Crop production changes and the impact of Grain for Green program in the Loess Plateau of China Postprint

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Abstract

Since the Grain for Green (GFG) program was implemented in 1999, most steeply sloping farmlands in the Loess Plateau of China have been returned to forestland and grassland. To understand its impact on the food production, this study analyzed the spatiotemporal changes of food crop production (FCP) in the plateau and quantified the contribution of sown area and yield changes to the total FCP during 1998-2014 using factor decomposition models, and then discussed the impact of GFG program on the FCP based on literature data. With the implementation of GFG program, total sown area in the Loess Plateau quickly deceased by 17.3% from 1998 to 2003, and then gradually restored to 1.03×107 hm2 in 2010. Thereafter, it slightly decreased to 1.02×107 hm2 (94.6% of the area in 1998) in 2014. By contrast, total FCP generally showed an apparent growth trend, averagely increased by 1.71% per year in the whole plateau during 1998-2014. This increase was jointly contributed by the improved yield of individual crops, and the adjustment of cropping structure, i.e., the expansion of high yield maize crop. The factor decomposition analysis results indicate that the sown area shrinkage only reduced the growth rate of total FCP by 0.29% per year during 1998-2014, although a significant impact was found for the early stage of 1999-2003. The results suggest that the implementation of GFG program would not induce an obvious risk of the food security. Therefore, it is suggested that the GFG program should be set as a long-term strategic policy, by not only supporting the conversion of slope farmlands, but also helping local farmers to seek sustainable ways of land use to improve the income and livelihood. It can be combined with the poverty eradication program, to simultaneously achieve the national goals of ecological civilization building and the livelihood improvement of rural people in the Loess Plateau. Considering rainfall limitation, the conversion of slope farmlands should be prioritized to grasslands.

Full Text

Preamble

Crop Production Changes and the Impact of Grain for Green Program in the Loess Plateau of China

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Abstract: Since the Grain for Green (GFG) program was implemented in 1999, most steeply sloping farmlands in the Loess Plateau of China have been returned to forestland and grassland. To understand its impact on food production, this study analyzed the spatiotemporal changes of food crop production (FCP) in the plateau and quantified the contribution of sown area and yield changes to the total FCP during 1998-2014 using factor decomposition models, and then discussed the impact of the GFG program on the FCP based on literature data. With the implementation of the GFG program, total sown area in the Loess Plateau quickly decreased by 17.3% from 1998 to 2003, and then gradually restored to 1.03×10 hm^2 in 2010. Thereafter, it slightly decreased to 1.02×10 hm^2 (94.6% of the area in 1998) in 2014. By contrast, total FCP generally showed an apparent growth trend, increasing by an average of 1.71% per year across the entire plateau during 1998-2014. This increase was jointly contributed by the improved yield of individual crops and the adjustment of cropping structure, i.e., the expansion of high-yield maize crops. The factor decomposition analysis results indicate that the sown area shrinkage only reduced the growth rate of total FCP by 0.29% per year during 1998-2014, although a significant impact was found during the early stage of 1999-2003. The results suggest that the implementation of the GFG program would not induce an obvious risk to food security. Therefore, it is suggested that the GFG program should be set as a long-term strategic policy, not only supporting the conversion of slope farmlands but also helping local farmers seek sustainable ways of land use to improve income and livelihood. It can be combined with the poverty eradication program to simultaneously achieve the national goals of ecological civilization building and livelihood improvement for rural people in the Loess Plateau. Considering rainfall limitations, the conversion of slope farmlands should be prioritized to grasslands.

Keywords: spatiotemporal change; farmland conversion; hilly region; factor decomposition; semi-arid regions

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1 Introduction

The Chinese Loess Plateau is well known for its severe soil erosion mainly resulting from over-cultivation of slope lands. To mitigate land degradation, the Chinese government implemented the Grain for Green (GFG) program in August 1999, aiming to convert steeply sloping or marginal croplands to forestland and grassland. Acknowledging that farmland conversion would significantly impact food production and farmers' livelihoods, the Chinese government adopted a policy to supply subsidies of food grain or money to farmers based on the converted area, which is why it is often called the Grain for Green program.

Since the program' s implementation, its effects on land use and the environment have been explored and evaluated by numerous studies. Many studies indicate that destroyed vegetation has been evidently restored [?, ?, ?, ?, ?], thus improving land use structure [?, ?, ?] and greatly reducing soil erosion intensity [?, ?, ?, ?, ?] in the Loess Plateau. Regarding its impacts on food production, Feng et al. (2005) estimated that GFG implementation would cause a 10.0%-13.5% reduction in total grain production in the Loess Plateau based on three scenarios of slope farmland conversion. Xu et al. (2006) simulated the program' s impact, concluding that GFG implementation would have a small impact on China' s grain production. However, one study by Deng and Shangguan (2011) indicated that the program threatened China' s food security although it increased farmers' income. Another study by Liu and Li (2012), based on statistical data from 100 typical counties in the Loess Plateau, found that total grain production decreased during 1996-2007. In recent years, numerous studies have analyzed the program' s effects on farmers' livelihoods based on household surveys for some counties in the Loess Plateau [?, ?, ?, ?, ?, ?], but seldom specified the whole plateau to analyze the GFG program' s impacts on food crop production.

The GFG program has been implemented for nearly two decades. An analysis of changes in total crop production and sown area during the implementation period could contribute to understanding the GFG program' s effects. Therefore, we selected 1998-2014 as the study period, where 1998 represents conditions just before GFG implementation in 1999 and 2014 represents conditions after the program had been executed for 16 years in the Loess Plateau. Three specific objectives were addressed: first, to detect variation trends in total food crop production (FCP) and sown area during the period; second, to quantify the contribution of changes in crop yield, sown area, and cropping structure to FCP change using a factor decomposition analysis approach; and third, to analyze the impact of the GFG program on FCP. We also explored policy implications and suggestions. Considering data consistency and availability, the analysis focused on five major food crops—wheat, millet, maize, soybean, and potato—using annual county-level data from 283 counties in the Loess Plateau. As farmland conversion was mostly implemented in hilly areas, the hilly region comprising all hilly counties (Fig. 1 [Figure 1: see original paper]) was addressed separately.

2.1 Study Area

The Loess Plateau (33°41 -41°16 N, 100°54 -114°33 E) covers an area of 6.34×10 hm², with the hilly region (Fig. 1) covering about 4.54×10 hm², accounting for 71.61% of the total area. The hilly region is highly dissected by gullies and suffers from severe soil erosion [?, ?]. In 2014, the plateau' s population totaled 1.10×10 , with a density of 174 inhabitants/km². With a temperate semi-arid to sub-humid climate, the annual mean temperature is 4.3°C-14.3°C and mean annual precipitation varies from 200 mm in the northwest to 700 mm in the southeast [?, ?]. Influenced by monsoon climate, more than 70% of annual precipitation falls in the rainy season from June to September. Before the GFG program implementation, about 30% of the plateau area was farmland, 30% was forestland and shrubland, and 38% was grassland [?, ?]. Of the total farmland, about 65% was slope land [?, ?], with the remaining part mainly distributed in tablelands and floodplains of the Yellow River and its tributaries, the Weihe River and Fenhe River. Crop production is largely rainfed due to slope limitations, but farmland in floodplains is mostly accessible to irrigation. The main crops grown in the region are maize, wheat, soybean, potato, and millet.

2.2 Data Sources and Preprocessing

Annual total food crop production, sown area, and yield of winter wheat, maize, soybean, millet, and potato were obtained for 283 county-level administrative units from local yearbooks for 1998-2014. To ensure comparability, the statistical yield of maize, soybean, potato, and millet was converted to wheat equivalent using conversion coefficients of 1.01, 1.42, 0.23, and 1.07, respectively. These coefficients (CF) were calculated based on energy and protein content using the following equation [?, ?]:

$$CF_i = \frac{H_i}{H_0} \times 0.9 + \frac{P_i}{P_0} \times 0.1$$

where H and P are the calorie and protein content in crop i, and H and P are the calorie and protein content in winter wheat, respectively.

2.3 Quantifying Factor Contribution to Total Crop Production and Yield Changes

This study applied the logarithmic mean Divisia index model (LMDI) to calculate the contribution of mean crop yield and sown area to FCP change, and the refined Laspeyres index model (RLI) to calculate the contribution of individual crop yields and cropping structure to mean yield. These two models are commonly used methods of factor decomposition analysis that decompose target variables into multiple factors through mathematical identity conversion and estimate each factor' s contribution [?, ?]. Unlike often-used methods such as multiple regression, LMDI and RLI methods can quantify the contribution of each factor to changes in total crop production [?, ?, ?, ?, ?].

The FCP (t) can be simply presented as a product of mean crop yield (Y , t/hm²) and total sown area (A, hm²) of all crops considered:

$$FCP = Y_M \times A$$

The change in total FCP between the starting year 0 and year t, denoted as "FCP -FCP " , can be approximately decomposed into two parts contributed by changes in mean crop yield and sown area, respectively:

$$FCP_t - FCP_0 \approx Y_0^M \times (A_t - A_0) + A_0 \times (Y_t^M - Y_0^M) + \varepsilon$$

where FCP and FCP are total FCP; A and A are total crop sown area; Y and Y are mean crop yield in year t and 0, respectively; and is the residual value that can be eliminated using the LMDI method [?, ?] by converting the equation to the form below:

$$FCP_t - FCP_0 = \frac{FCP_t - FCP_0}{\ln(FCP_t) - \ln(FCP_0)} \times \ln\left(\frac{Y_t^M}{Y_0^M}\right) + \frac{FCP_t - FCP_0}{\ln(FCP_t) - \ln(FCP_0)} \times \ln\left(\frac{A_t}{A_0}\right)$$

The two items on the right side represent the contribution of changes in Y and A to the change in total FCP. A positive value indicates a positive contribution, otherwise a negative contribution.

For Y , the RLI model was adopted to identify the contribution of different crops. The decomposed form is presented below:

$$Y_M = \sum_{i=1}^{5} Y_i \times S_i = Y_e + S_e$$

where Y is the yield (t/hm²) of crop i and S is the sowing proportion of crop i to total crop sown area; Y is the total contribution by yield change of each crop; and S is the total contribution by change in sowing area between year 0 and t. Both can be decomposed as follows based on the RLI method [?, ?]:

$$Y_e = \sum_{i=1}^{5} \frac{Y_i^t + Y_i^0}{2} \times (S_i^t - S_i^0)$$

$$S_e = \sum_{i=1}^{5} \frac{S_i^t + S_i^0}{2} \times (Y_i^t - Y_i^0)$$

3.1 Spatiotemporal Changes of Sown Area and Crop Production

During 1998–2014, total crop sown area in the plateau showed phased variation characteristics (Fig. 2a [Figure 2: see original paper]) and can be divided into three stages: decreasing (1998-2003), restoring (2003-2010), and stabilizing (2010–2014). In the first or early implementation stage of the GFG program, sown area quickly decreased from 1.08×10 hm^2 in 1998 to 8.94×10 hm^2 in 2003, a reduction of 17.3%, then gradually restored in the second stage to 1.03×10 hm^2 in 2010 (95.5% of that in 1998). Thereafter, crop sown area slightly decreased to 1.02×10 hm^2 in 2014, 94.6% of the area in 1998, relatively stabilizing in the last stage. Similarly, total sown area in the hilly region of the plateau was rapidly reduced by 16.2% during 1998–2003, then gradually restored to 5.93×10 hm^2 in 2010 from the lowest point of 5.46×10 hm^2 in 2003. After 2010, sown area slightly decreased to 5.86×10 hm^2 in 2014, 10.1% lower than that in 1998 (Fig. 2b [Figure 2: see original paper]).

During 1998–2014, the reduction of crop sown area occurred mainly in counties of hilly areas, whereas expansion was mainly in the northwest, river basins, and low hilly areas in the northeastern and southeastern parts (Fig. 3 [Figure 3: see original paper]). For individual crops, maize and potato in the plateau maintained an expanding trend in sown area, increasing by 68.8% and 29.2%, respectively, while wheat, soybean, and millet decreased by 36.2%, 38.3%, and 48.6%, respectively.

Crop yield showed a different variation pattern. Mean yield of the five major crops declined from 3461 kg/hm^2 in 1998 to 3151 kg/hm^2 in 2000, then rapidly increased to 3904 kg/hm^2 in 2004. Following a stagnation period from 2004 to 2007, yield turned to rapid growth again and reached 4791 kg/hm^2 in 2014 (Fig. 2 [Figure 2: see original paper]). In the hilly region, mean crop yield showed a similar trend, but with lower variation amplitude (Fig. 2 [Figure 2: see original paper]). Yield of individual crops all showed a similar improving trend. From 1998 to 2014, mean yield of wheat in the plateau increased from 3290 to 3990 kg/hm^2, maize from 5398 to 6122 kg/hm^2, soybean from 1519 to 2110 kg/hm^2, and potato from 2895 to 3534 kg/hm^2.

As a result of changes in crop sown area and yield, total FCP in the whole plateau quickly declined in the first three years, from 3.74×10 t in 1998 to 3.18×10 t in 2001. Since then, FCP generally maintained a continuously growing trend (Fig. 2 [Figure 2: see original paper]), increasing by 54.4% to 4.90×10 t in 2014. From 1998 to 2014, the mean growth rate of total FCP in the plateau was 1.71% per year and varied greatly among different counties. In 28 counties, the annual growth rate exceeded 5.0%; in 76 counties it was between 2.5%–5.0%; in 36 counties 1.5%–2.5%; and in 56 counties less than 1.5% (Fig. 4 [Figure 4:

see original paper]). In the remaining 87 counties, about 30% of the total, mainly located in the southern part of the region, FCP showed a decreasing trend.

3.2 Contribution of Crop Yield and Sown Area Changes to Total FCP

The LMDI decomposition analysis results (Table 1) indicated that, associated with yield improvement, the growth rate of total FCP should be 2.00% per year during 1998-2014 for the whole plateau and 2.26% for the hilly region, but it decreased to 1.71% and 1.65%, respectively, due to the negative contribution of sown area shrinkage. During 1998-2003, sown area shrinkage was significant, causing FCP to decline by 3.11% per year, more than twofold the positive contribution of yield increase in the plateau. From 2004 to 2010, both crop sown area and yield increased, jointly stimulating quicker FCP growth. During 2010-2014, FCP growth was mostly contributed by improved crop yield (Table 1).

During 1998-2014, all crop yields were significantly improved. Meanwhile, the cropping structure was obviously adjusted, characterized by expansion of maize and potato and shrinkage of wheat, soybean, and millet (Table 2). These changes jointly contributed to mean crop yield growth, of which yield improvement contributed 62% and 68%, and cropping adjustment contributed 38% and 32% in the whole plateau and hilly regions, respectively. Among the three stages, the contribution of individual crops varied due to changes in yield and sown area, but maize showed a positive contribution to mean crop yield in all stages, implying that maize played a key role in increasing total FCP (Table 3).

4.1 Impacts of GFG Program on Crop Production

Based on the county-level land use survey of China completed in 1996, total farmland in the Loess Plateau was 1.61×10 hm^2, of which 1.32×10 hm^2 was distributed in hilly areas and not accessible to irrigation [**?**, **?**]. From literature data [**?**, **?**, **?**, **?**], about 33%-40% of farmlands, i.e., 4.35×10 -5.27×10 hm^2 in hilly areas, were steep farmlands with slope steepness greater than 15°. These steep croplands are categorized as temporary farmlands [**?**, **?**], temporarily used for growing minor crops such as sesame, naked oats, and foxtail millet with very limited inputs. Excluding these temporary croplands, total farmland in the plateau before the GFG policy was enacted was around 1.08×10 -1.17×10 hm^2, close to the total sown area (1.08×10 hm^2) of major crops in 1998. This implied that conversion of only steep slope farmlands should not significantly influence the sown area of major crops.

However, over-conversion of farmlands occurred during 1999-2003, resulting in evident reduction of crop sown area (Fig. 2 [Figure 2: see original paper]). After pilot demonstrations in selected areas in 1999, the GFG program was implemented throughout China with a planned implementation period of 8 years.

During this period, farmers who returned steeply cultivated lands to forestland or grassland could receive an annual subsidy of 1.5 t grains (or monetary equivalent) per hm^2. This subsidy was very attractive and thus stimulated serious over-conversion of farmlands, causing a rapid decrease in crop sown area and thus a negative impact on food crop production. In 2003, total crop sown area of major crops in the Loess Plateau decreased by 17.3% compared to 1998, and similarly, China' s total crop production was reduced by 16.0% for the same period. Recognizing this serious problem, the Chinese government strictly regulated the scope of farmland conversion [?, ?], and meanwhile enacted a policy to exempt agricultural tax and adopted direct subsidies for food crop production in 2004. As subsidies were supplied according to food crop sown area, slope farmlands not mandated for conversion were gradually restored to grow food crops in the Loess Plateau. Additionally, the Chinese government enhanced support for converting slope farmlands to terraces, which also contributed to increased crop sown area after 2003. Our team conducted an analysis on land use change between 2003 and 2009 for a typical hilly area of 900 km^2 (36°45 15 N–37°01 26 N, 109°25 02 E–109°45 22 E) in northern Shaanxi Province using 2.5 m resolution imagery data [?, ?]. It was found that slope farmland was reduced by 32.2% in 2009, but terraced land increased by 33.6%, of which 86.7% was converted from slope farmlands.

With farmland conversion, crop sown area was reduced by 5.4% in the whole plateau and by 10.1% in the hilly region during 1998–2014. The reduction of crop sown area did not cause a corresponding decrease in total FCP, except during 1999–2001 (Fig. 2 [Figure 2: see original paper]). From 2002 onwards, total FCP in the plateau maintained rapid growth, thus improving food self-sufficiency, with mean food grain per capita increasing to 446 kg in 2014 from 376 kg in 1998. This increase was contributed by crop yield improvement due to increased inputs and adjustment of cropping structure, i.e., replacement of traditionally grown crops such as millet and wheat with higher-yield maize crops (Table 3). Additionally, terrace building and conversion of slope lands improved land quality and reduced surface water loss, thus contributing to yield increases. Observation data from Ansai County in northern Shaanxi Province during 1994–2001 showed that crop yield in terraced farmlands was 140%–200% higher than in slope farmlands [?, ?]. A study in Dingxi of Gansu Province reported that when slope farmland was converted to terraces, yield increased by 600–1050 kg/hm^2 [?, ?].

In general, the GFG program had no significantly adverse impact on crop production in the Loess Plateau. Recent studies for Ansai County comparing conditions before and after GFG implementation reached similar conclusions that food security was not negatively affected by the program [?, ?, ?, ?]. Another study for Huining County of Gansu Province by Wang et al. (2014) indicated that agricultural inputs were markedly increased and thus obviously improved crop productivity and food security levels with GFG implementation. Based on survey data from 793 households in five provinces of northwestern China, Su et al. (2011) found that GFG program implementation evidently improved ecological conditions and rural livelihoods.

4.2 Policy Implications

The implementation of the GFG program has promoted restoration of the degraded environment in the Loess Plateau as reported by many studies [?, ?, ?]. The results of this study suggest that conversion of slope farmlands in a gradual and planned way could not affect crop production and thus food security. The influence of reduced farmland area can be mitigated by improved land productivity. The conversion of farmlands reduced labor involved in cropping activities, thus liberating rural labor to seek off-farm employment. Several studies indicated that total income increased for most rural households involved in the GFG program, mainly due to increased off-farm income [?, ?, ?, ?].

With urbanization and young people moving to urban areas, population pressure in the plateau is expected to decrease, providing an opportunity to further reduce cultivation of slope farmlands. Through reconnaissance surveys in 2017 in northern Shaanxi Province, we observed that abandonment of slope farmlands was quite common in areas along roads. However, there is also a risk of re-cultivation of converted farmlands. Farmer surveys conducted in 2005 for 2000 households in 25 counties of northern Shaanxi Province indicated that 37.2% of farmers intended to re-cultivate forested areas and grassland once the program' s subsidy ends [?, ?]. Recognizing this risk, the Chinese government extended an additional 8 years of subsidies for farmland conversion from 2010 to 2018 and has continued support from 2019 onwards. To stabilize achievements, the GFG should be set as a long-term strategic policy, not only supporting conversion of slope farmlands but also helping farmers seek sustainable land use ways to improve income and livelihood. It is suggested that the national poverty eradication program currently practiced in poor regions including the Loess Plateau could be incorporated into this strategy. This would help further improve the natural environment and consolidate land rehabilitation achievements in the Loess Plateau, contributing to the national strategy of ecological civilization building.

Due to rainfall limitations under semi-arid climate, afforestation can cause soil desiccation problems [?, ?]. Some studies indicate that the Loess Plateau is probably reaching its sustainable limit of water resources for supporting tree growth [?, ?], and thus tree vegetation should not be further expanded [?, ?]. Therefore, the GFG program strategy should be targeted to promote conversion of slope farmlands to grasslands. Further afforestation in the Loess Plateau should be approached with caution to avoid negative impacts.

5 Conclusions

With GFG program implementation, total crop sown area in the Loess Plateau quickly decreased by 17.3% to 8.94×10 hm^2 from 1998 to 2003, then gradually restored to 1.03×10 hm^2 in 2010, and thereafter relatively stabilized. In the hilly region of the plateau, sown area rapidly reduced by 16.2% during 1998–2003 to 5.46×10 hm^2, followed by restoration to 5.93×10 hm^2 in 2010, then slightly decreased to 5.86×10 hm^2 in 2014, reduced by 10.1% compared to 1998. By contrast, total crop production generally showed an increasing trend, except during the early three years for both the whole and hilly regions of the Loess Plateau. Our analyses indicate that the increase in total crop production was mainly contributed by yield improvement and adjustment of cropping structure, while changes in total sown area had minor influence. This implies that the GFG program has no significant impact on total crop production, as reduced crop production from farmland area shrinkage has been greatly compensated by yield improvement and cropping structure adjustment. It is suggested that the GFG program should be set as a long-term strategy by incorporating the poverty eradication program to promote transformation of land use patterns, thereby simultaneously achieving environmental restoration and livelihood improvement for local people. Slope farmland conversion should be prioritized to grasslands.

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Note: Figure translations are in progress. See original paper for figures.