

Figure 1. Location of the experimental site. The red triangle represents the location of the experimental site. The photo on the right represents the location and sampling distribution of reclaimed farmland and control farmland. RF, reclaimed farmland; CK, unaltered farmland.

2.2. Filling Reclamation Process

The construction of the experimental site began in February 2011 and was completed in July 2011. The process for filling reclamation with Yellow River sediments (Figures 2 and 3) was as follows: (1) Layered stripping of topsoil and subsoil: water was drained from the subsidence land, and then the topsoil (0–20 cm) and subsoil (20–50 cm) were stripped layer by layer using mechanical equipment. The stripped soil was placed nearby. (2) Extracting a water-sediment mixture from the Yellow River: A cutter suction dredger was used to extract the water-sediment mixture at a rate of 1100 $m^3 \cdot h^{-1}$. (3) Transporting the water-sediment mixture to the subsidence land: An ordinary steel pipeline with an inner diameter of 350 mm was selected to transport the water-sediment mixture to the experimental site. The length of the pipeline was approximately 7 km, and the pressure pump was set up 3.5 km away from the suction dredge to ensure that the mixture could be transported to the destination. (4) Deposition of Yellow River sediments: The sediment was allowed to settle at the experimental site, and excess water was discharged into the nearby drainage ditch. (5) Placing the stripped soil onto the sediment: When the sediment appeared to be consolidated, the stripped topsoil and subsoil were placed layer by layer onto the sediment. The total thickness of topsoil and subsoil was 50 cm. (6) Improvement of the soil quality in the reclaimed land: Measures were taken to improve the quality of the reclaimed soil, such as the application of fertilizer and farm manure each year. The total cost of the experimental site (48.67 ha) construction was approximately 7 million CNY (approximately $1 million USD).

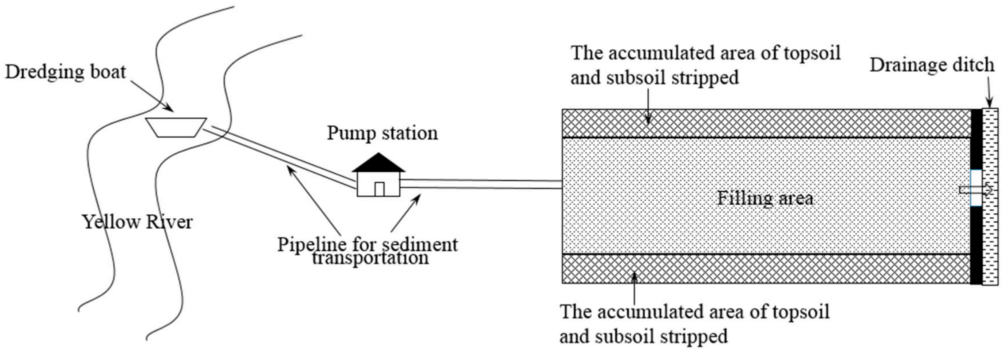

Figure 2. The technological process of filling reclamation with Yellow River sediments.

Figure 3. Actual technique of filling reclamation with Yellow River sediments. 1—subsidence land; 2—layering stripping topsoil and subsoil; 3—extracting a water-sediment mixture; 4—transporting the water-sediment mixture; 5—removing excess water; 6—deposition of Yellow River sediments; 7—placing the stripped soil onto the sediment; 8—reconstructed soil profile; and 9—after reclamation.

After reclamation via this process, the farmland area reached 95% of the experimental site, essentially encompassing the entire area except for field roads, drainage ditches and other infrastructure.

2.3. Experimental Field Management

To facilitate management, 3000 m^2 of reclaimed farmland (RF) was selected from the experimental site to monitor soil properties and crop yields. Similarly, 3000 m^2 of nearby unaltered farmland (CK) was selected to monitor soil properties and crop yields (Figure 1). Unified management of RF and CK was carried out, including planting and fertilization.

Local agriculture uses a double-cropping planting structure with winter wheat and summer maize. After the construction of the experimental site, the same crop rotation was carried out for RF and CK. The planting density of summer maize variety Chenghai 605 was 50,000 plants per hectare and the plant width was 40–80 cm. The seeding depth was approximately 5 cm. Wheat variety Jining 22 had a planting density of 1.8 to 2.2 million plants per hectare. The seeding depth was approximately 3 cm. The first crop of wheat was planted in October 2011, followed by maize in June 2012, wheat in October 2012, maize in June 2013, wheat in October 2013, maize in June 2014, wheat in October 2014, maize in June 2015, wheat in October 2015, maize in June 2016 and wheat in October 2016. Chemical fertilizers were applied uniformly for RF and CK. Fertilizer was applied before maize and wheat sowing; during the maize and wheat growing period, fertilizer was applied with irrigation according to soil moisture and crop growth. Farmyard manure was used as fertilizer after the maize was harvested. The specific amounts of fertilization per year were as follows: 800 kg of urea per hectare, 150 kg of P_2O_5 per hectare, 150 kg of K_2O per hectare, 15 kg of $ZnSO_4$ $7H_2O$ per hectare and 45 t of farmyard manure per hectare. During the planting process, crop wastes (straws and stalks) were returned to the fields after harvesting wheat and maize every year.

2.4. Soil Sampling and Analysis

Soil samples were collected in February 2012, September 2012, April 2013, September 2013, April 2014 and September 2014, and for every sampling, two areas were sampled, i.e., the reclaimed farmland filled with Yellow River sediments (RF) and the original, unaltered farmland (CK). The locations of the sampling points are shown in Figure 1. Five soil sampling points each were set at the RF site and the CK site. The distance between each sample point was approximately 20 m. Each soil profile (2 × 1 × 0.8 m) was excavated at each sampling point. Samples were taken from three layers of the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm). Fifteen soil samples were collected at each sampling time for both RF and CK. Thus, the samples were divided six times for a total of 180 soil samples, of which 90 were from RF and 90 were from CK.

The samples were analyzed for soil water content, acidity/alkalinity (pH), electrical conductivity (EC), organic matter, total nitrogen, available phosphorus and available potassium.

The soil samples were air-dried under natural sunlight for an extensive period of time to make their water contents constant (approximately 1–3%). Some soil samples were then sifted through a 10-mesh screen (screen size of 2.00 mm) and retained for sample analysis of pH, EC, available phosphorus and available potassium. Other soil samples were then sifted through a 100-mesh screen (screen size of 0.15 mm) and retained for sample analysis of total nitrogen and organic matter.

The soil water content was measured according to an oven-drying method [23], the soil pH value was measured with a glass electrode pH meter [24], and the soil EC was measured with a conductivity meter [25]. The soil total nitrogen content was determined using a semi-micro-Kjeldahl method [26]. The available phosphorus content (extraction using 0.5 $mol \cdot L^{-1}$ $NaHCO_3$) was determined with a molybdenum antimony colorimetric method [26,27]. First, reagents were prepared; 42.0 g of $NaHCO_3$ was dissolved in 800 mL distilled water, and a 0.5 $mol \cdot L^{-1}$ NaOH solution was used to adjust the pH of the extract to 8.5. Then, extractions were carried out. Air-dried soil samples were passed through a 20-mesh (screen size of 0.85 mm) sieve, 2.5 g of the sample was weighed into a 150-mL conical flask, and 50.00 mL $NaHCO_3$ solution with the concentration of 0.5 $mol \cdot L^{-1}$ was added; a spoonful of phosphorus-free activated carbon was added. The stopper was tightened, and the bottle was shaken for 30 min on an oscillator [28]. Soil available potassium content (extraction using 1 $mol \cdot L^{-1}$ NH_4OAc) was determined with a flame photometer [29]. Again, reagents were prepared; 77.09 g of chemical pure ammonium acetate (CH_3COONH_4) was diluted with water; the volume was fixed to nearly 1 L and adjusted to pH 7.0 with NH_4OH before dilution to 1 L. Extractions were also carried out; air-dried soil samples were passed through a 18-mesh (screen size of 1.00 mm) sieve, 5.00 g of the sample was weighed into a 100 mL conical flask, and then 50.00 mL neutral NH_4OAc solution with the concentration of 1 $mol \cdot L^{-1}$ was added. The rubber stopper was tightly plugged, and the bottle was shaken for 30 min. The sample was filtered into a 150-mL triangle bottle with dry ordinary filter paper [28]. Soil organic matter content was determined according to a potassium dichromate volumetric method [30].

2.5. Data Analysis

The SPSS 19.0 program was used to calculate the standard deviation (SD) of each sample. The SPSS 19.0 program (one-way ANOVA at 0.05 level) was also used to calculate the significant difference among different samples.

3. Results and Discussion

3.1. Soil Water Content

The soil water contents of RF and CK are shown in Table 1. The soil water content of the topsoil layer (0–20 cm) of the reclaimed farmland with Yellow River sediment (RF) changed from 16.8% at the initial stage of reclamation to 14.1%, 18.8%, 14.8%, 17.1% and 18.0% on the subsequent sampling dates. Overall, the soil water content showed fluctuating changes. The changes in the soil water contents of the subsoil layer (20–50 cm) and deep soil layer (50–80 cm) at the RF site were similar to those of the topsoil layer (0–20 cm) and showed fluctuating changes. The main reason for this pattern may be related to the climate and irrigation frequency. In most agroecosystems, the soil water content changes rapidly following rainfall, particularly after high-intensity, short-duration events [31]. Compared with that of CK, the water content of RF was significantly lower. With an increase in the reclamation time, the difference in the soil water content between RF and CK gradually decreased. This difference existed because the Yellow River sediments are sandy and have a weak water-holding capability [18]. The water content of RF was higher due to increased irrigation frequency.

Table 1. Soil water content, pH, and EC of the RF site and CK site.

Depth	Time	SWC (%)		pH		EC (μs·cm^{-1})	
		RF	CK	RF	CK	RF	CK
0–20 cm	Feb. 2012	16.8 ± 1.2 cde	23.1 ± 1.7 a	7.61 ± 0.13 a	7.54 ± 0.12 a	135 ± 4 c	152 ± 4 a
	Sept. 2012	14.1 ± 1.5 e	17.4 ± 1.4 cd	7.55 ± 0.18 a	7.66 ± 0.14 a	140 ± 2 bc	146 ± 4 ab
	Apr. 2013	18.8 ± 2.2 bc	22.7 ± 2.2 a	7.52 ± 0.11 a	7.62 ± 0.16 a	126 ± 3 d	136 ± 5 c
	Sept. 2013	14.8 ± 1.2 de	20.0 ± 2.3 b	7.66 ± 0.22 a	7.67 ± 0.17 a	127 ± 6 d	140 ± 7 bc
	Apr. 2014	17.1 ± 1.4 cde	23.1 ± 2.1 a	7.74 ± 0.11 a	7.52 ± 0.10 a	139 ± 6 bc	149 ± 6 a
	Sept. 2014	18.0 ± 1.4 bc	21.0 ± 1.0 ab	7.71 ± 0.09 a	7.77 ± 0.07 a	147 ± 3 ab	145 ± 3 ab
20–50 cm	Feb. 2012	24.4 ± 1.5 e	29.4 ± 0.8 ab	7.72 ± 0.08 abc	7.76 ± 0.09 abc	165 ± 5 de	181 ± 2 bc
	Sept. 2012	19.9 ± 2.4 f	26.6 ± 1.6 cde	7.82 ± 0.11 abc	7.69 ± 0.10 abc	182 ± 6 bc	190 ± 6 b
	Apr. 2013	26.4 ± 1.0 cde	29 ± 1.4 abc	7.68 ± 0.09 bc	7.64 ± 0.09 c	171 ± 8 cd	162 ± 5 de
	Sept. 2013	23.9 ± 1.2 e	31 ± 1.7 a	7.84 ± 0.06 ab	7.73 ± 0.09 abc	158 ± 8 e	164 ± 7 de
	Apr. 2014	21.2 ± 2.1 f	27.7 ± 0.9 bcd	7.87 ± 0.09 a	7.7 ± 0.09 abc	162 ± 103 de	186 ± 10 b
	Sept. 2014	21.6 ± 2.3 f	25.8 ± 1.5 de	7.78 ± 0.06 abc	7.82 ± 0.07 abc	179 ± 106 bc	201 ± 6 a
50–80 cm	Feb. 2012	18.1 ± 0.6 cd	29.1 ± 2.3 a	7.91 ± 0.07 abc	7.76 ± 0.08 c	102 ± 8 e	174 ± 8 b
	Sept. 2012	15.2 ± 0.9 d	25.9 ± 2.0 b	8.02 ± 0.14 a	7.88 ± 0.13 abc	124 ± 6 d	192 ± 8 a
	Apr. 2013	17.2 ± 0.8 cd	27.4 ± 1.7 ab	7.89 ± 0.07 abc	7.79 ± 0.13 bc	116 ± 6 d	153 ± 7 c
	Sept. 2013	16.2 ± 0.8 d	27.4 ± 1.7 ab	7.98 ± 0.15 ab	7.73 ± 0.09 c	95 ± 9 e	168 ± 9 b
	Apr. 2014	19.3 ± 1.4 c	30.2 ± 2.0 a	7.83 ± 0.08 abc	7.79 ± 0.12 bc	94 ± 6 e	192 ± 8 a
	Sept. 2014	17.4 ± 2.0 cd	28.1 ± 2.1 ab	7.89 ± 0.05 abc	7.73 ± 0.09 c	103 ± 9 e	179 ± 9 b

Note: SWC, soil water content; RF, reclaimed farmland; CK, unaltered farmland. Values are means ± standard deviations of five soil samples. Values with the same letter for the same depth of different treatments (RF and CK) are not significantly different at the $p < 0.05$ level.

3.2. Acidity/Alkalinity (pH) and Electrical Conductivity (EC) of Soil Solutions

3.2.1. pH Value

The soil pH values of RF and CK are provided in Table 1. There was no significant difference between the soil pH values of the topsoil layer (0–20 cm) of the RF and CK at the 0.05 level, and the same was found in the subsoil layer (20–50 cm) and the deep soil layer (50–80 cm). The pH values of the samples were higher than 7, which indicated that the soil of RF and CK were both alkaline. The sediments of the Yellow River were derived from quaternary sediments of the Loess Plateau, which was similar to the loess of the midstream of the Yellow River in particle size distribution, organic matter content and mineral composition [32]. Therefore, the Yellow River sediments were weakly alkaline, which was consistent with the pH value of loess (7.5–8.6) [33]. Maize and wheat are the main local crops. The suitable pH value for the growth and development of the local crops ranges from 6.5 to 8.0 [34]. The soil pH value of RF ranged from 7.5 to 8.0, which is suitable for the cultivation of the main local crops.

3.2.2. Electrical Conductivity (EC)

Soil EC is an index for determining soil water-soluble salt, which is a factor that limits seed germination and crop growth, and is an important property of soil [34]. As shown in Table 1, the soil EC of topsoil layer (0–20 cm) of RF was lower than that of CK except in September 2014. The soil EC of the subsoil layer (20–50 cm) of RF was lower than that of CK. The soil EC of the deep soil layer (50–80 cm) of RF was significantly lower than that of CK at the 0.05 level. At the same time, the soil EC of RF showed an overall trend of increasing at first and then decreasing with increasing soil depth. The soil EC of the subsoil layer (20–50 cm) was greater than that of the topsoil layer (0–20 cm) and soil EC of the deep soil layer (50–80 cm) was the lowest. Normal growth and development of crops requires the non-salinization of soil, in which the EC of the soil is lower than 2000 $\mu s \cdot cm^{-1}$ [34]. The maximum EC of the topsoil layer (0–20 cm) of RF was 147 $\mu s \cdot cm^{-1}$, that of the subsoil layer (20–50 cm) was 182 $\mu s \cdot cm^{-1}$, and that of the deep soil layer (50–80 cm) was 124 $\mu s \cdot cm^{-1}$. The soil EC of RF was far lower than the standard value (2000 $\mu s \cdot cm^{-1}$). Therefore, the soil EC of RF was suitable for the growth and development of crops.

3.3. Soil Status of Major Nutrients

3.3.1. Organic Matter

Soil organic matter is an important component of soil that plays a key role in improving soil physical and chemical properties and plant growth and is an important index used to evaluate soil fertility and quality [35]. The soil organic matter contents of RF and CK are shown in Table 2. With increasing depth, the organic matter content of RF gradually decreased, and the same trend was observed for CK. The topsoil had the highest organic matter content in the soil structure [36]. The soil organic matter contents of the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm) of RF were less than those of CK. The loss of soil organic matter in RF was related to the filling reclamation process. Topsoil and subsoil stripping and backfilling were carried out in the filling reclamation project, which led to soil mixing and improved soil aeration. Soil disturbance via mixing and moving can improve soil aeration, enhancing aerobic microbe activity and accelerating the microbe decomposition activity, which decreases the content of soil organic matter [37]. Furthermore, organic and inorganic fertilizers were applied over a long period, and the root residues of the crops increased the organic matter content [38–40] in CK. With the increase of reclamation years, the organic matter in the topsoil layer (0–20 cm) of RF increased; for example, the organic matter of RF was 12.07 g kg^{-1} in February 2012 and 17.51 g kg^{-1} in September 2014. The same trend was found in the subsoil layer (20–50 cm) and deep soil layer (50–80 cm).

Table 2. Soil status of major nutrients of the RF site and CK site.

Depth	Time	OM (g kg^{-1})		TN (g kg^{-1})		AP (mg kg^{-1})		AK (mg kg^{-1})	
		RF	CK	RF	CK	RF	CK	RF	CK
0–20 cm	Feb. 2012	12.07 ± 1.48 e	26.55 ± 1.67 b	0.52 ± 0.06 g	1.02 ± 0.11 bc	8.3 ± 0.7 de	15.4 ± 1.4 c	122.0 ± 10.2 cd	167.8 ± 8.3 b
	Sept. 2012	10.69 ± 2.66 e	24.86 ± 1.94 bc	0.58 ± 0.06 fg	0.95 ± 0.11 cd	7.6 ± 0.6 e	17.0 ± 1.5 abc	114.0 ± 6.8 d	197.8 ± 11.3 a
	Apr. 2013	11.85 ± 1.10 e	30.58 ± 2.31 a	0.64 ± 0.09 efg	1.11 ± 0.15 abc	8.2 ± 0.7 de	18.2 ± 1.8 ab	140.2 ± 10.5 c	202.0 ± 15.4 a
	Sept. 2013	14.23 ± 1.75 de	28.01 ± 3.28 ab	0.66 ± 0.07 efg	1.24 ± 0.08 a	8.5 ± 0.9 de	16.4 ± 1.2 bc	131.2 ± 14.8 cd	174.0 ± 17.2 b
	Apr. 2014	14.20 ± 2.49 de	22.83 ± 2.28 c	0.74 ± 0.06 ef	1.19 ± 0.16 ab	9.1 ± 0.9 de	18.8 ± 1.9 a	132.8 ± 12.9 cd	197.4 ± 11.9 a
	Sept. 2014	17.51 ± 2.09 d	26.79 ± 3.74 b	0.81 ± 0.11 de	1.09 ± 0.19 abc	10.0 ± 0.9 d	17.9 ± 1.5 ab	158.0 ± 13.6 b	200.4 ± 11.0 a
20–50 cm	Feb. 2012	7.24 ± 1.28 e	15.19 ± 1.19 a	0.36 ± 0.06 d	0.61 ± 0.10 a	3.6 ± 0.5 cde	4.7 ± 0.7 abc	79.0 ± 12.4 cd	155.4 ± 16.4 a
	Sept. 2012	6.10 ± 1.00 e	12.48 ± 1.79 bc	0.31 ± 0.08 d	0.58 ± 0.06 ab	4.5 ± 0.5 abc	5.0 ± 0.6 ab	61.2 ± 8.8 d	136.8 ± 8.8 b
	Apr. 2013	6.72 ± 1.00 e	14.69 ± 1.53 ab	0.36 ± 0.06 d	0.65 ± 0.09 a	2.7 ± 0.4 e	3.3 ± 0.5 de	76.2 ± 10.9 cd	166.6 ± 14.0 a
	Sept. 2013	9.28 ± 1.52 d	12.24 ± 1.41 bc	0.38 ± 0.11 cd	0.53 ± 0.08 abc	4.7 ± 0.6 abc	3.8 ± 0.5 cde	59.6 ± 9.3 d	138.8 ± 11.9 b
	Apr. 2014	10.40 ± 1.81 cd	15.50 ± 1.90 a	0.42 ± 0.07 cd	0.60 ± 0.09 a	5.0 ± 0.9 ab	5.6 ± 1.0 a	67.0 ± 9.4 d	157.4 ± 13.9 a
	Sept. 2014	10.04 ± 1.68 cd	14.14 ± 2.08 ab	0.44 ± 0.11 bcd	0.58 ± 0.1 ab	3.1 ± 0.3 de	4.1 ± 0.6 bcd	86.2 ± 7.7 cd	161.6 ± 9.6 a
50–80 cm	Feb. 2012	2.61 ± 0.55 f	10.39 ± 1.06 a	0.09 ± 0.02 f	0.50 ± 0.10 ab	3.0 ± 0.3 d	4.9 ± 0.6 ab	61.4 ± 8.2 e	98.2 ± 10.4 bc
	Sept. 2012	4.10 ± 1.22 ef	7.69 ± 0.78 cd	0.17 ± 0.04 ef	0.40 ± 0.10 bc	3.7 ± 0.5 cd	3.3 ± 0.4 cd	47.0 ± 6.4 ef	80.8 ± 11.2 d
	Apr. 2013	2.99 ± 0.32 f	9.36 ± 1.28 ab	0.16 ± 0.05 ef	0.43 ± 0.09 ab	3.3 ± 0.4 cd	2.6 ± 0.4 d	41.8 ± 7.8 f	114.4 ± 15.9 a
	Sept. 2013	4.06 ± 0.66 ef	6.43 ± 0.86 d	0.22 ± 0.05 def	0.52 ± 0.10 ab	2.8 ± 0.6 d	5.1 ± 0.8 ab	46.8 ± 9.0 ef	83.6 ± 10.0 cd
	Apr. 2014	2.73 ± 0.69 f	7.16 ± 1.30 cd	0.25 ± 0.05 de	0.47 ± 0.10 ab	4.4 ± 0.7 bc	5.6 ± 1.0 a	50.2 ± 6.8 ef	90.2 ± 10.9 cd
	Sept. 2014	4.69 ± 0.76 e	8.22 ± 1.65 bc	0.31 ± 0.09 cd	0.55 ± 0.09 a	3.6 ± 0.6 cd	5.3 ± 0.4 ab	55.4 ± 7.8 ef	107.8 ± 9.1 ab

Note: OM, organic matter; TN, total nitrogen; AP, available phosphorus; AK, available potassium. Values are means ± standard deviations of five soil samples. Values with the same letter for the same depth of different treatment (RF and CK) are not significantly different at the $p < 0.05$ level.

3.3.2. Total Nitrogen

The soil total nitrogen contents of RF and CK are shown in Table 2. The soil total nitrogen content of the topsoil layer (0–20 cm) of RF was lower than that of CK. With an increase in the reclamation time, the difference in the soil total nitrogen content between RF and CK decreased. In September 2012, the total nitrogen content of the topsoil layer (0–20 cm) of RF was 0.58 $g \cdot kg^{-1}$, whereas that of CK was 0.95 $g \cdot kg^{-1}$, a difference of 0.37 $g \cdot kg^{-1}$. By September 2014, the total nitrogen content of the topsoil layer (0–20 cm) of RF was 0.81 $g \cdot kg^{-1}$ and that of CK was 1.09 $g \cdot kg^{-1}$, a difference of 0.28 $g \cdot kg^{-1}$. With the increase in the soil depth, the soil total nitrogen content decreased. A similar result was reported by Xu [41]. This result was due to the decreased amount of decomposed debris of plants and animals with increasing soil depth [42–44]. The soil total nitrogen contents of the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm) of RF were less than those of CK. Soil total nitrogen in CK exhibited a long-term accumulation process. In the filling reclamation process, soil stripping and backfilling disturbed the soil. The stripped soil was exposed to air for a long time. After the completion of sediment consolidation, the soil was backfilled. During the entire process, the soil was disturbed twice, destroying the soil structure, affecting the water permeability and corrosion resistance of the soil, and reducing the infiltration, interception and water storage capacity of the soil, thereby changing the original soil nutrients [45]. The soil total nitrogen content in an artificially disturbed plot is significantly lower than that in an unaltered plot. The soil total nitrogen content in RF increased with the increase of reclamation years in the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm). Under the conditions of cultivation and fertilization, water, fertilizer, gas and heat were continuously harmonized such that the soil quality could be improved continuously.

3.3.3. Available Phosphorus

The soil available phosphorus contents of RF and CK are shown in Table 2. With the increase in reclamation years, the content of available phosphorus in the topsoil layer (0–20 cm) gradually increased. The reason for this increase is that the application of phosphorus fertilizer affects the available phosphorus content, and the available phosphorus content in the topsoil layer (0–20 cm) is greatly affected by artificial tillage and artificial fertilization [31]. There was little difference in the soil available phosphorus of the subsoil layer (20–50 cm) between RF and CK. With an increase in the reclamation time, the available phosphorus content in the deep soil layer (50–80 cm) of RF changed little because phosphorus is easily fixed in soil [31,46], and the effect of fertilization on the available phosphorus content in deep soil was not obvious. Soil fixation methods for phosphorus include adsorption fixation and chemical reaction fixation. Soil phosphorus fixation depends on the contents of calcium carbonate, iron-aluminum oxides, soil clay and the initial concentration of phosphorus in the soil. A large amount of adsorption fixation occurs at the beginning of fertilization, lasting for several hours to tens of hours, and then gradually converts to chemical reaction and fixation. Thus, the available phosphorus is converted into invalid phosphorus for several months or even several years [47]. The soil available phosphorus levels in the subsoil layer (20–50 cm) and deep soil layer (50–80 cm) mainly result from the release of phosphorus from the soil and the transport of available phosphorus from the topsoil layer (0–20 cm). The soil itself contains a certain amount of phosphate. When the phosphate concentration in the solution is lower than a certain value, the soil begins to release phosphorus [48]. Soil available phosphorus can be transported in the environment through hydrological pathways (leaching) [31]. The content of available phosphorus in the topsoil layer (0–20 cm) is more susceptible to fertilization than in the subsoil layer (20–50 cm) and deep soil layer (50–80 cm). Because phosphorus fertilizer is applied to the topsoil layer, phosphorus is easily fixed and difficult to move to the subsoil and deep soil. With the increase of reclamation years, the soil available phosphorus in the topsoil layer (0–20 cm) of RF presented an increasing trend. An appropriate amount of phosphorus fertilizer was applied to improve the content of available phosphorus [31,49] of RF.

3.3.4. Available Potassium

Soil available potassium refers to potassium that is easily absorbed and utilized by crops, and the abundance and deficiency of potassium nutrition in crops is directly restricted by the available potassium content in soil [50]. The soil available potassium contents of RF and CK are shown in Table 2. With an increase in soil depth, the soil available potassium content of RF decreased, and the same trend was observed for CK. The soil available potassium contents of the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm) of RF were less than those of CK. The loss of soil available potassium in RF was related to the filling reclamation engineering process. The effect of the reclamation process on available potassium is the same as the effect on total nitrogen. In addition, the reclaimed farmland was only cultivated for three years. The fertility cultivation time after the reclamation of RF was much shorter than that of CK, and the accumulation of available potassium was insufficient. With the increase of reclamation years, the content of available potassium in the topsoil layer (0–20 cm), subsoil layer (20–50 cm) and deep soil layer (50–80 cm) of RF increased. Inorganic potassium fertilizer and organic fertilizer were applied to supplement the available potassium content [51] of RF.

3.4. Crop Yields

From June 2012 to October 2016, wheat was harvested in June and maize was harvested in October every year. The crop yields of RF and CK are shown in Table 3. In June 2012, the wheat yield of RF was 3215 kg·ha^{-1}, while that of CK was 7581 kg·ha^{-1}; thus, the wheat yield of RF was only 42.41% of that of CK. In October 2016, the maize yield of RF was 7776 kg·ha^{-1}, while that of CK was 9714 kg·ha^{-1}; thus the maize yield of RF was 80.05% of that of CK. A total of 10 crops were planted, and the proportion of the RF yield to the CK yield increased. With the increase in reclamation years, the crop yield of RF increases. Because soil fertility increases annually, the crop yield also increases annually. However, by 2016, the crop yield of the reclaimed farmland was still lower than that of the normal farmland.

Table 3. Crop yields of the RF site and CK site.

Harvest Time	Crop	RF (kg·ha^{-1})	CK (kg·ha^{-1})	RF/CK (%)
Jun. 2012	Wheat	3215	7581	42.41
Oct. 2012	Maize	4629	9649	47.97
Jun. 2013	Wheat	3552	7366	48.22
Oct. 2013	Maize	5624	10250	54.87
Jun. 2014	Wheat	4532	7048	64.30
Oct. 2014	Maize	6727	9794	68.68
Jun. 2015	Wheat	5341	7176	74.43
Oct. 2015	Maize	7313	9487	77.08
Jun. 2016	Wheat	5934	7553	78.56
Oct. 2016	Maize	7776	9714	80.05

4. Conclusions

The filling reclamation procedure included stripping the topsoil and subsoil layer by layer, transporting Yellow River sediments to the subsidence land with a hydraulic pump, and backfilling the topsoil and subsoil layer by layer. Filling reclamation with Yellow River sediments has realized the restoration of cultivated land in the experimental site. A 95% farmland recovery rate was achieved in the experimental site in Liangshan County, Jining City, Shandong Province, China. For mines near the Yellow River, this approach is an important method for restoring cultivated land lost due to coal mining subsidence.

The water content of RF presented a fluctuating trend, mainly related to climate and irrigation. The water contents in the topsoil layer, subsoil layer and deep soil layer of RF were lower than those of CK because the Yellow River sediments are sandy with a weak water-holding capability.

With an increase in the reclamation time, the difference in the soil water content between RF and CK gradually decreased.

No significant difference was observed between the soil pH values of the topsoil layers of RF and CK at the 0.05 level, and the same trend was found for the subsoil layer and deep soil layer. The RF and CK soils were weakly alkaline, which was suitable for cultivation of the main local crops (maize and wheat). The EC of RF indicated that the reclaimed soil was a non-salinized soil suitable for the growth and development of crops.

With the increase of reclamation years, the soil organic matter, total nitrogen, available phosphorus and available potassium of RF showed an increasing trend. The accumulation of soil nutrients is a long-term process. Measures to improve the water content and fertility of RF included the following: increasing the irrigation frequency; returning crop waste; applying organic fertilizers such as green manure, farmyard manure and compost; and applying inorganic fertilizers such as nitrogen fertilizer, phosphorus fertilizer and potassium fertilizer.

Crop yields of RF showed an increasing trend year by year. By 2016, the fifth year of cultivation, the maize yield of RF was 80.05% of that of CK.

In summary, the filling reclamation the subsidence land with Yellow River sediments is an effective way to restore farmland and realize the sustainable utilization of cultivated land in China. With the increase of reclamation years, the soil nutrients and crop yields of RF showed an increasing trend.

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