Effects of Fly Ash and Organic Fertilizers on Water Use Efficiency

Qilong Wang1, 2, 3, 4, *, Zhe Pang1, 2, 3, 4, Yang Wei1, 2, 3, 4

1Shaanxi Provincial Land Engineering Construction Group Co, Ltd, Xi'an 710075, China
2Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resources, Xi'an 710075, China
3Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an 710075, China
4Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co, Ltd, Xi'an 710075, China

*Corresponding author e-mail: wql199008@126.com

Abstract. In the process of land consolidation in the hilly regions, the water shortage is the main factor that restricts the Agricultural development in the hilly regions, and the fly ash and organic fertilizers are often used as the main field materials to improve the quality of soil. In order to investigate effects of fly ash and organic fertilizers on water use efficiency, related experiments were carried out at Fuping Pilot-base. The results showed as follows: (1) Different field materials had significant effect on oil temperature, with the values as TFC (fly ash and organic fertilizers) > TC (fly ash) > TF (organic fertilizers) > T0(control). (2) Different experimental treatments significantly affected crop yield and water use efficiency. The variation order between crop yield and water use efficiency among different treatments was TFC > TF > TC > T0. After considering the increase of soil temperature, yield and water use efficiency, fly ash and organic fertilizers should be compound use in the process of land consolidation in the Hilly Regions, which will greatly contribute to the yield and water use efficiency.

1. Introduction
Under the background of rapid industrialization and urbanization in China, the problem of rural hollowing in mountainous and hilly areas had become increasingly prominent, which had seriously hindered the development of rural areas and the improvement of human settlements. Rural hollowing was a bad phenomenon in the evolution of rural human land relationship system in the process of urban rural development and transformation. It was an important basis for the overall development of urban and rural areas and the construction of the new countryside to carry out the comprehensive land renovation in the hilly and hilly village. The research showed that the potential of China's hollow village renovation was huge and could be increased to 7580000 hectares. To carry out comprehensive land consolidation in Hilly and hollow villages can not only increase the area of available cultivated
land, but also improve the conditions of agricultural production, promote the scale management of agriculture, and promote the coordinated development of the rural area's economy and society.

The distribution of the hollow village in the hilly and hilly areas is relatively scattered and the water conservancy facilities are not convenient. In the process of land renovation in the hilly and hilly hollow village, water resources are the main factors restricting the development of agricultural development in hilly and hilly areas. Therefore, the study on the effect of different field returning materials on soil water use efficiency and the selection of land returning materials with economic, convenient and effective effect are of great significance for the comprehensive improvement of hollow villages in Hilly and hilly areas.

Through comprehensive evaluation of the distribution, quantity, physical and chemical properties, effective cycles, pests and diseases, risk of pollution, cost and promotion difficulty of various returned materials, it was found that the agricultural utilization of fly ash has the characteristics of less investment, large capacity and quick effect. The nutrient content of the fly ash basically coincide with that of the yellow cinnamon soil, except for the low nitrogen content. In addition, silicate minerals and carbon particles in the fly ash with porous structure, is beneficial to reduce the soil bulk density, increase the porosity, improve the ground temperature, decrease soil swelling rate, accelerate plant roots to absorb nutrients and promote plant growth.

In the process of using fly ash, the secondary pollution of heavy metals in fly ash to soil environment couldn't be ignored. The foreign research showed that 10% fly ash would not cause crop toxicity. Some domestic experimental research results also showed that when the amount of fly ash was applied to 60–600 tonnes per hectare, the harmful elements in soil and food crops did not reach the pollution level. Organic fertilizer could improve soil physical and chemical properties while improving soil nutrients, and had the character of wide distribution, easy to make and low cost. In this paper, two kinds of field materials were selected for further study. In the process of studying the effects of different materials on soil water use efficiency and yield, it was found that the profile distribution of soil moisture content and the soil temperature had important effects on root water absorption.

Therefore, the effect of soil water absorption caused by soil temperature on water use efficiency could not be ignored. In order to predict the suitable land returning materials in the process of land renovation in the hollow village, based on soil moisture and temperature monitoring, the factors of plant height and yield under the application of all kinds of returning fields was observed, and the effects of different returning field materials on soil water use efficiency were analysed and discussed.

### 1.1. general situations of study region

In the background of hollow village land consolidation project, the experimental area was simulated to study the returning condition of the abandoned village homestead in the loess hilly area, and the fly ash and organic fertilizer were selected as fertilizer materials. The soil section below 30cm is the original soil, and 0-30cm is the backfill soil (the soil physical and chemical properties in Table 1), and the fertilizer is mainly applied and mixed on the soil layer.

| Layer thickness (cm) | Bulk density (g cm⁻³) | Clay(%) <0.002 | Powder(%) 0.002-0.05 | Sand(%) 0.05-2 | pH | Conductivity (μs cm⁻¹) |
|---------------------|-----------------------|---------------|----------------------|---------------|----|----------------------|
| 0-15                | 1.32                  | 10.15         | 77.82                | 12.03         | 8.5| 252                  |
| 15-30               | 1.60                  | 12.25         | 83.19                | 4.56          | 8.5| 245                  |
| 30-45               | 1.50                  | 11.38         | 82.54                | 6.08          | 8.6| 362                  |
| 45-60               | 1.48                  | 9.15          | 76.99                | 13.86         | 8.6| 255                  |
| 60-75               | 1.39                  | 12.25         | 78.34                | 9.41          | 8.6| 252                  |
| 75-90               | 1.55                  | 12.29         | 78.76                | 8.95          | 8.6| 291                  |
| 90-105              | 1.49                  | 10.23         | 80.12                | 9.65          | 8.7| 298                  |
1.2. Sample processing
The test began in early June 2015. First of all, the surface layer 30 cm soil layer was detached, and the surrounding wall was built. The wall height was 40 cm, and 10 cm is exposed to the surface. Then, the soil was backfilled, the ground was shaved, the backfilling thickness was 30 cm, and the bulk density was controlled at 1.5-1.6 g cm\(^{-3}\). Finally, the fertilizer material was applied uniformly on the surface and mixed evenly.

Four kinds of treatments including manure, fly ash, mixed application and blank control were considered in the experimental design. At the same time, 2 repetitions were set up in 8 experimental plots. The area of the experimental plot was 2 m x 2.24 m. The experimental design was shown in Table 2. The tested maize variety was Xianyu 335, sowing amount was 4000 strains per mu. All treatments were treated with compound fertilizer 150 kg per mu before sowing. The first season of corn was planted on June 15, 2015, and harvested on October 5, 2015. The second season of corn was planted on June 5, 2016 and harvested on October 6, 2016.

During the experiment, the growth and development of crops were recorded, including plant height and crop yield. Recording meteorological data, mainly including rainfall and evaporation; Record field management, including irrigation (irrigation time and irrigation amount), fertilizer (fertilization time and fertilizing amount), etc.

| Number | Treatments                | Application amount               |
|--------|---------------------------|----------------------------------|
| 1      | Organic manure            | TF                               | 22.5 m\(^3\) hm\(^{-2}\) |
| 2      | fly ash                   | TC                               | 75 m\(^3\) hm\(^{-2}\) |
| 3      | fly ash + Organic manure  | TFC                             | 75 m\(^3\) hm\(^{-2}\)+22.5 m\(^3\) hm\(^{-2}\) |
| 4      | Control                   | T0                               | 0 |

1.3. Measuring items
Soil water and soil temperature were determined. Crops are mainly used to determine plant height and yield. Soil moisture content determination: determining soil water content at 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm, and 90-105 cm. Taking samples of soil samples every two weeks. The time domain reflectometer (TDR) was installed in the experimental plot. The soil moisture content at all levels was measured continuously every 10 minutes, and the data was recorded every hour.

Maize yield calculation: in order to prevent the marginal effect, 2 rows in each plot (except the edge 0.5 m) were threshing, air dried, weighing and converted to standard water content (14%).

2. Interpretation of results

2.1. Effect of application of fly ash and organic fertilizer on soil temperature
The temperature of soil layer under different treatment of experimental plots was monitored and recorded in real time, and the difference of soil temperature under different treatments was analysed. From Figure 1 and Figure 2, it can be seen that the surface temperature of the soil in TC and TFC both increased. The treatment of TC increased by 0.4 centigrade compared with T0 treatment, and the TFC treatment increased by 0.8 degrees. However, the TF treatment without adding fly ash increased 0.3 degrees. This may be due to the deeper color of the fly ash, which increases the absorptive capacity of the soil to solar radiation. In addition, during the main growth period of corn (June -10 months), the daily surface temperature distribution on the surface of the soil was mostly below 30 degrees. In this temperature range, the increase of soil temperature significantly increased the water uptake efficiency of roots.
2.2. Effect of application of fly ash and organic fertilizer on plant height, 100 grain weight and yield

The purpose of various kinds of returning materials was to enhance soil fertility and increase crop yields. The effect of different materials on plant height during the two season of crop growth was shown in Figure 3. In the process of soil remediation, the use of organic manure and fly ash could raise the plant height of maize, and the combination of fly ash and organic fertilizer had the best promoting effect on maize growth.

TC treatment did not significantly increase crop yield compared with T0 treatment, while TF and TFC significantly increased crop yield compared with T0 (See Figure 4). The yield in TFC (The combination of organic manure and fly ash) reached the maximum in all treatments. In 2015, the difference was relatively large. TFC increased by about 52% compared with T0 processing, while the difference in 2016 was relatively small. TFC processing increased by 23% compared with T0 processing. It shows that single measures could not meet the needs of soil improvement for the land renovation of hollow village abandoned homestead. Only a combination of multiple improvement measures could rapidly improve soil fertility and obtain high yields.

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2.3. Effect of application of fly ash and organic fertilizer on soil water use efficiency

In the process of research on the technology of increasing soil fertility in hollow villages, it was very important to study the effect of different returning materials on soil water use efficiency due to the scattered distribution of hollow villages and the inconvenience of water conservancy facilities in mountainous and hilly areas. Different fertilization measures had a significant impact on the change of soil water content. Soil water storage was the main characterization of soil water content (see Figure 5 and Figure 6). Because of the deep underground water level in the Loess Plateau, the soil water condition of the crop root layer could be ignored by the influence of groundwater. Soil water conditions were mainly affected by natural precipitation, irrigation and crop evapotranspiration. This research was mainly used to evaluate the effect of different field return materials on crop growth. The changes of soil water storage between different treatments tend to be consistent with traditional planting and conventional irrigation.

According to the changes in the water content of the crop growth cycle, the amount of water stored in the soil is calculated (see Figure 5, Figure 6). Based on soil water storage, irrigation and rainfall, the
water consumption in crop growth cycle was calculated. Water consumption under each treatment was calculated by evaporation, irrigation and rainfall. The water use efficiency among different treatments was calculated by the combination of the crop yield and water consumption.

The difference of water consumption was due to the change of soil moisture content at the end of different treatments. Different water consumption and yield determined the soil water use efficiency of each treatment. There was no significant difference between the water use efficiency of the control treatment (T0) and the TC treatment with only the fly ash, and the utilization efficiency was low.

In 2015, the water use efficiency were only 13.06 and 15.46 kg/ha/mm respectively, 10.98 and 16.96 kg/ha/mm in 2016. The water use efficiency of organic manure was significantly higher than that of control. The water use efficiency of TFC treated with fly ash and organic manure reached 23.52 kg/ha/mm in 2015, and 18.27 kg/ha/mm in 2016, which was significantly higher than that in the other 3 treatments.

![Figure 5](image1.png)

**Figure 5.** The change of water storage (0-105 cm) between different treatments in 2015

![Figure 6](image2.png)

**Figure 6.** The change of water storage (0-105 cm) between different treatments in 2016
### 3. Discussion

#### 3.1. Analysis of the effect of application of fly ash and organic fertilizer on soil temperature

Soil temperature is of great significance in crop growth and development, water and salt movement in soil, soil carbon balance and so on. In this study, TC and TFC with fly ash increased the surface temperature of the soil (7.5 cm). The mixed application of fly ash and organic fertilizer (TFC treatment) had the greatest increase in surface temperature, with an average increase of 0.8 degrees centigrade. During the main growth period of corn (July to October), the temperature distribution of soil profile was mostly below 30 degrees. In this temperature range, the increase of soil temperature significantly increased the water uptake efficiency of roots. In the cold season, improving soil temperature by applying a proper amount of fly ash on the clay soil with poor thermal conductivity had certain practical significance for early emergence, early seedling wins and high yield of spring crop.

The mixed application of fly ash and organic matter increased soil temperature. On the one hand, most of the fly ash was dark gray, which absorbed the heat of the sun and enhances soil heat absorption capacity, thus improving geothermal energy. On the other hand, fly ash could change the REDOX state of soil. The most active iron ore in fly ash released 169.35 J/mol of heat when it was gradually hydrolyzed and oxidized to hematite, and released 44.75 J/mol of heat when it further converted to lepidocrocite. The hydrolysis of minerals released a large amount of energy, which accelerated the mineralization of organic matter and the process of its oxidation. The oxidation hydrolysis of the magnetic minerals in the fly ash and the acceleration of the oxidation decomposition of the organic matter all had been a strong release of energy, which further improved the temperature of the earth.

The improvement of ground temperature had promoted the decomposition of organic manure, the reproduction of microorganism and the metabolic processes of crops, and increased the availability of nitrogen, potassium and phosphorus in soil. Finally, a benign hydrothermal cycle environment was formed.

#### 3.2. Analysis of the effect of the application of fly ash and organic fertilizer on crop yield

Fly ash had a positive influence on the yield and quality of crops. Application of mixture of fly ash and organic fertilizer can reduce peroxidase and polyphenol oxidase activity, inhibit crop photo respiration, promote crop metabolism, facilitate accumulation of substances and increase crop yield. In addition, 2% fly ash in soil could significantly improve soil respiration, promote invertase activity, enhance microbial activity, facilitate various biochemical reactions in soil, promote nutrient release, and accelerate soil maturation. Accelerating soil ripening was the key to the improvement of soil fertility during the renovation of the hollow village.

#### 3.3. Analysis of the effect of the application of fly ash and organic fertilizer on soil water use efficiency

As a highly dispersed fine particle aggregate, fly ash was an excellent soil amendment, which could reduce soil bulk density, enhance water holding capacity, reduce saturated hydraulic conductivity and effectively reduce the possibility of water fracture in soil film. The mixed application of fly ash and organic fertilizer improved the soil structure characteristics, and increased the net photosynthetic rate.
of soil and reduced the transpiration rate at the same time, so as to reduce water consumption, maintain the moisture content in plants and promote plant growth. In the last section, soil temperature increased significantly to root water uptake efficiency, which increased soil water use efficiency to a certain extent. In the environment of water conservancy facilities inconvenient, soil water storage performance increased, and also increased crop yield.

4. Conclusion
In the process of hollow village in hilly area of rectification, the choice of field materials is the key. Through the comparison of experimental plots, the surface temperature of the mixed application of fly ash and organic matter (TFC treatment) is the highest, and the average increase is 0.8 degrees centigrade. The yield of maize increased by about 52% in 2015 and about 23% in 2016, and the crop yield reached the maximum in four treatments in 2015. The water use efficiency of TFC treatment was 23.52 kg/ha/mm in 2015 and 18.27 kg/ha/mm in 2016, which was significantly higher than that of other treatments. The mixed application of fly ash and organic fertilizer has the best effect on the improvement of the ground temperature, the yield and the soil water use efficiency.

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