Research progress on ecological effects of land consolidation in the Loess Plateau

Wang Jing¹,², Bai Qingjun¹∗

¹Institute of Water Resources and Hydro-Electric Engineering, Xi'an University of Technology, Xi'an 710048, China
²Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resource, Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an 710075, China

∗Corresponding author’s e-mail: wangjing0722@126.com

Abstract. It is an inevitable requirement of national strategic development to promote the ecological construction of land consolidation in the Loess Plateau. This paper summarized the development of land consolidation and ecological management in the Loess Plateau, analyzed the effects of land consolidation on soil quality, hydrological environment, soil erosion, biological and ecological systems, and put forward the prospect of ecological construction of land consolidation in this area. It is expected to provide scientific basis for the decision-making and management of land consolidation.

1. Introduction

The Loess Plateau is one of the most important agricultural production bases in China, but it is also the region with the most serious soil erosion and the most fragile ecological environment. Historically, the ecological environment in this area has been seriously damaged by reclaiming farmland [1], and the cultivated land has been reduced by vigorously ecological restoration, resulted in prominent contradictions between local human and food [2]. Since the 18th National Congress of the Communist Party of China, General Secretary Xi Jinping has started from the construction of ecological civilization and has repeatedly emphasized that mountains, rivers, forests, fields, lakes and grasses are a life community. Therefore, it is an inevitable requirement for the national strategic development to find a balance between food security and ecological environment, and promote the ecological construction of land consolidation in the Loess Plateau.

Land consolidation can promote high-standard farmland building, develop facility agriculture, improve food productivity, resolve conflicts between people and land, alleviate food crisis, and consolidate the achievements of ecological management projects such as returning farmland to forests and grasslands, and promote the sustainable development of ecology, economy and society in the Loess Plateau [3]. Based on this background, this paper summarized and analyzed the results of the academic research on the ecological effects of land consolidation in the Loess Plateau, explored the ecological effects and looked forward to the trend of ecological construction, so as to provided a scientific basis for the planning, implementation and management of land consolidation projects in this area.
2. Development of land consolidation and ecological management in the Loess Plateau

After the founding of New China, faced with the problems of serious soil erosion and soil and water loss of the Loess Plateau, our country has carried out a series of major projects for land consolidation and ecological management, such as slope treatment project, gully and slope combined management project, small watershed comprehensive management project, “Grain for Green (GFG)” project, soil and water conservation project on sloping farmland and gully land consolidation project.

After more than 60 years of treatment, especially since the implementation of the GFG project, the vegetation area of the Loess Plateau has been greatly increased, soil erosion has been effectively curbed, and the ecological environment has been restored[4]. But at the same time, problems such as insufficient arable land and prominent contradiction between human and grain in some areas have arisen.

Table 1. Land Consolidation and Ecological Management Development in the Loess Plateau

| Time               | Major project                                                                 | Main measures                                                                 | Problem                                                                 |
|--------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------|
| 1950s to mid-1960s| Slope treatment project                                                       | Terraced field and afforestation were used to control slope and increased grain production, dam construction at the bottom of gully were used to conserve soil and water. | Low flood discharge design standards, less engineering construction investment, and frequent dam collapse in case of rainfall[5]. |
| Mid-1960s to the late 1970s | Warping dam construction project                                              | Used warping dam to control gully, terraced field and afforestation to control slope, and strengthened the basic farmland construction based on small-scale projects such as terraces, dams and small patches of water, increased grain output, and realized combined treatment of gully and slope. | There were problems such as “low flood discharge design standards, less engineering construction investment, and frequent dam collapse in case of rainfall”[5]. |
| The early 1980s to the late 1990s | The comprehensive management of small watersheds project: put forward the “28-word strategy for land consolidation in the Loess Plateau”[1] | Through the combination of engineering measures, tillage measures and biological measures, control gully and slope erosion, intercepted sediment, improved ecological environment, carried out soil and water conservation ecological agriculture construction, increased grain output and realized the coordinated development of soil and water conservation and economic development in the basin. | Low governance benefits, unreasonable allocation of measures, low project quality and ineffective management[7]. |
| 1999 - 2010       | “Grain for Green” project: The basic policy measures were “returning farmland to forests, closing mountains for afforestation, food relief and individual contracting”. | The ecological restoration was carried out by converting sloping farmland to forestation and afforestation in barren hills and wasteland. Biological control was the main measure. | The cultivated land area and regional food production were reduced, and there was a local prominent contradiction between human and grain, which affected the livelihood of farmers and food security[8]. |
| 2010-present      | Gully land consolidation project put forward the “26 words comprehensive management strategy of the Loess Plateau”: gully protection and land conservation in the plateau area, slope conversion to forestry and grassland, gully reclamation and land consolidation of gully, and forest conversion to shrub and grassland in the desert area. [9] | The protection of cultivated land has changed from slope to gully, silt to land-making, and decentralized management to large-scale management. Through a series of engineering measures and ecological restoration measures, such as dam system construction, old dam restoration, saline-alkali land reconstruction, development and utilization of waste ditch idle land. Eventually, realized the increase of cultivated land resources and improvement of ecological environment. |
3. Ecological effects of land consolidation on the Loess Plateau

Land consolidation is actually a process of ecosystem reconstruction, which changes the surface mulch, land use types and spatial distribution. In land leveling, farmland water conservancy, road and shelterbelt construction projects, the original state of ecological factors in the region will inevitably be broken, resulting in factors such as soil, hydrology, climate, vegetation and ecological processes in the project area or even in the wider region. The impact is both direct and indirect, positive and negative, reversible and irreversible[10].

3.1. Effect of land consolidation on soil quality

The effect of land consolidation on soil quality is mainly through land leveling project. In land leveling engineering, large-scale mechanical operation results in soil compaction, increases soil bulk density and compactness, changes the texture and structure, and affects soil permeability and so on. Loess is loose in texture and compacted more easily. Meng H.S.[11] studied the compacted soil in the land consolidation project of the Loess Plateau in Shanxi Province, which showed that the soil bulk density increased, the porosity decreased, soil moisture content was low, the compactness was extremely high and the seepage rate of water permeability was extremely low.

Loess has low fertility. In the process of land consolidation, the soil quality was reduced due to the fact that raw soil at higher elevations was covered at lower elevations and soil disturbance, the soil structure and surface soil maturation layer were destroyed and the soil harden caused by compaction. Hu Y. et al [12] analyzed the soil nutrients before and after land consolidation in gully area of the Loess Plateau, which indicated that land consolidation resulted in the decrease of organic matter and available phosphorus content in the tillage layer. Xue S et al [13] studied the physical, chemical and biological properties of terraced soils transformed from slope cropland in the Loess Hilly region. It was found that under the dual effects of soil disturbance and soil erosion, organic carbon, total nitrogen, alkali-hydrolyzed nitrogen, total phosphorus, available phosphorus and available potassium and other indicators decreased to varying degrees. He C.X.[2] found that there were few soil aggregates in newly cultivated land in the loess plateau, and the soil enzyme activity and microbial abundance were significantly lower than those in sloping land and dam land. However, due to the land consolidation, especially the terrace engineering changed the slope gradient, reduced the soil erosion intensity, as well as the self-fertilization of organisms and chemical fertilizers application, the soil structure improved effectively, which promoted the nutrient accumulation in situ and the gradual increasing of organic matter, further promoted the formation of soil aggregate structure [14] and the increase of microbial biomass, and the soil fertility was gradually improved. The study found that the soil quality index (SQI) appeared a significant linear increasing with years of land consolidation [13].

3.2. Effect of land consolidation on hydrological environment

The leveling engineering in land consolidation changed the surface slope, eliminated the microtopography in nature, and then affected the confluence and infiltration of surface runoff. At the same time, the change of surface vegetation coverage indirectly affected the process of infiltration and evaporation, and changed the regional water cycle. The construction of irrigation water conservancy projects also changed the allocation of regional water resources artificially[15]. For example, building gully reservoirs and intercept precipitation resources in situ is one of the effective measures for soil loss control and improve water resources utilization efficiency in the Loess Plateau.

Lou X.Y. [16] and Sun P.C.[17] studied the gully land consolidation project in the loess hilly and gully region, and found that gully construction was conducive to in-situ infiltration of precipitation. With the increasing of land consolidation on proportion, the average velocity of surface runoff decreased. Meanwhile, gully land improvement regulated the output process of surface runoff non-point source pollutants and reduced the output of sediment, nitrate nitrogen, ammonium nitrogen and dissolved phosphorus in surface runoff. Jin Z. et al[18] found that the groundwater of newly cultivated land in the valley was significantly elevated after gully land consolidation in the basin. Lei N. et al[19]
found that irrigation water conservancy project affected the natural recharge and discharge of soil moisture, which caused the rise of groundwater level and the increase of soil moisture content in the gully, and easily formed the gullied soil flow in the Loess Plateau. The construction of interception ditches could effectively regulated the effective utilization of soil flow in gully. Since the bottom of the intercepting ditch was lower than the groundwater level of the farmland, and the water in the ditch was connected with the groundwater, during the flood season, the interception ditch collected the soil flow in the field, the accumulated water in the field soil was quickly drained and the groundwater level was reduced. It lead to alleviated the flood disaster and effectively prevented the secondary salinization of the soil. During the drought period, the water stored in the ditch could be re-irrigated to the field, which effectively alleviated the drought. In addition, the function of drainage ditch in irrigation and water conservancy could effectively prevented the influence of soil erosion on farmland and ensure farmland safety.

3.3. Effect of land consolidation on soil erosion

Many studies at home and abroad showed that land consolidation has a negative impact on soil and water loss, and significantly increased the soil erosion [20-21]. The topography of the Loess Plateau is fragmented, the loess is vulnerable to erosion, and soil erosion is serious during the rainy season. During the construction of the land consolidation project in this region, the soil structure was damaged by excavation and backfilling, which provided loose deposits for the occurrence of soil erosion. Slope cutting and other projects would disturbed the stability of the side slope, exposed loess vertical joints, prone to induced collapse or rain erosion. In addition, the surface vegetation and crust were destroyed in the implementation of the project, their functions of soil and water conservation were rapidly reduced or lost, and the intensity of soil erosion was sharply increased. In case of rainstorm, partial collapse or even slope collapse might be induced.

On the other hand, the change of slope gradient in land leveling engineering increased infiltration, reduced runoff rate and soil erosion intensity [22]. After the construction period of land consolidation, all kinds of soil erosion factors caused by disturbance gradually disappeared and entered the natural recovery period. With the increase of the reconstruction years, the soil and water conservation functions of various measures gradually played a role. The vegetation coverage was increased, soil erosion gradually was controlled, and the function of soil and water conservation was gradually accumulated. Liu Y. et al[23] and Gao H.D. et al[24] showed that the use of terrace construction for the regulation of sloping farmland could control soil erosion and improve soil and water conservation. According to the statistics, by 2014, the Yan'an gully land consolidation project has managed more than 1,800 km² of soil erosion area and reduced about 13 million tons of sediment into the Yellow River annually [2].

3.4. Effect of land consolidation on biology and ecosystems

The implementation of a series of projects in the land consolidation process has a profound impact on surface vegetation and its related ecological processes. The large-scale disturbance of land consolidation on the ground would destroyed local vegetation, and the species and quantity of original and secondary natural vegetation would also reduced and degraded because the single crop planting after land consolidation [25]. Most scholars believed that the increase of cultivated land after land consolidation lead to the decreased of other landscape units and landscape diversity. At the same time, the landscape became more regular and the structure was simpler, which weaken the ecological function of regional landscape. The fragmentation of natural ecosystem caused by land consolidation was one of the main reasons for the decrease of biodiversity[26-27].

However, the implementation of forest and grass projects would also increased vegetation coverage and improved the ecological environment. Fei’s research showed that land consolidation has increased the per capita ecological carrying capacity and reduced the per capita ecological deficit in the Loess Plateau Gully Region of northern Shaanxi, effectively alleviated the pressure of the ecological environment in this region[28]. Jiang L. et al [29] used the method of monetization of ecosystem
service value to draw the conclusion that the monetization value of ecological benefits increased after land consolidation in Loess region, and the implementation of land consolidation projects had significant ecological benefits. He[2] and Liu[6] indicated that the converting sloping farmland into forest, terrace and dam was a process of carbon sink. The Gully land consolidation project on the Loess Plateau not only avoided the reclamation of sloping farmland for reforestation, consolidated the achievements of GFG, but also improved microclimate, prevented wind and sand, conserved water resources. The average annual rainfall around Baota District had exceeded 550 mm.

4. The enlightenment of ecological land consolidation in the loess plateau

Because of its harsh natural conditions and fragile ecological environment, the Loess Plateau has been exploring the balance between food security and ecological environment, land consolidation projects and ecological rehabilitation projects. Therefore, ecological construction should be emphasized in the preliminary investigation and evaluation, planning and design, implementation and post-management of land consolidation projects.

4.1. Pay attention to ecological security risk assessment and carry out land consolidation according to local conditions

Not all regions of the Loess Plateau are suitable for land consolidation. Watershed area, natural topography, slope, vegetation cover and other natural conditions are factors to be considered in the selection of the consolidation areas. Therefore, before the consolidation, the suitability, feasibility and ecological security risk assessment should be carried out according to the local natural conditions, combined with the project investment, infrastructure, local social and economic conditions, land use characteristics and overall planning.

We should fully predict and evaluate the possible actions of aggravating soil erosion and destroying the ecological environment, and strictly follow the green development concept and the priority principle of ecological protection, select suitable land consolidation areas according to local conditions, determine the reasonable time sequence of development and utilization, promote different land consolidation modes according to different regional characteristics and types, and implement diversified technical standards, objectives requirements, management modes and safeguard measures to prevent ecological problems such as soil erosion caused by development, and minimize the adverse impact on the ecological environment.

4.2. Layout ecological planning and design and protect of the ecological environment scientifically

In the land consolidation of the Loess Plateau, if we can through rational planning, layout and ecological design, balance the runoff producing areas such as cultivated land, road slope, and runoff detention areas such as forest and grass in the watershed space according to the regional topographic and geomorphic characteristics and the law of soil erosion, the soil and water loss in the basin can be effectively controlled.

Through rational planning of arable land, roads, forest networks, dam systems and other landscapes, construction of tree-shrub-grass combination, coniferous-broad-leaved mixed forest protection belt, and optimization of land use pattern, can diversify the ecosystem structure, promote the landscape spatial heterogeneity and diversity, improve the ecological system fragility and stability[30].

At the same time, the combination of ecological planning and high-standard farmland construction can promote the development and utilization of scattered cultivated land reserve resources, summarize the appropriate ecological agricultural technology system and development model, and achieve the unification of ecological benefits and economic and social benefits.

4.3. Strengthen the evaluation of ecological effects and improve the application of land consolidation decisions

Ecological effect evaluation is an important means to measure the effect of land consolidation, and its fundamental purpose is to practice and application. In the land consolidation of the Loess Plateau, we
should focus on ecological processes such as soil erosion, clearly identify the factors affecting the landscape ecological environment, establish a scientific index system, and make a comprehensive and reasonable ecological effect evaluation.

Through the evaluation results, we can understand the nature and extent of each factor's impact on the regional ecological environment, find out the problems in time, and put forward improvement suggestions and measures.

Strengthen the feedback mechanism of evaluation results, integrate the ecological benefits with decision support system of land consolidation projects, apply the benefit evaluation results to provide basic data support for policy formulation, planning and design, project management and other aspects of land consolidation project, so as to comprehensively improve the management level and implementation benefits of land consolidation, and realize the sustainable utilization of land resources.

5. Conclusion

(1) Faced with the serious soil erosion on the Loess Plateau, the country has successively carried out a series of major projects of land consolidation and ecological management, which have restored the ecological environment, but at the same time caused some new problems.

(2) The implementation of land consolidation projects have an impact on soil, hydrology, climate, vegetation and other factors and ecological processes in the region. In a relatively short period of time, land consolidation on the Loess Plateau has a negative impact on the ecological environment. However, with the increase of the consolidation years, the ecological environment can usually recover or even exceed the level before the consolidation, and the ecological benefits show a long-term positive trend.

(3) According to the harsh natural conditions and fragile ecological environment in the Loess Plateau, ecological construction should be emphasized in the preliminary investigation and evaluation, planning and design, implementation and post-management of land consolidation projects.

Acknowledgments

This work was financially supported by “Ecological Security Technology Integration and Comprehensive Demonstration of Channel and Slope Treatment Project” fund.

References

[1] Zhu, X. M. (1984) Land renovation on the Loess Plateau. Soil and Water Conservation Bulletin, (4): 1-6.
[2] He, C.X. (2015) The situation, characteristics and effect of the gully reclamation project in Yan'an. Journal of Earth Environment, 6:255-260.
[3] Li, Y.H., Du, G.M., Liu, Y.S. (2016) Transforming the loess plateau of china. Frontiers of Agricultural Science and Engineering, 3:181-185.
[4] Chen, Y.P. (2015) Balancing green and grain trade. Nature Geoscience, 10: 739-741.
[5] Wang, Z.Q. (2011) Discussion on the related problems in the development of dam land in the hilly and gully area of Northern Shaanxi. China Soil and Water Conservation, 4: 14-16.
[6] Liu, Y.S., Li, Y.R. (2017) Engineering philosophy and design scheme of gully land consolidation in loess plateau. Transactions of the Chinese Society of Agricultural Engineering, 33:9-17.
[7] Li, Y., Wang, L. Q. (2008) Research progress of comprehensive management in small watershed and its benefit evaluation. Journal of Beijing Forestry University, 7:62-66.
[8] Chen, Y.P., Luo, S.M., Li, F.M., Lin, W.X., Yang, Z.L., Wang, K.B. (2015) Proposals on the sustainable development of agriculture in yan'an gully regions. Journal of Earth Environment, 6: 265-269.
[9] Zhou, W.J., An Z.S., (2014) Suggestions on the implementation of the principle of “Gully Land Consolidation” with equal emphasis on “GFG”. Journal of Chinese Academy of Sciences.
[10] Wang, J., Zhong, L.N., Ying, L.X. (2018) Review on the study of the impacts of land consolidation on ecosystem services. Journal of Ecology and Rural Environment, 34: 803-812.

[11] Meng, H.S., Wang, J., Guo, J.K., Zhang, X.M., Yan, Y.K., Yin, H.S. (2009) Preliminary study on physical properties of soil compact in land consolidation in loess plateau. Chinese Agricultural Science Bulletin, 25: 549-552.

[12] Hu, Y., Han, J.C., Gao, H.B., Ma, Z.H., Zhang, Y. (2016) Soil nutrient characteristics in channel region prior and after land consolidation. Tianjin Agricultural Sciences, 22: 20-24.

[13] Xue, S., Liu, G.B., Zhang, C., Fan, L.X. (2011) Effects of terracing slope cropland on soil quality in hilly region of loess plateau. Transactions of the Chinese Society of Agricultural Engineering, 27: 310-316.

[14] Li, J., Han, J.C., Chen, C., Ye, S.L., Li, J.B. (2017) Effects of land use types on soil aggregate characteristics in hilly-gully region of Loess Plateau. Journal of Soil and Water Conservation, 31: 248-253, 259.

[15] Zhang, Z.F., Zhao, W. (2007) Effects of land consolidation on ecological environment. Transactions of the Chinese Society of Agricultural Engineering, 23: 281-285.

[16] Lou, X.Y., Gao, J.E., Han, S.Q., Guo, Z.H., Yan, Y. (2016) Influence of land consolidation engineering of gully channel on watershed runoff yield and concentration in loess hilly and gully region. Water Resources and Power, 34: 23-27.

[17] Sun, P.C. (2017) Simulation experiment on the influence of typical gully land consolidation project on precipitation conversion. Northwest A&F University.

[18] Jin, Z., Guo, L., Wang, Y.Q., Yu, Y.L., Lin, H., Chen, Y.P., Chu, G.C., Zhang, J., Zhang, N.P. (2019) Valley reshaping and damming induce water table rise and soil salinization on the Chinese Loess Plateau. Geoderma, 339: 115-125.

[19] Lei, N., Han, J.C., Gao, H.B., Chen, X. (2017) An analysis of regulation and utilization of water resources of gully control and land reclamation in yan’nan. China Rural Water and Hydropower, 5: 26-30.

[20] Evrard, O., Nord, G., Cerdan, O., Souchère, V., Bissonnais, Y., Bonté, P. (2010) Modelling the impact of land use change and rainfall seasonality on sediment export from an agricultural catchment of the northwestern European loess belt. Agriculture Ecosystems & Environment, 138: 83-94.

[21] Chartin, C., Evrard, O., Salvador-Blanes, S., Hirschberger, F., Oost, K.V., Lefèvre, I., Daroussin, J., Macairea, J. (2013) Quantifying and modelling the impact of land consolidation and field borders on soil redistribution in agricultural landscapes (1954–2009). Catena, 110: 184-195.

[22] Liu, S.L., Dong, Y.H., Li, D., Liu, Q., Wang, J., Zhang, X.L. (2013) Effects of different terrace protection measures in a sloping land consolidation project targeting soil erosion at the slope scale. Ecological Engineering, 53: 46-53.

[23] Liu, Y.S., Guo, Y., Li, Y.R., Li, Y.H. (2015) GIS-based effect assessment of soil erosion before and after gully land consolidation: a case study of wangjiagou project region, loess plateau. Chinese Geographical Science, 25: 137-146.

[24] Gao, H.D., Li, Z.B., Li, P., Jia, L.L., Zhang, X. (2012) Influences of terrace construction and check dam silting-up on soil erosion. Acta Geographica Sinica, 67: 599-608.

[25] Yamaguchi, H., Umemoto, S., Maenaka, H. (1998) Floral composition of the vegetation on levees of traditional and reconstructed paddies in Sakai city, Japan. Weed Sci, 43: 249 - 257.

[26] Bonfanti, P., Fregonese, A., Sigura, M. (1997) Landscape analysis in areas affected by land consolidation. Landscape and Urban Planning, 37: 91-98.

[27] Lisec, A., Pintar, M. (2005) Conservation of natural ecosystems by land consolidation in the rural landscape. Acta Agriculturae Slovenica, 85(1): 73-82.

[28] Fei, L.J., Huang, B.Y., Sun, S.X. (2008) Ecological foot-print model of land consolidation project in shaanxi province. Transactions of the Chinese Society of Agricultural Engineering. 24: 80-83.
[29] Jiang, L., Pu, C.L., Liu, Y.J, Su, L.L., Ma, W.J., Liang, W.J. (2016) Ecological benefit evaluation of land consolidation based on ecological service value: xifeng district of qingyang city, dongzhi town land consolidation project as an example. Tianjin Agricultural Sciences. 22:68-74.

[30] Wang, J., Han, J.C. (2013) Ecological problems and countermeasures in land consolidation on the Loess Plateau. Land of China, 7: 55-56.