Restoration technologies of damaged paddy in hilly post-mining and subsidence-stable area of Southwest China

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Abstract: The paddy fields and water storage facilities are seriously damaged by the coal mine subsiding in the hilly post-mining and subsidence-stable areas in China, which make the farmers there being suffered greatly from the lack of water for traditional rice cultivation and daily life. The purpose of this paper is to find a method to restore the damaged paddy fields, thereby promoting sustainable development of land resources, and alleviating the contradiction between people and land, as well as creating a more inhabitable environment. The research methodology included field experiments, cultivated observation, and field investigation. This paper selected the Songzao Mining Area as the research area, and focused on the restoration technologies of damaged paddy fields, through the following four different measures at three experimental fields: (1) Traditional repeated cattle plowing (CK); (2) Water retention agent with repeated cattle plowing (W&C); (3) Film without holes under tilth depth (FO); and (4) Film with holes under tilth depth (FW). At last, a contrastive analysis of the four measures was made according to the results of the experiments. The results show that the use of water retaining agent with repeated cattle plowing (W&C) can be the most appropriate method to restore the damaged paddy field in the hilly post-mining and subsidence-stable area in southwest China. Compared with the other three measures, its water productivity is the maximum (0.81 kg/m^3), and the net income is the highest (1 403 \$/hm^2). What's more, it is simple, short time-consuming, and low cost, which is benefit to generalize the use of this restoration technology.

Keywords: land restoration, damaged paddy field, post-mining and subsidence-stable area, water consumption, hilly areas
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1 Introduction

Coal has been considered as an affluent non-renewable resource in the world[1]. As the largest coal producer and consumer of coal, China treats coal as the uppermost source of energy. According to the statistics, coal has accounted for almost 70% of the primary energy consumption in China[2]. With the rapid growth of the national economy and population, the coal mining has caused the damage to plenty of land resources. Currently, the total amount of damaged land resources is more than 400 million hm^2, and with an increasing damage rate of 3.3-4.7 million hm^2/a[3]. The restoration of mine wasteland began in late 1970s, but the restoration process was sluggish[4]. In China, the overall reclamation rate of mine land (the ratio of reclaimed land area to the total degraded land area) is only about 15%[5], which is far behind that of developed countries (more

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than 70%)[6]. Therefore, the land reclamation in China is faced with the problem of "the old accounts no return, the new accounts also debt".

Studies have shown that the long-term underground mining operations caused the stress of geological structure changed, the rock broken and huge areas of collapse and subsidence, which made the impervious layer produced cracks[7-10]. These have led to falling the groundwater level, reducing the surface runoff, destroying the paddy fields, especially in Chongqing, Sichuan, Guizhou provinces, which are typical limestone areas in southwest China. Damaged geological structure has also caused many other problems, such as the decreasing water retention capacity of paddy fields and the serious leakage of water storage facilities (e.g., reservoir, pond and stream). Therefore, the local farmers suffer seriously from the lack of water for traditional rice cultivation and domestic use of daily life. The deeply planted tradition in their minds makes some local famers reluctant to migrate to other places. In addition, there is no more land to which to move to for such a huge population. In the mining areas, this phenomenon is undermining the ecological environment, exacerbating the contradiction between people and land, and affecting any economic and social sustainable development[11-13]. Rice is one of the most important staple food in the world[14,15], especially in China. In order to ensure the farmers' normal production and life in a coal post-mining and subsidence-stable area, damaged paddy field restoration technologies are in urgent need. However, existing restoration technologies are not applicable in the study area at present. Many research results are still in the theoretical stage and some accomplishments were all at laboratory or small-scale field demonstration stage and still far from the practical use in reality[16-19], or they approach the topic only from the waste utilization perspective for cultivated land reclamation[4,20]. Studies show that the mine wastelands were rehabilitated through engineering, biotechnology or vegetation restoration to improve soil properties, biodiversity and vegetation[21-27]. These methods are more mature, but still not for the damaged paddy fields. So the damaged paddy field restoration technologies are still lack of experimental studies and field applications. If the existing engineering technologies mentioned above were used to rehabilitate damaged paddy fields in Hilly Post-mining and Subsidence-Stable Area of Southwest China, it will face a lot of problems, such as high technical requirements, great investment, large earthwork transportation, long construction period, difficult to master by the local farmers. Therefore, further exploring and improving the damaged paddy field restoration technologies is of great significance for the sustainable development of land resources, and alleviating the current contradiction between people and the land, especially in hilly post-mining & subsidence-stable areas in southwest China.

This study is designed to investigate the restoration technologies of damaged paddy in hilly post-mining and subsidence-stable area in southwest China. Specifically, the restoration measures described below will be examined. As the most traditional plowing method in China, the cattle plowing can form a plowpan under the plough layer. The plowpan profile constitution can help to improve soil structure and the condition of aggregates[28], hinder the dissolved organic carbon (DOC) leaching into the lower soil horizon[29], and it is conducive to the accumulation of soil organic carbon (OC), total nitrogen and available nitrogen in plough layer[28-32]. As a water-saving measure of chemical regulation, water retaining agent received widespread attention immediately when it appeared in the world. In the 1960s, United States started to use the starch graft polyacrylonitrile made of corn as aquasorb[33]. Its beginning of development can date back to the 1980s in China[34]. Studies have shown that the water retaining agent can improve the soil water holding capacity and soil structure, reduce deep percolation of water and soil nutrient loss, and increase crop yields[34-37]. As one of the most important agricultural applications, the plastic films are widely used in greenhouse, walk-in tunnel and low tunnel covers, and mulching[38], they pervade all aspects of agriculture and horticulture[39-41]. In arid regions, the plastic piping/drainage systems can cut the costs of irrigation by one to two-thirds, while as much as doubling crop yield[42]. The development of the agricultural plastic films is explosively growing in China. Based on these materials and methods mentioned above, this thesis is designed to study the restoration technologies of damaged paddy in hilly post-mining & subsidence-stable area of southwest China.

2 Materials and methods

2.1 Study area

The test region is located in Songzao Mining Area, Qijiang, 174 km from the main city of Chongqing (Figure 1). The north-south length is about 39.5 km, and the east-west width ranges from 2 km to 15 km with a total area about 235 km^2. The altitude is about 303 m to 1 322 m, the main geomorphic type is a hilly topography, and the main soil types are purple soil, limestone soil, and yellow soil in the mining area. The climate of the area is of the subtropical monsoon climate type with an annual average temperature, precipitation and runoff of 18.8°C, 1 070 mm and 533.5 mm, respectively, based on observations at the weather station of Qijiang from 1961 to 2010. Most of the precipitation occurs between April and September, with a marked dry season between October and March.

The history of Songzao Mining Area can date back to the late Qing Dynasty, and the production capacity has reached 5.1-5.6 × 10^4 t/a. After the coal mined out, the original mechanical equilibrium of surface rock were destroyed. Therefore, the paddy fields and water storage facilities were seriously damaged (Figure 2). According to surveys, a large area of paddy fields had been transformed into drylands, or even waste grasslands in post-mining & subsidence-stable area of Songzao Mining Area.

2.2 The experimental design

The monitoring sites were located in Longcang village, Meizi village of Ganshui town, and Zaoni village of Shihao town, which are all located in the coal post-mining and subsidence-stable zone of Songzao Mining Area (Figure 1). The damaged paddy fields were abandoned and looked just like waste grasslands (Figure 2). Soil samples were collected to test their physical-chemical characters. Four restoration methods were taken as the testing technologies in the experimental design (Table 1). In the preparation stage, in order to prevent the lateral flow among different paddy fields, the surrounding ridges of paddy fields were covered with a plastic film buried in the soil with the depth of 30-40 cm. In each testing paddy field, the inlet pipes, drainage pipes and water meters were designed for measuring irrigation amount and drainage. Fine Quality Hybrid Rice, the T-You 109 variety was adopted as the testing rice variety.

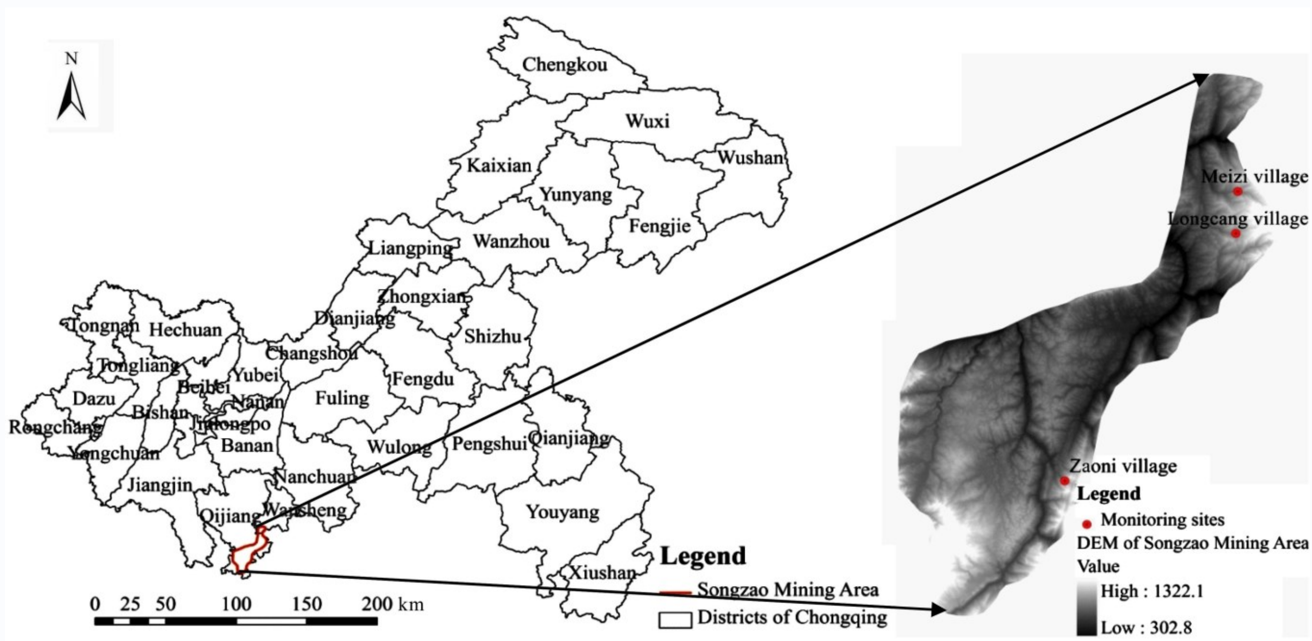


Figure 1 The location of study area and monitoring sites

Notes: a-c: Damaged water storage facilities, such as dried-up reservoir, pond and stream are very common in the study area. d-f: Paddy fields had been transformed into drylands. g-i: Testing fields at three monitoring sites at the villages of Longcang, Meizi and Zaoni (taken in the beginning of testing), and the damaged paddy fields (not processed) were abandoned and looked just like waste grasslands.

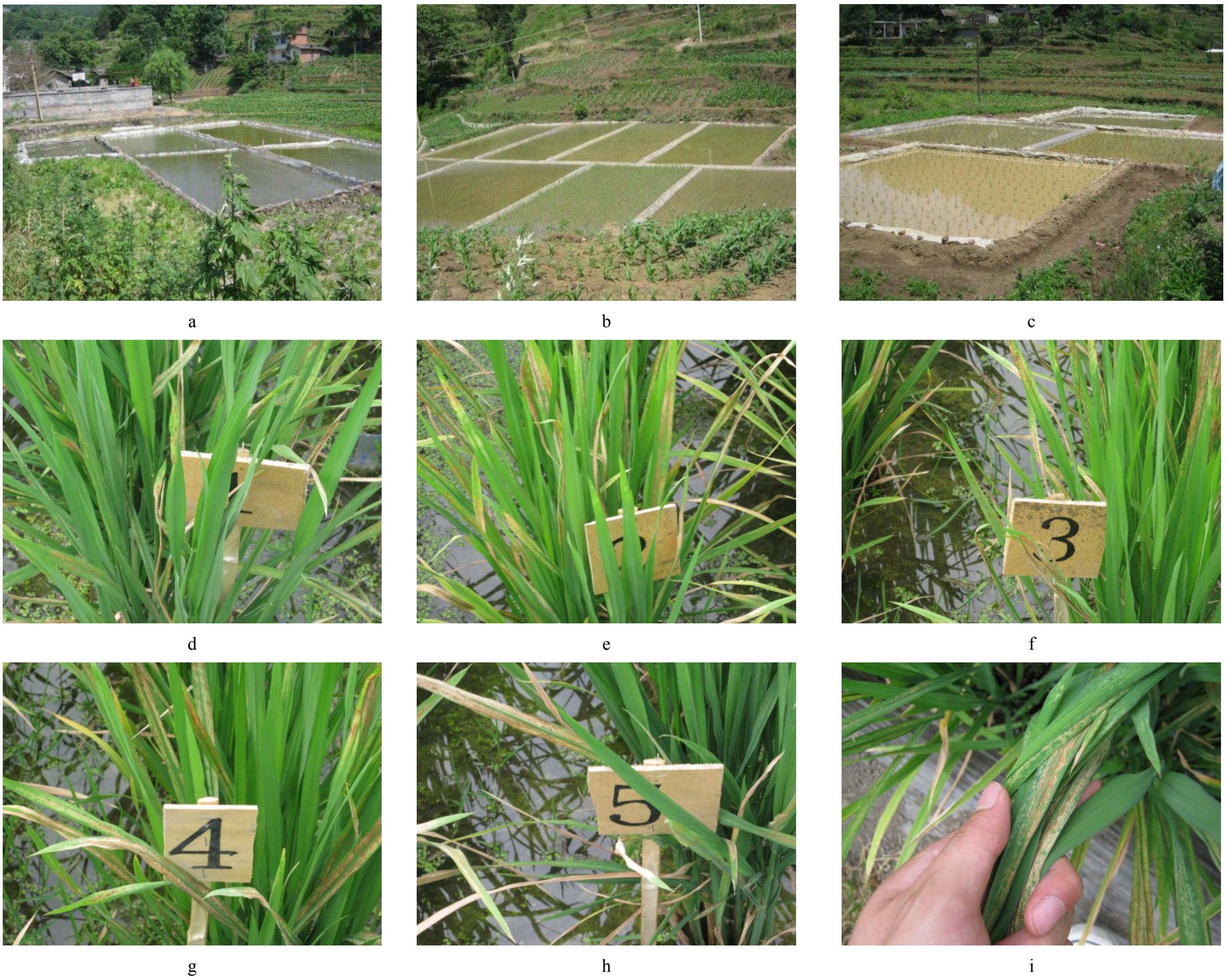
Figure 2 The situation of damaged water storage facilities and paddy fields

Table 1 The restoration methods of experimental design

Restoration Methods	Shortened Form	Choice Basis	The Introduction of Main Materials	Operation Points
Repeated cattle plowing (used as control group)	(CK)	As the most traditional plowing method in China, this method is able to accelerate the plowpan layer formation, and can improve soil structure and nutrient[28-32]	Cattle plowing equipment (plowing cattle, plows, rakes, etc.)	(1) Store water in the paddy field, meanwhile plow it repeatedly with the cattle in the middle of April, the tilling depth being about 12-20 cm. (2) Then, soak the paddy field with the water depth reached about 2/3 clod height for 3 d to 5 d. (3) After that, rake the field repeatedly, mix the soil into a slurry and level off the paddy field: usually beginning on April 20th, and ending in early May. (4) Settle 15-20 d with the water depth about 5-7 cm for precipitation.
Water retaining agent with repeated cattle plowing	(W&C)	This method is able to mobilize the clay components of soil to form an impermeable membrane under the plow layer, with functions of water-saving, fertilizer conservation and a yield increasing effect[33-37].	Water retaining agent named "paddy anti-seepage water retaining agent [a] " is produced by Jilin province new century agriculture technology co., cattle plowing equipment	Step (1) and (2) are the same with CK's. (3)Sprinkle the water retaining agent on the field surface with the standards of 250 $kg \cdot hm^{-2}$, then do as the step (3) and (4) of CK.
Film without holes under tilth depth	(FO)	This method is able to create a new impermeable layer under the plow layer, while preventing the paddy fields leakage due to goaf.	0.03 mm thick plastic sheeting, tillage tools such as hoes and shovels	(1) Dig the paddy from one corner with the depth of 30-40 cm, put the soil on the ridge, and lay the plastic film under this corner. (2) Then keep digging, and lay the new soil on the film, the rest can be done in the same manner. (3) If one film is not enough, another one needs to relay under the previous one with overlapping 2 cm. In order to avoid moisture loss, the junction should be pasted together using waterproof tape.
Film with holes under tilth depth	(FW)	This method is able to reduce the influence of the plow layer caused by the geological structural changes in goaf, and to ensure the permeability of the arable layer soil.	0.03 mm thick plastic sheeting, tillage tools such as hoes and shovels, about 5cm in diameter perforated bamboo poles	On the basis of "FW", punch the film with the hole density 100 cm × 100 cm (line spacing × hole spacing) and hole diameter (Φ) 5 cm.

Notes: a. The components by weight percentage of this paddy anti-seepage water retaining agent comprise 85% clay, 10% soil particles activator (Potassium humate), 3% soil layer forming additives (Hydrolyzed polyacrylamide) and 2% of fertilizer additives (N, P, K, et al.), respectively[36].

Breeding started in late April, and in late May, the seedlings were transplanted to the paddy field and according to the planting density of 25 cm × 15 cm (line spacing × plant spacing), two strains have been planted in one hole. According to the farmers' normal tillage requirements, the fertilizers used were urea, phosphate, potash, and ammonium hydrogen carbonate. In order to protect the crops from pests, the requisite pesticides were sprayed. During the process of rice growing, the data were measured regularly at fixed points to observe the rice growth of a fixed strain (Figure 3).



Notes: a-c: Three test regions - Longcang village, Meizi village, and Zaoni village; d-i: Observing the rice growth.

Figure 3 Observation of growing process of rice

2.3 Data collection and its analyzing method

Rice growth data are measured regularly at fixed points to observe rice growth of five fixed strains. Early work has involved recording tiller changes, and collecting the panicles in different periods after heading, for the determination of the panicle moisture content changes.

The SM1 rain (snow) gauges (Φ200 mm, outline Φ210 mm×1 030 mm) are used to measure the precipitation (*P*); the AM3 evaporation pans (Φ200 mm, outline Φ322 mm×228 mm) are used to measure the evaporation (*E*); water meters are used to measure the irrigation (*I*) and drainage (*D*). Comparing the rainfall with drainage, we can get the effective rainfall (*P*-*D*). By comparing with the meteorological data from 1961 to 2010 (50 years), the regional precipitation in 2011 was equivalent to the precipitation of 96% designed low-flow years. The effective rainfall plus irrigation is the water consumed (*Q*). Water balance equation[43] is as below:

$$\text{Inflow} = \text{Outflow} \pm \Delta \text{ Storage} \quad (1)$$

$$\text{Inflow} = P + I,\ \text{Outflow} = D + E + T + S,\ \Delta \text{ Storage} = U$$

$$P + I = D + S + E + T + U \quad (2)$$

The water consumption (*Q*) of rice can be defined as following:

$$Q = S + E + T + U \quad (3)$$

$$P + I = D + Q \quad (4)$$

$$Q = (P + I) - D = (P - D) + I \quad (5)$$

where, P: Precipitation, mm; I: Irrigation, mm; E: Evaporation, mm; D: drainage, mm; S: Seepage, mm; T: Transpiration, mm; U: Used for synthetizing organic compounds, mm; Q: Water Consumption, mm; $P–D$: Effective Rainfall, mm.

Data analysis was conducted in Excel 2010 and SPSS13.0. The physical-chemical characters of soils and meteorological data are listed in Table 2 and Table 3.

Table 2 Physical-chemical properties of soils[a]

Location	Depth /cm	Specific gravity /g·cm^{-3}	Bulk density /g·cm^{-3}	Porosity /%	Field capacity /%	Soil mechanical composition (mm; %)							pH
						2-1	1-0.25	0.25-0.05	0.05-0.02	0.02-0.005	0.005-0.001	<0.001	
Longcang village	0	2.43	1.25	48.63	-	13.05	11.29	14.10	15.94	12.17	24.87	8.57	5.5
	20	2.47	1.34	45.82	32.57	12.66	12.85	12.84	14.56	11.94	25.39	9.78	6.1
	Av	2.45	1.30	47.23	32.57	12.86	12.07	13.47	15.25	12.05	25.13	9.17	5.8
Meizi village	0	2.65	1.22	53.95	-	4.53	4.36	6.73	20.98	13.94	25.82	23.65	5.9
	20	2.66	1.31	50.68	36.03	3.17	5.12	10.70	21.31	13.21	24.85	21.64	6.2
	40	2.64	1.47	44.37	-	4.11	10.83	7.94	23.04	13.34	17.92	22.83	6.2
	Av	2.65	1.33	49.67	36.03	3.93	6.77	8.46	21.78	13.50	22.86	22.71	6.1
Zaoni village	0	2.64	1.14	56.86	-	7.76	4.44	7.67	24.37	12.76	17.86	25.14	5.6
	20	2.66	1.32	50.33	33.61	10.61	4.51	14.42	20.92	10.64	16.56	22.34	6.1
	40	2.66	1.32	50.31	-	7.29	5.62	7.20	24.90	9.73	21.40	23.86	6.3
	Av	2.65	1.26	52.50	33.61	8.55	4.86	9.76	23.40	11.05	18.61	23.78	6.0

Notes: a. The physical-chemical properties of soils were measured according to Lu (2000)[44]. Specific gravity was measured by the pycnometer method. Bulk density and field capacity were measured by cutting ring method. Soil mechanical composition was measured by the hydrometer method. The pH was measured by acidometer. Porosity (%) = (1 − Bulk density/ Specific gravity) × 100.

Table 3 Meteorological data

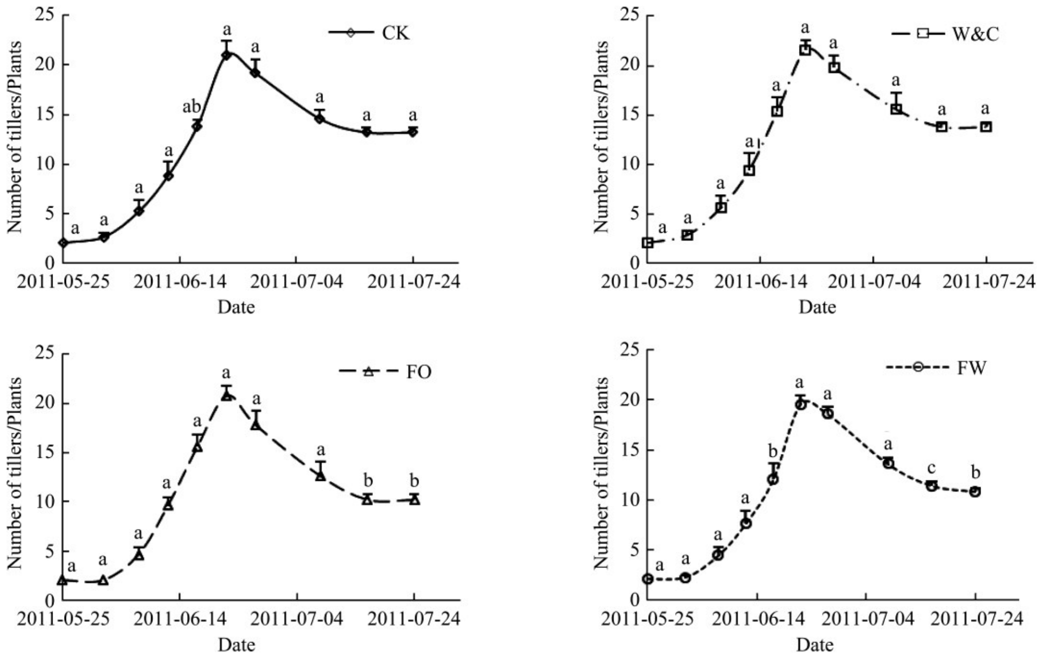
Test Region	Growing Stage of Rice	Reviving-Tillering	Tillering-Booting	Booting-Heading	Heading-Maturity	Observation Period[a]
Ganshui Town (Longcang Village & Meizi Village)	Starting and Ending Date	6.2-6.11	6.12-7.27	7.28-8.3	8.4-9.4	6.2-9.4
	The Number of Days	10	46	7	32	95
	Effective Rainfall[b] (mm)	14.4	155.7	0.6	50.4	221.1
Shihao Town (Zaoni Village)	Starting and Ending Date	5.30-6.10	6.11-7.23	7.24-8.11	8.12-9.8	5.30-9.8
	The Number of Days	12	43	19	28	102
	Effective Rainfall[c] (mm)	24.8	167.3	16.1	47.4	255.6

Notes: a. Observation Period started from the date of reviving (on June 2 in Ganshui Town, on May 30 in Shihao Town). And the data of "Observation Period" equal to the sum of all the data from reviving to maturity. b & c. The data of "Effective Rainfall" equal to "Precipitation" minus "drainage".

3 Results

3.1 Impact of restoration methods on rice growth

Comparing the tillering dynamic data resulted from the four restoration methods as listed in Table 1, the trend of rice tillering dynamic curves are basically the same. The growth rate of early tillering has a smaller difference, as well as the maximum tiller number. After reaching the maximum tiller number, the tiller number of FO and FW decreased significantly, with a reduction rate of 36%-39% (Table 4). The results indicate that the effective tiller number (or earbering tiller percentage) has the relationship with W&C > CK > FW > FO. Through the above analysis, compared with CK, W&C, FO and FW have a certain impact on the late of rice tillering stage. The trend of rice panicle moisture content dynamic curves is basically the same, with a decreasing trend for all the treatment (Figure 5). On one hand, the earbering tiller percentage under W&C is greater than that under the CK treatment, which can promote the tillering and has an effective impact on the late of tillering stage. On the other hand, the FW (or FO) have resulted in less earbering tiller percentage than that of CK, which can inhibit the tillering and has a negative impact on the late of tillering stage.



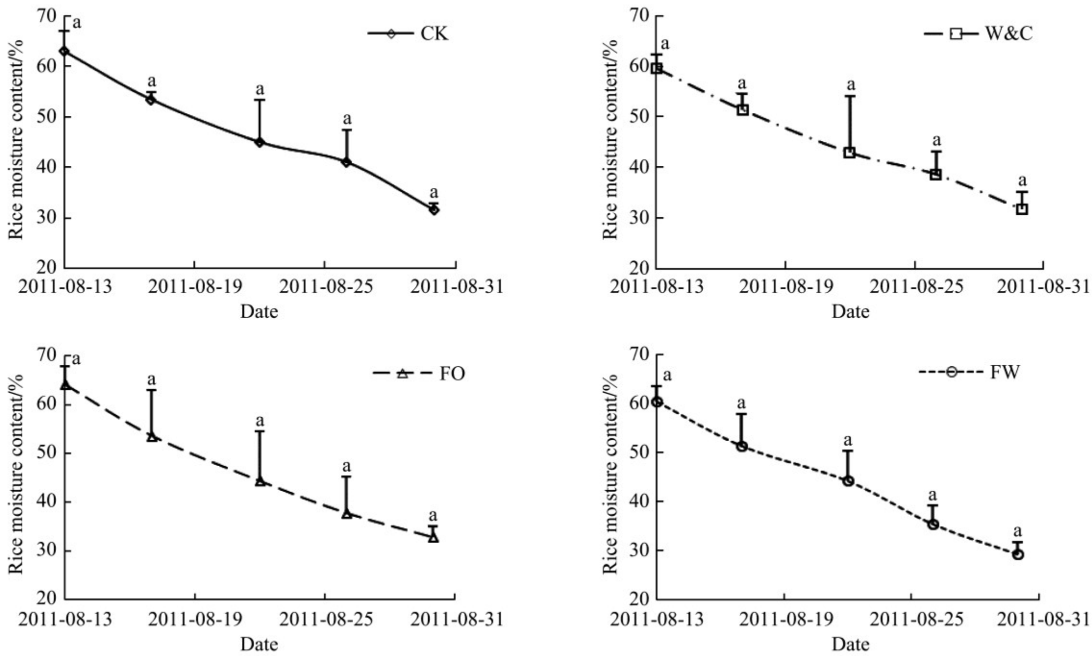
Notes: The values with the same letter are not significantly different at sig <0.05.

Figure 4 Tillering dynamics curves under different restoration methods (listed in Table 1)

Table 4 Data analysis of rice growth

Restoration Methods[a]	Maximum tiller number /plants·hole^{-1}	Effective tiller number /plants·hole^{-1}	Tillering increase rate /%·d^{-1}	Tillering reduce rate /d·%$^{-1}$	Earbering tiller percentage /%
CK	21.2	13.2	58.18	29.63	62.26
W&C	21.6	13.8	59.39	28.89	63.89
FO	20.8	10.2	56.97	39.26	49.04
FW	20.6	10.8	56.36	36.3	52.43

Notes: a. CK, W&C, FO and FW denote the Traditional repeated cattle plowing, Water retention agent with repeated cattle plowing, Film without holes under tilth depth and Film with holes under tilth depth.

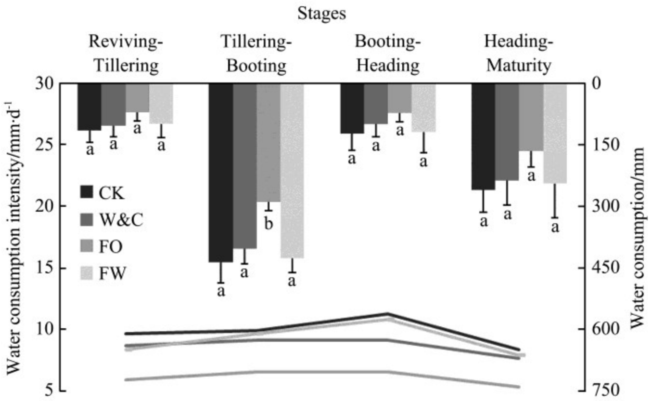


Notes: The values with the same letter are not significantly different at sig <0.05.

Figure 5 Panicle moisture content dynamics curves under different restoration methods (listed in Table 1)

3.2 Water consumption (*Q*)

The water shortage problem of the study area is serious, so the water consumption (effective rainfall plus irrigation) of the rice growing will be directly related to the normal rice cultivation. The water consumption is used to analyze the water demand analysis of rice throughout the growing period. Different stages of rice have different water consumption intensity. The value of the intensity increases from reviving, reaching the maximum from booting to heading, then starts to decrease until maturity. In the observation period for different growth stages under the four restoration methods listed in Table 1, the water consumption intensity of CK is always the largest (Figure 6). And the intensity of FO is always the smallest. The trend in water consumption in each growth stage was as follows: “Tillering to Booting” > “Heading to Maturity” > “Booting to Heading”> “Reviving to Tillering”. The relationship of water consumption of different methods in each stage is as following: CK > FW > W&C> FO. For total water consumption, compared with CK, the water-saving rate of the other three methods (W&C, FO and FW) is about 10%, 36% and 5%. Therefore, from the water consumption analysis, the water retention effect of FO is the best, followed by W&C, and FW, and there is little difference between FW and CK.



Notes: Line graph represents the water consumption intensity (mm/d). Bar graph represents the water consumption (mm). The values with the same letter are not significantly different at sig <0.05.

Figure 6 Water consumption and intensity analysis for different restoration methods (listed in Table 1)

3.3 The index set of comprehensive benefits evaluation

3.3.1 Water use efficiency analysis (Water productivity)

With the consumption of 1 m^3 of water, the average crop grain yields under the four restoration methods (CK, W&C, FO and FW) are 0.71, 0.81, 0.66, and 0.55 kg, respectively (Table 5). Therefore, the relation of the water use efficiency is as follows: W&C > CK > FO > FW.

Table 5 Data analysis of water consumption

Test Region[a]	Rice yields /kg·hm^{-2}	Water consumption /m^3·hm^{-2}	Water productivity /kg·m^{-3}	Test Region[b]	Rice yields /kg·hm^{-1}	Water consumption /m^3·hm^{-2}	Water productivity /kg·m^{-3}
CK-L	6490	9160	0.71	FO-L	3970	6110	0.65
CK-M	6570	9210	0.71	FO-M	3520	5910	0.60
CK-Z	7030	9760	0.72	FO-Z	4380	5960	0.73
Average	6697	9377	0.71	Average	3957	5993	0.66
W&C-L	6680	8210	0.81	FW-L	4900	8710	0.56
W&C-M	6730	8110	0.83	FW-M	4240	8210	0.52
W&C-Z	7190	9060	0.79	FW-Z	5470	9860	0.55
Average	6867	8460	0.81	Average	4870	8927	0.55

Notes: a & b. CK, W&C, FO and FW denote the Traditional repeated cattle plowing, Water retention agent with repeated cattle plowing, Film without holes under tilth depth and Film with holes under tilth depth. And L, M and Z denote the Longcang Village, Meizi Village and Zaoni Village.

3.3.2 Economic benefits analysis

In the first half of 2011, the unhusked rice was priced as about 0.383 \$/kg[45]. Based on this pricing, the average values of gross income of each restoration method in the three experimental areas were calculated. The input costs of each experimental field included the costs of seeds, pesticides, fertilizers, plastic sheeting, W&C and other materials, excluding labour costs, management fees and irrigation water charge, because farming mode in the study area was a mutual help in smallholder farming production, and irrigation water relied principally on rainfall. The values of each restoration method have ranked as: W&C > CK > FW > FO (Table 6).

Table 6 Economic benefit analysis[a]

Restoration Methods	Average yield[b] /kg·hm^{-2}	Gross income /×10^3 \$·hm^{-2}	Average cost /×10^3 \$·hm^{-2}	Net income /×10^3 \$·hm^{-2}
CK	6697	2.565	1.168	1.397
W&C	6867	2.630	1.227	1.403
FO	3957	1.516	5.967	-4.451
FW	4870	1.865	5.967	-4.102

Notes: a. Currency exchange rate has been carried out as "1 CNY=0.163 USD" to calculate the price of unhusked rice. b. The Average yield value of each measure equals to the average yield of three test regions, and the Average cost value is calculated in the same way.

4 Discussion

The experimental results show that, among the four restoration methods, the W&C is the most appropriate method to restore the damaged paddy field in hilly post-mining and subsidence-stable areas in southwest China. The water-use efficiency (water productivity) of 0.81 kg/m^3 and net income of 1 403 \$/hm^2 under W&C are the maximum among these four restoration methods examined in this study. Compared with CK, the W&C can produce extra 0.10 kg unhusked rice with a consumption of 1 m^3 of water, and save about 0.17 m^3 water for producing 1 kg unhusked rice. The method also has inherited advantages of the traditional repeated cattle plowing[28-32] and water retaining agent[33-37]. Therefore it can improve the structure of the soil and water-retaining capacity of damaged paddy field, with a simple operation which is easy for local farmers to master. The water retaining agent is always widely used for water-saving agriculture and the restoration of the ecological environment[46-48], as well as dry farming[37,49,50]. However, the research work about paddy field water retaining agent hasn't appeared in China untill 2006[36]. This paper first introduced the paddy field water retaining agent study in the hilly area of Southwest China. Our result of W&C's significant water-saving effect is consistent with other researchers' findings[34-37], which implies that the restoration method is applicable and effective in hilly area of Southwest China with special Karst and other complex geology.

Comparing with W&C, the other three restoration methods examined in this study have some deficiencies. As a control treatment, CK has positive impact on plough layer and plowpan, but not as effective as W&C for improving the soil water retention. FO has formed a new water-proof layer under the cattle plowing layer, so its total water consumption is the smallest. However the impermeability of plastic film to air and water directly affect the rice in late tillering, and makes the effective tillers decreased while comparing to the W&C (the spike rate reduction is about 10%). FO has also produced lower rice yield. Coupled with relatively high cost of the film itself the economic consequences are negative. In addition, the waste plastic film left in the soil cannot be degraded in a short time, which causes soil pollution and problems for growing rice in following seasons[42,51,52]. Compared to FO, air permeability and water permeability of FW increased, but fime still negatively impact rice growth. To sum up, the W&C (Water retaining agent with repeated cattle plowing) is the most practical method for damaged paddy field restoration in the hilly post-mining and subsidence-stable area in southwest China. Traditional repeated cattle plowing over a long period leads to the desired compacted plowpan and increasing the plant available water capacity[53], and it can improve soil structure, the condition of aggregates and soil nutrient[28-32]. Water retaining agent is able to mobilize the soil's clay components to form an impermeable membrane under the plough layer, with functions of water-saving, fertilizer conservation and a yield increasing effect[33-37]. Therefore, the combination of both, namely, the method of W&C, not only can effectively save costs and improve the effective utilization of water resources, but it is also suitable for the local farmers to master, and has a positive role in improving soil environment.

In this article, the irrigation water, water consumption and leakage are all calculated from the transplanted seedling to the mature period of rice. So the water quota of the seedling and plowing were not included. In fact, this part of the water consumption cannot be ignored and should be taken into account in future studies. Many factors, such as solar radiation, air temperature, wind speed, humidity, cultivation techniques, and irrigation system, can affect irrigation water use, water consumption and overall benefits. These aspects need to be further studied. In addition, although the water-use efficiency (water productivity) of water retaining agent with repeated cattle plowing (W&C) was the highest (0.81 kg/m^3) in this study, there is a big gap compared with the national average level (1.1 kg/m^3) and that in developed countries (2-3 kg/m^3)[54]. The results of this study are based on experiment in a small-scale field. Further studies of applying W&C to large-scale fields are necessary in order to draw broader conclusion.

5 Conclusions

This paper have introduced four restoration methods of damaged paddy in order to find a practicable approach to restore these damaged paddy in hilly post-mining and subsidence-stable areas of Southwest China. This study shows that, CK (Traditional repeated cattle plowing) and W&C (Water retention agent with repeated cattle plowing) have positive impact on plough layer and plowpan, and W&C can improve the soil water retention, promote the formation of tiller and increase rice yield; FO (Film without holes under tilth depth) is the most efficient method for irrigation water saving, but the cost is relatively high, and the impermeability of plastic film to air and water directly affect the rice growth, which made its rice yield and net income lower than others'; for FW (Film with holes under tilth depth), the air permeability and water permeability increased in a certain degree, but the film still negatively impact the rice growth. Therefore, the W&C (Water retaining agent with repeated cattle plowing) is the most practical method for damaged paddy field restoration in the hilly post-mining and subsidence-stable area in southwest China.

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