Evolution characteristics of soil carbon density after homestead remediation

Zhen Guo¹,²,³,⁴, a, Juan Li¹,²,³,⁴, b, Chendi Shi¹,²,³,⁴, c and Huanyuan Wang¹,²,³,⁴, *

¹Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi’an, China
²Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi’an, China
³Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural and Resources, Xi’an, China
⁴Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi’an, China

*Corresponding author e-mail: wanghuanyuan@aliyun.com, ⁶675334047@qq.com, blijuan8136@163.com, ⁵516487749@qq.com

Abstract. In order to gain an in-depth understanding of the effects of different reclamation years on soil carbon sequestration after remediation of abandoned homesteads, this study relied on the land improvement project carried out in Changchun County, Shaanxi Province, to study the soil carbon density of different reclamation years. The results shown that the total carbon and inorganic carbon content of 0-20cm and 40-60cm soil layers increased steadily with the extension of cultivation time after the rectification of abandoned homesteads. In the 20-40 cm soil layer, the soil total carbon and inorganic carbon content increased firstly, then decreased and then increased with the extension of the cultivation period, especially the total carbon content changed the most. In the 0-40 cm soil layer, the organic carbon showed a tendency to decrease first, and the change trend of the organic carbon content in the 40-60 cm soil layer increased first and then decreased. The trend of carbon density changes was consistent with the trend of carbon content. After 10 years of reclamation compared with before the renovation, soil total carbon and inorganic carbon density increased by 22.93% to 47.72% and 16.11% to 45.30%, respectively, the regularities of vertical distribution was 40-60 cm > 0-20 cm > 20-40 cm. The density of organic carbon increased by 41.12% to 68.27% compared with before the renovation, and the regularities of vertical distribution was 0-20cm>20-40cm>40-60cm. It shows that long-term reclamation after homestead remediation is beneficial to the increase and fixation of surface soil organic carbon.

1. Introduction
As a world’s most populous country and a large agricultural country, China was accompanied by the basic national conditions of less people, less arable land and poor quality of cultivated land. A phenomenon of “hollow village” where people going to the house and leaving the building was accompanied. The occurrence of this phenomenon has caused the central housing site to be abandoned
and the surrounding cultivated land to be occupied, which has seriously threatened the situation of cultivated land in China [1, 2]. The emergence of “hollow village” was in line with the current vision of building a new countryside. In the practice of production, the process of industrialization shifts the labor force to urbanization, and then the idle agricultural land and abandoned homestead increase, and the approval system for the homestead is not strict. The phenomenon of new houses and populations in urban and rural areas was gradually increasing, thus making the phenomenon of “hollow villages” more and more serious [3]. Therefore, while building a new countryside and solving the problem of “balance of occupation and compensation” of cultivated land, it was particularly important to properly manage the expansion of the inner space such as “hollow village”, because this was a realistic problem to achieve sustainable development of cultivated land.

In view of the current situation of the "hollow village" problem and the principle and policy of realizing the "balance of occupation and compensation" of cultivated land, it is an inevitable trend to rectify and reclaim the abandoned house site. The land after the governance is not directly classified as effective cultivated land, but needs to be judged and accepted for its quality [4]. According to the “Notice of the Ministry of Land and Resources on Strengthening the Control and Implementation of the Strictly Cultivated Land Protection System”, it is emphasized that the land remediation and replenishment of cultivated land must first be assessed and re-inspected. If the requirements are not met, the inspection will not be accepted. Therefore, it is particularly important to evaluate the soil fertility of different reclamation homesteads. As the main parameter of soil quality evaluation and soil fertility improvement, soil organic carbon not only regulates the physical and chemical processes and biochemical processes of soil, but also plays an important role in the global carbon cycle and atmospheric environment regulation [5, 6]. Post et al. [7] scholars have shown that the soil carbon pool of farmland in the terrestrial ecosystem was relatively large, and it was an important part of the ecosystem. Its carbon pool was about 2-3 times that of the plant carbon pool and atmospheric carbon pool. Song et al. [8] believe that the improvement of soil carbon sequestration capacity was not only the need to increase the quality of cultivated land, but also an important way to improve carbon sources to carbon sinks and to achieve carbon reduction and emission reduction, and to meet the key points of international conventions such as the Kyoto Protocol [9]. Liang et al [10] studied the soil carbon sequestration capacity through engineering remediation measures, the results showed that the rational use of ecological engineering technology in the land remediation process can reduce the loss of organic carbon. Some studies have also shown that, through land engineering remediation measures can directly affect the physical properties and ecological functions of soil, indirectly have a positive or negative correlation effect on soil fertility, of which the effect of organic carbon content storage was most significant.

It can be seen that the study of carbon reserves after land remediation is an important research content for improving the requirements of land resources and realizing the principle of “balance of occupation and compensation”. Therefore, this paper studies the carbon density of soils with different reclamation years after remediation of abandoned homesteads, and finds the distribution characteristics of soil carbon density in different sections of remediation years, which provides a theoretical basis for soil fertility after reclamation.

2. Materials and methods

2.1. Overview of the study area
The abandoned homestead rectification project was carried out in Changchun County, Weinan City, Shaanxi Province (109°46’-110°05’E, 34°55’-35°27’E), which bordered Dali County and Huanglong County respectively. The east and west are adjacent to Heyang County and Pucheng County. The terrain is high in the north and low in the south. The average elevation is 406.9-1268 m. The four seasons are distinct. It belongs to the continental monsoon climate. The temperature difference between day and night is large. The annual average temperature is 12 °C. The annual average precipitation is 680 mm, the frost-free period is 204 days, and the annual sunshine time is 2616 h.
2.2. Land reclamation method
The abandoned house sites in the hollow village of Chengcheng County mainly include the abandoned earth caves and adobe houses in the Weibei tableland. The project department improved the utilization efficiency of cultivated land through site arrangement, demolition of abandoned houses, irrigation and water conservancy projects, leveling ground, balanced fertilization and other major engineering and technical measures to improve the abandoned homestead, so that the original “hollow village” abandoned homestead can grow crops just like the cultivated land. In the renovation of the project, the leveling project was the most prominent one. The wall of the abandoned house was pushed down and backfilled, and the soil was ploughed and loosened, which can meet the growth range of the crop root system. The project was completed in 2009. After reclamation, the land was mainly planted with wheat, with the newly increased arable land area of 868.4 hm².

2.3. Soil sample collection and processing
After field visits in 2018, the soils with different reclamation years of the homestead were selected for carbon density evolution analysis, and the sites with the same crop type and similar soil conditions were selected for sampling. It mainly includes Yihe village, which was renovated and reclaimed 10 years ago in 2009; Changning village, which was renovated and reclaimed 5 years ago in 2014; Shanhua village, which was renovated and reclaimed for 1 year starting in 2018. The wall of the abandoned house was directly knocked down and the soil which was crushed into uncultivated crops as unimproved soil (Xifu village). Soil sections of 0-20 cm, 20-40 cm and 40-60 cm were respectively taken with a soil drill to measure total soil carbon, organic carbon and bulk density. After the wheat harvest in May 2018, soil samples were taken in selected villages, 7 points were collected by the “S” shaped sampling method in each place as one soil sample, and 3 samples were taken as duplicates. The collected soil samples were naturally air-dried through a 0.149 mm sieve for the determination of total carbon and organic carbon in the soil.

2.4. Determination method
The soil total carbon and organic carbon were measured by TOC analyzer (Multi N/COR 3100), and the soil bulk density was measured by the ring cutter method and the cross-section sampling was performed at the sampling site.

2.5. Calculation methods and data processing
The calculation formula of soil organic carbon density is as follows:

\[
\text{SOCD} = (1 - \theta_i) \times \rho_i \times C_i \times T_i / 10
\]  

Among them, the SOCD is the organic carbon density (t·hm⁻²), \(\theta_i\) is the volume percentage of the coarse particles >2 mm in the soil, \(\rho_i\) is the soil bulk density (g·cm⁻³), and \(C_i\) is the soil organic carbon content (g·kg⁻¹), \(T_i\) is the thickness (cm) of the soil measurement layer.

Data preprocessing was performed using Excel software. ANOVA analysis was carried out on soil data of different reclamation years in the homestead using SPSS 18.0 statistical software.

3. Results and analysis

3.1. Spatial distribution difference of soil bulk density under different rectification years of abandoned homestead
The soil bulk density of each soil layer is 40-60cm (1.41 g·cm⁻³)>20-40cm (1.36 g·cm⁻³)>0-20cm (1.24 g·cm⁻³), with the deepening of the soil layer, the bulk density increases gradually (Fig.1). In the 0-20 cm soil layer, the soil bulk density decreased by 0.02 g·cm⁻³ in 1 year after cultivation, and increased by 0.02 g·cm⁻³ and 0.09 g·cm⁻³ in 5 years and 10 years after cultivation, respectively. The change rules of
soil bulk density in soil layers of 20-40 cm and 40-60 cm were basically consistent. With the increase of farming years, the soil bulk density also increased gradually.

![Figure 1. Distribution of soil bulk density under different soil layers in different remediation years.](image)

3.2. Spatial distribution of soil total carbon and carbon density under different remediation years of abandoned homestead

After the abandonment of the homestead, the total carbon content of the soil will change with the increase of cultivation time. As shown in Fig. 2, before the remediation, the total carbon content is 20-40 cm (19.54 g·kg⁻¹) > 0-20 cm (19.34 g·kg⁻¹) > 40-60 cm (18.58 g·kg⁻¹). Then, the total carbon in the 0-20 cm and 40-60 cm soil layers continued to increase at an average annual growth rate of 2.58% and 2.96%. The total carbon in the 20-40 cm soil layer showed a decrease to the lowest point after farming for 5 years, which was 18.59 g·kg⁻¹, and then increased rapidly. After 10 years of cultivation, the total carbon distribution of each layer of soil was 0-20 cm (24.34 g·kg⁻¹) > 40-60 cm (24.09 g·kg⁻¹) > 20-40 cm (22.18 g·kg⁻¹).

The total carbon density of soil layer 0-20 cm presented a trend of steady growth with the growth of cultivation years after regulation. The average annual growth rate was 1.66 t·hm⁻², and the total carbon density of soil layer 20-40 cm increased by 0.80 t·hm⁻² from regulation to cultivation one year. During the 1-5 years of cultivation, the total carbon density showed a decreasing trend with an annual average rate of decrease of 0.37 t·hm⁻². After that, the average annual growth rate of 2.57 t·hm⁻² increased rapidly during the 5-10 years of cultivation. The total carbon density of soil in 40-60 cm soil layer increased rapidly with the annual growth rate of 2.41 t·hm⁻² with the increase of tillage years after remediation (Fig. 2).
Figure 2. Distribution of soil total carbon and carbon density under different soil layers in different remediation years.

3.3. Spatial distribution of soil organic carbon and carbon density under different remediation years of abandoned homestead

The average soil organic carbon content of each soil layer was 4.61 g·kg⁻¹, 3.18 g·kg⁻¹ and 2.80 g·kg⁻¹, and the overall performance was 0-20 cm>20-40 cm>40-60 cm (Fig. 3). However, the variation trend of soil organic carbon in different soil layers under different tillage years was still different. In 0-20 cm soil layer, the organic carbon content in the soil layer was reduced by 10.15% compared with that before remediation, and then cultivated for 5 years and 10 years respectively. The annual growth rate of 1.80% and 4.65% was significantly increased by 0.89 g·kg⁻¹ and 1.78 g·kg⁻¹ compared with 1 year of cultivation, which was increased by 0.45 g·kg⁻¹ and 1.34 g·kg⁻¹ respectively before remediation. The variation of organic carbon content in 20-40 cm soil layer and 0-20 cm soil layer was consistent. In the soil layer of 40-60 cm, the organic carbon content significantly increased by 79.08% in 1 year compared with that before the regulation, and then slowed down to 2.82 g·kg⁻¹ after 5 years of cultivation at an average annual rate of 3.93%. The organic carbon content gradually increased again in 5 to 10 years of cultivation, with an average annual growth rate of 0.50%.

The vertical distribution of soil organic carbon density before remediation was 0-20 cm (10.41 t·hm⁻²)>20-40 cm (7.47 t·hm⁻²)>40-60 cm (5.33 t·hm⁻²). The organic carbon density of 0-20 cm soil layer and 20-40 cm soil layer decreased at an average annual rate of 1.21 t·hm⁻² and 0.32 t·hm⁻², respectively. The organic carbon density of 40-60 cm soil layer increased at an average annual rate of 4.22 t·hm⁻². At this time, the vertical distribution pattern was showed as 40-60 cm (9.55 t·hm⁻²)>0-20cm (9.20 t·hm⁻²)>20-40 cm (7.15 t·hm⁻²) (Fig. 3). In the following 5 and 10 years of cultivation, the organic carbon density of 0-20 cm and 20-40 cm soil layers increased steadily at an annual growth rate of 0.55 t·hm⁻² and 0.50 t·hm⁻², respectively. The density of organic carbon in 40-60 cm soil layer decreased to the lowest point when cultivated for 5 years, and gradually increased after 5-10 years. Therefore, the vertical distribution of organic carbon density during the 5 years of cultivation was 0-20 cm (11.71 t·hm⁻²)>20-40 cm (7.99 t·hm⁻²)>40-60 cm (7.78 t·hm⁻²). The vertical distribution of organic carbon density under 10 years of cultivation was 0-20 cm (14.70 t·hm⁻²)>20-40 cm (12.19 t·hm⁻²)>40-60 cm (8.97 t·hm⁻²).
Figure 3. Distribution of soil organic carbon and carbon density under different soil layers in different remediation years.

3.4. Spatial distribution of soil inorganic carbon and carbon density under different remediation years of abandoned homestead

The spatial distribution difference of soil inorganic carbon was similar to that of total carbon. The average content of soil inorganic carbon in 0-20 cm, 20-40 cm and 40-60 cm soil layers was 17.67 g·kg⁻¹, 16.82 g·kg⁻¹ and 18.66 g·kg⁻¹, respectively (Fig. 4). The inorganic carbon content in the soil layer of 0-20 cm increased year by year with the cultivation period, and reached the maximum at 19.34 g·kg⁻¹ in the 5th year of cultivation, and then gradually decreased. In the 5th year of cultivation, the inorganic carbon content in the soil layer of 40-60 cm was the highest, followed by the soil layer of 0-20 cm, and the inorganic carbon content in the soil layer of 20-40 cm was the lowest, which was 15.65 g·kg⁻¹. The inorganic carbon content in the soil layer of 20-40cm was consistent with the change rule of total carbon. After cultivation for 1 year, the inorganic carbon content first decreased and then increased year by year, and the growth rate was the fastest in 5-10 years, which was 2.89%. The inorganic carbon content in soil layer of 40-60 cm increased with the increase of farming years, and the growth rate was 1.52%, 4.01% and 2.75% respectively in 1 year, 5 years and 10 years. In 10 years of farming, the inorganic carbon content was shown as 40-60 cm (21.19 g·kg⁻¹) >0-20 cm (18.73 g·kg⁻¹) >20-40 cm (17.91 g·kg⁻¹).

The density change of soil inorganic carbon in abandoned homestead in different regulation years was consistent with the change rule of total carbon (Fig. 4). Before the remediation, the vertical distribution of soil inorganic carbon was 40-60cm (45.21 t·hm⁻²) >20-40 cm (44.13 t·hm⁻²) >0-20 cm (36.78 t·hm⁻²). The soil inorganic carbon density in the 0-20 cm and 40-60 cm soil layers showed a continuous increase trend after the remediation. The inorganic carbon density in the soil layer of 20-40 cm also increased after cultivation for 1 year, but to a small extent, it was 1.12 t·hm⁻². The inorganic carbon density in the soil layer of 1-5 years and 5-10 years after cultivation increased by 0.53 t·hm⁻² and 1.73 t·hm⁻² respectively.
4. Discussion

The rectification and rehearsal of the “Hollow Village” homestead has promoted the increase of cultivated land area, and intensification has promoted the use of land and played an important role in realizing the “balance of occupation and compensation” of cultivated land. The results of this study showed that the soil total carbon and inorganic carbon content in the abandoned house site of “hollow village” in Changchun county increased to varying degrees between 0-60 cm soil layers during the period of 1-10 years of reclamation, with increases ranging from 0.78% to 29.61% and 1.52% to 27.49%, respectively. After one year of reclamation, soil organic carbon content in the 0-40 cm soil layer showed a downward trend, with a decrease rate between 4.94% and 10.15%. This was because the depth of regulation of engineering regulation measures was about 40 cm, so the soil organic carbon content in this layer significantly decreased while the inorganic carbon content significantly increased. After 5 years of reclamation and cultivation, due to the balanced fertilization measures, the nutrient accumulation has been accumulated, so the soil organic carbon content in the 0-40 cm soil layer has increased compared with the resumption of 1 year. However, in the Weibei tableland, the root system of crops mainly grows in the 20-40 cm soil layer, and the soil moisture in this soil layer was relatively stable. The suitable water conditions enhance the soil respiration and root respiration in this layer, thus enhancing the concentration of CO₂ in the soil air. Under the action of high concentration of CO₂, the insoluble inorganic carbonic acid in the soil was converted into a transportable and easily soluble carbonate. Due to the gas diffusion and the migration of soil moisture, the inorganic carbonate enters the 0-20cm surface soil, and the infiltration can also enter the 40-60 cm soil layer, so the inorganic carbon content of the 20-40 cm soil layer declined, increasing inorganic carbon content in 0-20 cm and 40-60 cm soil layers [1, 13]. After 10 years of reclamation, the increase of total carbon content in 0-60 cm soils was a result of the combined effects of soil organic carbon and inorganic carbon. Among them, the increase of organic carbon content in the 0-20 cm soil layer (18.75%) was greater than the decrease of inorganic carbon (3.18%), and the organic carbon and inorganic carbon content in the 20-40 cm soil layer have different degrees of increase compared with the reclaimed 5 years soil. Similar to the results of Cao et al [13]. All these processes of soil carbon are normal biogeochemical changes. Although the reclamation period was only 10 years, it can be predicted that the soil has started its own geochemical development process under the condition of planting crops and in the process of evolution and under the promotion of biology [14, 15]. The dynamic change characteristics of total carbon, organic carbon and inorganic carbon in the soil during the reclamation period were the historical traces of the abandoned house site of the “Hollow Village” after the land remediation process.

Land remediation of the “Hollow Village” homestead was a multi-factor-oriented land use activity, which will have an important impact on the carbon storage and carbon cycle of the area [16, 17].
remediation of rural land not only optimizes the local land use structure, but also increases the area of cultivated land. From the homestead to the new cultivated land, a significant carbon effect was produced due to a large number of carbon exchange processes. Studies have shown that the carbon density of different land use patterns will be significantly reduced after a sudden change to cultivated land [18, 19]. It can be seen that the short-term land engineering remediation measures will lead to the loss of soil carbon pool, but after long-term cultivation and farmland water management, the soil carbon pool will have a large scale improvement. The results of this study showed that with the extension of cultivation time, the difference in carbon density gradually increased. During the 10 years of cultivation, the average change rules of total soil carbon density and inorganic carbon density in different soil layers were both 40-60 cm>0-20 cm>20-40 cm, which increased by 22.93%-47.72% and 16.11%-45.30% respectively compared with that before the regulation. The change rules of organic carbon density were 0-20 cm>20-40 cm>40-60 cm, which increased by 41.12%-68.27% compared with that before the regulation. The results indicated that long-term cultivation after treatment was beneficial to the increase and fixation of organic carbon in surface soil.

5. Conclusion
The soil total carbon and inorganic carbon content in the 0-20 cm and 40-60 cm soil layers gradually increased with the extension of cultivation time, and in the 20-40 cm soil layer, the trend increased first, then decreased and then increased. In the 0-40 cm soil layer, the organic carbon showed a trend of first decreasing and then increasing, and the 40-60 cm soil layer showed a trend of increasing first, then decreasing and then increasing.

The trend of carbon density change was consistent with the change trend of carbon content. Long-term reclamation was beneficial to the increase of surface soil organic carbon. After 10 years of reclamation, the vertical distribution of soil total carbon density and inorganic carbon density was 40-60 cm>0-20 cm>20-40 cm, the vertical distribution of organic carbon density was 0-20 cm>20-40 cm>40-60 cm.

Acknowledgments
This work was financially supported by The Shaanxi Provincial Land Engineering Construction Group Internal Research Project (DJNY2017-20).

References
[1] L. Zhang, J.C. Han, Z.H. Ma, Soil properties after renovation of “hollow villages” in different hilly areas in mountainous and hilly areas, J. Soil Water Conserv. 29 (2015) 176 - 180.
[2] L. Xue, Discussion on the “hollow village” phenomenon and its countermeasures in the background of urbanization: taking Jiangsu Province as an example, City Plann. 25 (2001) 8 - 13.
[3] H. Zhang, L. Liu, S. Zuo, Research on the governance of “hollow village” under the background of new rural construction, Anhui Agr. Sci. 39 (2001) 5599 - 5601.
[4] J. Yu, C.Y. Sun, Review on the research of land consolidation in rural residential areas in China, China Land Sci. 22 (2008) 69 - 71.
[5] R. Lal, M. Griffin, J. Apt, Managing soil carbon, Sci. 304 (2004) 393.
[6] W.R. Wieder, M.D. Hartman, B.N. Sulman, Carbon cycle confidence and uncertainty: Exploring variation among soil biogeochemical models, Global Change Biol. 24 (2018) 1563-1579.
[7] W.M. Post, T.H. Peng, W.R. Emmanuel, The global carbon cycle, Am. Sci. 78 (1990) 310 - 326.
[8] G. H. Song, L.Q. Li, G.X. Pan, Topsoil organic carbon storage of China and its loss by cultivation, Biogeochemistry 74 (2005) 47 - 62.
[9] R. Lal, Soil carbon sequestration to mitigate climate change, Geoderma 24 (2004) 1 - 22.
[10] Y. Liang, P. Yan, H.J. Bao, Study on the influence of ecological land consolidation project on soil carbon sequestration capacity, Shanghai Land Resour 37 (2016) 5 - 8.
[11] M. Tan, X.J. Huang, T.Y. Zhong, Effects of land consolidation on soil carbon content in farmland,
[12] G. Z. Liu, Research on rural homestead renovation-taking Tongfu village as an example, Hunan Agr. Sci. 7 (2013) 135 - 138.
[13] T. T. Cao, Y.Y. Sun, D.W. Hua, Effects of land remediation projects on soil carbon sequestration, Agr. Res. Arid Areas 36 (2018) 250 - 269.
[14] G. S. Liu, D. Chang, X.F. Ye, Spatial variability of soil nutrients in gentle slope tobacco fields based on GIS, Chin. J. Ecology 33 (2013) 2586 - 2595.
[15] X. B. Sun, Y.C. Du, Y.Y. Sun, Effects of paddy field construction on nutrient and carbon sequestration in different types of soil, Henan Agr. Sci. 47 (2108) 54 - 58.
[16] L. C. Fei, C. Wu, J.M. Cheng, Carbon effect and policy response of rural land remediation, Resour. Sci. 39 (2017) 2073 - 2082.
[17] X. H. Guo, Y.L. Dun, G.T. Bo, Study on carbon emission effect of land consolidation project in plain area—a case study of land consolidation project in Julu County, Hebei Province, Soil Water Conser. Res. 22 (2015) 241 - 246.
[18] A. Hmad, S.M. Nizami S, Carbon stocks of different land uses in the Kumrat Valley, Hindu Kush Region of Pakistan, J. For. Res. 26 (2015) 57 - 64.
[19] X. W. Chuai, X.J. Huang, W.J. Wang, Spatial simulation of land use based on terrestrial ecosystem carbon storage in coastal Jiangsu, China, Sci. Rep. 4 (2014) 5667 - 5667.