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EFFECTS OF GULLY LAND CONSOLIDATION ON SOIL ORGANIC CARBON, SOIL ENZYMES AND ITS INFLUENCES ON MAIZE YIELD

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Key words: Gully land consolidation, Maize yield, Soil enzyme activity, Soil Organic carbon, Remediation years

Abstract

The change characteristics of 5 indicators of soil organic carbon (SOC) content, dehydrogenase activity, protease activity, catalase activity, and maize yield were analyzed at 0a before and 3, 4, and 8 years after remediation in the study area. Results showed that the coefficient of variation (*CV)* of each index in the study area was generally small, the variation degree of soil organic carbon content was the highest, and the variation degree of catalase activity and maize yield was the least. After the implementation of the gully land consolidation, the *CV* of each index in the gully showed a decreasing trend, and the distribution of each index in the gully tended to be uniform. With the increase of remediation years, SOC content, soil enzyme activity and maize first yield showed a trend of decrease and then increase, and the change trend of each index was slightly different at gully head, the middle of gully and the gully outlet, the change is significant. At the gully head, the SOC content did not return to the level of 0a after 8a of remediation, and the other indicators returned to the level of 0a or higher than that of 0a. At the gully head, at $p < 0.05$ level, maize yield showed a very significant positive correlation with catalase activity, and a negative correlation with protease activity. In the middle of gully, there was a significant positive correlation with organic carbon content, soil protease and catalase activities, and it was negatively correlated with dehydrogenase activity but not significantly. At the gully outlet, there was a very significant positive correlation with protease activity.

Introduction

Gully land consolidation is a new model of gully management in Yan'an, which integrates the construction of dam systems, restoration of old dams, reconstruction of saline-alkali land, development and utilization of idle gully land, and ecological construction for the special landforms of the hilly and gully areas of the Loess Plateau. It is a systematic project to increase farmland, protect ecology, and benefit people's livelihood (Wang *et al.* 2020). By the end of 2020, 369.86km^2 of gully land consolidation had been completed, 189,000 hm^2 of high-standard farmland had been constructed, and 68.62km^2 of newly added arable land had been built (Li *et al*. 2016).

Soil organic carbon (SOC) is the core of soil nutrient transformation, which reflects the ability of soil to intercept carbon and is closely related to soil nutrients (Cui *et al*. 2021). Soil enzymes are catalysts of soil biochemical reactions, which promote the transformation of soil nutrients and can sensitively respond to changes in soil quality (Sun *et al*. 2021). As one of the main food crops in Yan'an, maize plays an important role in ensuring regional food security. Revealing the succession law of SOC and soil enzymes status maize yield is of great significance to agricultural

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production and environmental management. Therefore, understanding the effects of gully land consolidation on SOC, soil enzyme activity and maize yield can not only reflect the response of the engineering mode of gully land consolidation to soil, but also provide a reference for soil fertilization and adjustment of the spatial layout of gully crops.

At present, the related researches on gully land consolidation mostly focus on the benefit evaluation analysis and cultivated land quality research (Chen *et al.* 2015, Liu *et al.* 2020, Huang *et al.* 2021) and there are few studies on the impact on SOC, enzyme activity and maize yield, especially the research on soil enzymes and maize yield is very few. Therefore, The present study was aimed to explore the relationship between gully land consolidation, SOC and soil enzymes and maize yield, and to reveal the response low which can provide scientific decision-making and theoretical basis for the construction of high-standard farmland in the channel and the implementation and promotion of the gully land consolidation project.

Materials and Methods

Jiulongquan gully (109°36′47″~109°39′27″E，36°14′46″~36°19′5″N) in Baota District of Yan ' an City was selected as the study area. The study area is in the hilly gully area in the south of Baota District, Gullyl whose length is about 9.5 km, valley width is generally between 250 ~ 500 m, area is 397.35 hm^2. The study area belongs to semi-humid, semi-dry and early continental monsoon climate. The annual average rainfall is 562 mm, the annual average temperature is 9℃, and the altitude is 1093 ~ 1170 m. The soil is mainly silt loam, and the land use is mainly cultivated land. The water resources are relatively scarce, and there is no irrigation condition. The grain yield level is low. The gully in the study area is vertical and horizontal, the terrain is broken, the slope is large, and the soil erosion is serious. The gully land consolidation project was started construction in early 2013 with a construction scale of 360.91 hm^2. The main project was completed in early 2014 (Wei *et al*. 2013), and farming was started in the same year. The main crop was maize, which was grown once a year. The application of compound fertilizer and one-time fertilizer was the same as before. The amount of fertilizer and fertilization were the same as before. Winter fallow, other tillage measures were the same as local traditional tillage methods. The yield of maize was measured after harvest.

In the Jiulongquan gully, GPS positioning was used. From the position of gully head, a point was set at every interval (800-1300 m) from the gully head to the gully outlet. A total of nine fixed sample points were set at the gully head, the middle of gully and the gully outlet. A sample plot of 10 ×10 m was set up for each sample point. The soil samples of 0–20 cm tillage layer were collected according to the five-point mixing method (Miao 2017). Each soil sample was about 1000 g, evenly mixed, repeated for three times, and brought back to the laboratory. The soil was air-dried, impurity removed, and passed through a 1–2 mm sieve to determine SOC and soil enzyme activity indexes. Soil samples were collected in May 2013 (0a before remediation), May 2016 (3a after remediation), May 2017 (4a after remediation) and May 2021 (8a after remediation) at fixed points in the same way, and 4 periods of soil samples were obtained. Sampling was conducted in early and middle October of maize harvest season in each period, and maize yield was measured by sampling method.

Soil organic carbon SOC was measured by TOC / TN analyzer (MultiC / N3100) (Zhao *et al*. 2021), dehydrogenase was measured by colorimetric method, protease was measured by copper salt colorimetric method, catalase was measured by volumetric method (Zhou *et al*. 1980). Each indicator was measured three times in parallel and then averaged.

Data were processed by SPSS22.0 and Excel2017 and mapped by Origin2018.

Results and Discussion

From Table 1, it can be seen that the SOC, soil enzyme activity and maize yield in the gully are generally low and the coefficient of variation *cv* is also low. The variation of SOC was highest, followed by soil dehydrogenase and protease activity, and the variation of catalase activity and maize yield was lowest. After the implementation of the gully land consolidation project, the variation coefficient of the research index in the gully had a smaller trend on the whole, the difference of each index content was smaller, and the distribution in the gully ended to be uniform. Soil dehydrogenase activity showed a trend higher than 0a before remediation 3a after remediation. Soil protease, catalase activity, and corn yield showed a trend higher than 0a before remediation 4a after remediation, indicating that the gully soil remediation through reasonable cultivation and management measures, the negative impact of land remediation disturbance on soil nutrients and soil enzymes can be quickly offset and have a positive impact.

Table 1. Characteristic values of gully SOC, soil enzyme activity and maize yield with different remediation years.

Index	Statistical indicator	Remediation years			
		0a	3a	4a	8a
SOC	Maximum value (g/kg)	8.25	4.31	6.89	10.24
	Minimum value (g/kg)	5.02	2.4	5	5.78
	Average value (g/kg)	6.54	3.41	6.88	6.92
	CV	0.25	0.28	0.25	0.20
Dehydrogenase	Maximum value (μL (H^+)/20g)	8773.91	9900.46	40857.02	22757.44
	Minimum value (μL (H^+)/20g)	6599.98	8030.6	18065.87	15154.33
	Average value (μL (H^+)/20g)	7738.92	8940.75	28463.09	18432.49
	CV	0.14	0.1	0.13	0.11
Protease	Maximum value (μg/g)	28.75	23.7	44.69	34.44
	Minimum value (μg/g)	24.78	22.24	26.01	24.97
	Average value (μg/g)	26.83	22.74	34.48	31.23
	CV	0.07	0.04	0.12	0.05
Catalase	Maximum value (g/kg)	7.97	7.68	8.13	9.45
	Minimum value (g/kg)	6.92	6.82	7.85	8.12
	Average value (g/kg)	7.4	7.24	8.02	8.68
	CV	0.07	0.06	0.05	0.02
Maize yield	Maximum value (kg/hm^2)	3716	2740.33	4019.67	7735
	Minimum value (kg/hm^2)	3167.33	2642.33	3567.67	7567.67
	Average value (kg/hm^2)	3441.67	2691.33	3793.67	7651.33
	CV	0.08	0.02	0.06	0.01

Results of the change of SOC content in the gully before and after gully land consolidation presented in Fig. 1 showed that overall, after the implementation of gully land consolidation, the SOC content first decreased and then increased. The SOC content of gully head and the middle of gully before remediation were 6.50 and 5.70g/kg, respectively, and reached the lowest value 3a after remediation. The SOC content of gully head and the middle of gully decreased by 63.78 and 60.00%, and then increased year by year, then reached the highest value at 8a after the remediation, which was 22.05 and 43.25% higher than before the remediation, and 235.10 and 257.72%, respectively compared to the 3a remediation. The gully head and the middle of gully were in the about 4a after the remediation, it could basically return to the level before the remediation, and it was higher than the level before the remediation at 8a; the change of the gully outlet was different from that of the gully head and the middle of gully. It decreased by 39.69%, and then increased year by year. It increased by 53.54% 8a after the remediation, but it still did not reach the level before the remediation, which was 7.36% lower than that before the remediation.

Fig. 1. Changes of SOC content in different remediation years.

Dehydrogenase can catalyze the dehydrogenation of organic substances and characterize the oxidation ability of microorganisms in soil well (Zhou *et al.* 2021). The soil dehydrogenase activity of different remediation years is presented in Table 2 which showed an increasing trend year by year, reaching the maximum level at 8a after reclamation, and there was a significant difference between 0a and 8a; the dehydrogenase activity reached the maximum level at 4a after reclamation in the middle of gully and gully outlet , which was 381.05 and 191.41% higher than that at 0a, respectively, and decreased at 8a, which was 66.20 and 14.22% lower than that at 4a, respectively, but 62.56 and 149.96% higher than that at 0a; in the middle of the gully, there were significant differences between 0a and 8a, but no significant differences in the gully outlet.

The soil protease activities of different remediation years presented in Table 3 showed that the gully head a trend of first increasing and then decreasing. After remediation, 4a reached the maximum value, which was 118.27% higher than 0a before remediation, and decreased to 8a, but increased by 21.79% compared to 0a, and the difference between the years was not significant. The positions of the middle of the gully and gully outlet showed a trend of first decreasing and then increasing, both reaching the minimum value at 3a, 22.23 and 27.8 μg/g, respectively, and began to increase at 4a after remediation, and reached the maximum value at 8a. In the middle of the gully, 8a after remediation recovered to 1 time that of 0a before remediation, and there was no significant difference between remediation years. At the gully outlet, it recovered to 1.1 times the

0a level by 4a, and reached 1.27 times the 0a level at 8a, and the difference between 0a and 8a was significant.

Table 2. Soil dehydrogenase activity in different remediation years.

Soil enzyme	Remediation years	Gully head	Middle of the gully	Gully outlet
Dehydrogenase µL (H^+)/20g	0a	2455.73±0.11a	8984.37±0.25a	11776.65±0.07a
	3a	3226.32±0.16a	10930.20±0.25a	12665.73±0.20a
	4a	7851.61±0.08b	43219.66±0.18a	34317.99±0.29a
	8a	11218.68±0.18c	14605.43±0.07b	29437.37±0.11a

Different lowercase letters in the same column indicate significant differences in different remediations (gully land consolidation years) at $P < 0.05$ level.

Table 3. Soil protease activity in different remediation years.

Soil enzyme	Remediation years	Gully head	Middle of the gully	Gully outlet
Protease µg/g	0a	17.90 ± 0.02a	29.89 ± 0.08a	32.71 ± 0.03a
	3a	18.21 ± 0.05a	22.23 ± 0.04a	27.80 ± 0.07ab
	4a	39.07 ± 0.26a	28.59 ± 0.02a	35.78 ± 0.01ab
	8a	21.80 ± 0.02a	30.31 ± 0.13a	41.58 ± 0.05b

Different lowercase letters in the same column indicate significant differences in different remediations (gully land consolidation years) at $p < 0.05$ level.

Catalase can promote the decomposition of hydrogen peroxide and help in preventing the toxic effect of hydrogen peroxide on crops (Wang *et al.* 2021). The soil dehydrogenase activities of different remediation years are shown in Table 4. With the increase of gully land consolidation years, the gully head and the middle of the gully showed a trend of first decrease and then increase, and reached the lowest value at 3a, which decreased by 7.58 and 12.38 % compared with 0a. At the gully head, 4a still did not return to the level of 0a, and reached the maximum value at 8a, which was 8.82% higher than that of 0a. At the gully head position, there was no significant difference between the remediation years. In the middle of the gully, 4a has increased by 20.72 %, reaching the maximum value, which was 24.62 % higher than that of 0a, and the difference between 4a, 8a and 0a was significant. At the gully outlet, there was a trend of first increasing, then decreasing and then increasing, with 0a being the lowest value, 8a being the highest value, and 4a being lower than that of 3a, but the difference was not significant, and the difference between 0a and 8a was significant.

It can be seen from Fig. 2 that maize yields were different in different gully land consolidation years. With the increase of remediation years, it showed a trend of first decreasing and then increasing. The change trend of gully head, the middle of the gully and gully outlet are the same, and the maize yields in different periods was the same (gully head < the middle of the gully < gully outlet). The lowest value was found to reach at 3a, the maize yields of gully head, the middle of the gully, and gully outlet were 2105, 2860, 3109 kg/hm^2, respectively, and reached the highest value at 8a, The maize yields in the trenches increased by 256.29, 165.35 and 152.98%, respectively compared to 3a, and 139.77, 119.46 and 110.35%, respectively compared with 0a. In

0a and 8a, the maize yield was not significantly different across the gully, but there was a significant difference in 3a and 4a.

Table 4. Soil catalase activity in different remediation years.

Soil enzyme	Remediation years	Gully head	Middle of the gully	Gully outlet
Catalase g/kg	0a	8.05 ± 0.02a	7.19 ± 0.06a	6.97 ± 0.10a
	3a	7.44 ± 0.03a	6.30 ± 0.10ab	7.97 ± 0.04ab
	4a	7.88 ± 0.05a	8.68 ± 0.11b	7.48 ± 0.04ab
	8a	8.76 ± 0.12a	8.96 ± 0.10b	8.31 ± 0.03b

Different lowercase letters in the same column indicate significant differences in different remediations (gully land consolidation years) at $p < 0.05$ level.

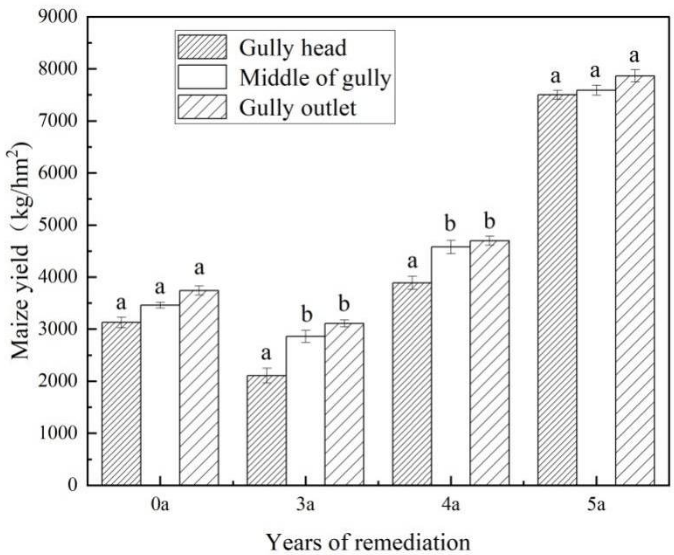

Fig. 2. Changes in maize yield in different remediation years.

The trend of each indicator was slightly different in gully head, the middle of the gully and gully outlet. At the gully outlet, the SOC did not return to the level before the remediation at 8a, and the other indicators returned to the level equal to or higher than the level of 0a. Loess plateau soil conditions are relatively poor, all kinds of nutrients, soil enzyme content is low, although the land regulation disturbance of soil nutrient and soil enzyme brings certain effect, but hong ditch stretched out the project after through more convenient cultivation management measures, such as machine ploughing, increased the soil porosity, ensure the arable layer soil evenly, ensure smooth infiltration of precipitation may, is conducive to the accumulation of crop roots and soil nutrient, fertilizer measures make the soil enzyme activity and active organic carbon, organic carbon content is growing rapidly, and in a certain time, such as crop absorption factor, stable state, the stability of soil structure is advantageous to the capability of retention of fertilizer of soil, enhance plant resistance, It provided good soil physical and chemical conditions for the formation of maize yield (Zhang *et al.* 2008, Xu *et al.* 2009, Du *et al.* 2019).

The correlation between corn yield and SOC content, dehydrogenase activity, protease activity and catalase activity was analyzed (Table 5). As can be seen from the Table 5, SOC, dehydrogenase activity, protease activity and dehydrogenase activity had a certain correlation with corn yield, and soil catalase activity was the most important factor. However, protease activity at gully head and dehydrogenase activity in the middle of the gully inhibit corn yield, but the correlation was small, which might be the error generated during sampling. There was not only a certain action characteristic but also a complementary relationship between maize yield and soil enzyme and soil nutrient indexes.

Table 5. Correlation coefficient of maize yield with SOC and soil enzymes.

Index	Maize yield		
	Gully head	The middle of the gully	Gully outlet
SOC	0.611*	0.671*	0.243
Dehydrogenase	0.735*	-0.325	0.659*
Protease	-0.251	0.578*	0.952**
Catalase	0.931**	0.578*	0.598*

**Significantly correlated at the 0.01 level (two-sided). *Significantly correlated at the 0.05 level (two-sided).

Studies have shown that the grain yield of gully cultivated land in the loess hilly and gully area was much greater than that of sloping cultivated land (Xue *et al.*2011). The present study showed that 4-8 years after the gully land consolidation project, the research indicators have recovered to the same level or higher than that before the remediation, and the level after the remediation has the potential to continue to improve. Therefore, compared with the slope, the gully in the loess hilly and gully area is more suitable for the construction of arable land, and the gully land consolidation project can effectively alleviate the contradiction between food security and human-land in this area, and consolidate the results of returning farmland to forest.

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