Cropland Changes Enhance Carbon Sequestration in Northwest China From 1995 to 2015

Junqia Kong

Northwest Institute of Eco-Environment and Resources

Zhibin He (✉ hzbmail@lzb.ac.cn)

Northwest Institute of Eco-Environment and Resources

Rong Yang

Northwest Institute of Eco-Environment and Resources

Longfei Chen

Northwest Institute of Eco-Environment and Resources

Jun Du

Northwest Institute of Eco-Environment and Resources

Research

Keywords: Cropland reclamation, Cropland transfer, Carbon storage, Northwest China

Posted Date: May 18th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-502428/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

1 **Cropland changes enhance carbon sequestration**
2 **in Northwest China from 1995 to 2015**

3 **Junqia Kong^{1,2}, Zhibin He^{1,*}, Rong Yang¹, Longfei Chen¹, Jun Du¹**

4 ¹ *Linze Inland River Basin Research Station, Chinese Ecosystem Research Network,*
5 *Key Laboratory of Eco-hydrology of Inland River Basin, Northwest Institute of*
6 *Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000,*
7 *China*

8 ² *University of Chinese Academy of Sciences, Beijing 100049, China*

9

10

11

12

13 * Corresponding author.

14 *E-mail address: hzbmail@lzb.ac.cn (Z. He).*

15 *Address: Northwest Institute of Eco-Environment and Resources, Chinese Academy of*
16 *Sciences 320# Dong Gang Road, Lanzhou 730000, Gansu Province, China.*

17

Abstract

Background: The Northwest China has experienced dramatic changes in agricultural land area in recent years; the effects of these changes on carbon storage are unknown and cannot guide further land development policies related to carbon emissions. In this study, we evaluated the effects of cropland changes (reclamation and transfer) during 1995-2015 on carbon storage in Northwest China by using land use data, carbon density data, and statistical yearbooks with the Intergovernmental Panel on Climate Change (IPCC) method.

Results: The results indicated that the area of cropland increased by 1.48×10^6 ha from 1995 to 2005, resulting in a total carbon sequestration of 12.46 Tg, in which conversion of cropland to forest (11.16 Tg) and other land to cropland (8.92 Tg) were the main sources of the increase in carbon storage. Specifically, regional carbon sequestration due to cropland changes exhibited an increasing trend during 1995-2002 (dominated by cropland transfer), a gradually decreasing trend during 2002-2009 (dominated by cropland reclamation), and stabilization since then (during 2009-2015).

Conclusions: These results suggest that the development of high carbon density lands or the conversion of low carbon density lands are critical to increasing future carbon sequestration due to cropland change. We used a novel approach of combining land use data, carbon density data, and statistical yearbooks to assess the impact of cropland change on carbon storage; this method is promising in applications which guide agricultural land-use management.

39 **Keywords:** Cropland reclamation, Cropland transfer, Carbon storage, Northwest

40 China

Background

Land use and cover change (LUCC), as the direct driver of human activities disturbing natural ecosystems [21, 22], is one of the critical sources of greenhouse gas emissions to the atmosphere, with direct or potential impacts on global climate [2]. It is estimated that LUCC accounts for approximately one-third (1.24×10^5 Tg C) of all anthropogenic carbon emissions between 1850 to 1990 and 12.5% of total emissions between 1990 to 2010 [14, 15]. The change of agricultural land is the most widespread form of LUCC [17]; the patterns of cropland have changed substantially due to anthropogenic disturbance, and these changes further affected the carbon balance in terrestrial ecosystems [11, 26, 36]. For example, IPBES (2019) reported that greenhouse gas emissions due to cropland reclamation accounted for about 25% of global greenhouse gas emissions [17].

Over the last several decades in China, large areas of cropland have been lost as a result of economic reforms and open-door policies initiated in 1978. Further, agricultural expansion claimed additional areas, including those in arid regions, due to the increasing global demand for food [32, 44]. Effect of intensive agricultural activities on carbon emissions cannot be ignored. Yang *et al.* (2019) estimated that the total carbon emissions from cropland expansion in China ranged from 2.94 to 5.61×10^3 Tg during the past 300 years [46]. However, China's carbon emissions have risen sharply with rapid industrialization of the past 30 years, making it the world's largest emitter of CO₂ [12, 34]. At present, China is facing global pressure to reduce carbon

emissions, and it pledged to strive for reversal of increasing carbon emissions by approximately 2030. Therefore, it is of critical importance that the impact of cropland change on carbon stocks and CO₂ emissions in terrestrial ecosystems is clearly determined; it will serve as baseline for future optimization of agricultural land use structure to relieve the present pressure of carbon emissions.

Uncertainty defines current estimates of impacts of cropland changes on carbon budgets for distinct and similar types of conversions alike, due to the diversity of associated environmental and anthropogenic factors. For example, conversion from forest, grassland, or wetland to cropland often leads to a major loss of carbon because carbon density decreases [13, 31]. Nevertheless, cropland abandonment and subsequent succession to forest typically increases the carbon pool [1, 27]. Even a similar conversion type may create differences in carbon budgets; such as, conversion from sparsely-covered grassland (e.g., desert grassland) to cropland may lead to an increase in carbon pool [43]. However, existing literature to date tended to concentrate solely on the effects of a single type of cropland change on carbon balance, without addressing the complex effects of different types of cropland change on carbon budgets. Additionally, research to assess the effects of LUCC on carbon budgets at varying scales resulted in development of some commonly used methods [9, 14]. Different chamber techniques (e.g., static and dynamic) have been used for almost a century for estimating greenhouse gas (CO₂, CH₄, N₂O) fluxes with varying degrees of success [29]. Generally, chamber measurements are particularly well suited for in situ and laboratory-based studies [29]. At regional or global spatial scales,

empirical statistical models (e.g., bookkeeping), remote sensing models (e.g., CASA) or process-based ecosystem models (e.g., TEM; LPJ) are usually used for evaluating the effects of LUCC on carbon budgets [28, 30, 35, 52]. However, accuracy of representation of both temporal evolution and spatial heterogeneity of carbon storage with modeling approaches is limited by the availability of land use data, and the model itself. Hence, more precise annual information of LUCC is needed to analyze temporal evolution and spatial heterogeneity of carbon budgets. Further, most of the estimates of carbon budgets following LUCC focused on humid and semi-humid areas primarily in tropical, subtropical, and temperate zones [38, 51]. However, arid and semi-arid areas at regional scales are still underrepresented in these efforts.

Northwest China, characterized by arid and semi-arid climate, is known for its long history of irrigation-dependent agriculture [49]. Over the past several years, the use of agricultural water and soil resource reached unprecedented levels in Northwest China to accommodate population growth and continuous expansion of urbanization [41, 48]. For instance, the process of oasis development was greatly promoted, resulting in the expansion of artificial oasis area from 2.1×10^5 to 10.4×10^5 ha since the 1950s [39]. However, the effects of land development on carbon storage remains unknown in this region.

In this study, remote sensing data with high spatial detail and statistical yearbook data with temporal frequency were combined to quantify temporal and spatial dynamics in cropland change throughout Northwest China. Then, we calculated

carbon storage induced by cropland change by matching vegetation and soil carbon density to the annual area of cropland conversion. Finally, we analyzed temporal evolution and spatial variability in carbon storage induced by cropland change and all types cropland conversion from 1995 to 2005, and 2005 to 2015. The results of this study can provide a reference for rational land use management and decision-making based on objective assessment of regional carbon storage, which is conducive to stable and sustainable development in arid and semi-arid regions.

Materials and methods

The overall approach used in this study consisted of two parts. First part included land use data and provincial statistical yearbooks for calculating annual area of cropland change, and mapping spatial distribution. Second part involved vegetation and soil carbon density data combined with the area of annual change in cropland for calculating carbon storage. The structure of this study is shown in [Fig. 1](#).

Fig.1 Here

Study area

This study was performed in Northwest China ($73^{\circ}15'E$ - $111^{\circ}15'E$, $31^{\circ}32'N$ - $49^{\circ}10'N$), located in the innermost part of the Eurasian continent [\[33\]](#). Administrative divisions in this area include Xinjiang, Qinghai, Gansu, Ningxia, and Shanxi provinces, accounting for 32.2% of the total land area of China, and an area of approximately 3.10 million km^2 ([Fig.2](#)). Most of the area exhibits a typical continental climate, with very low mean annual precipitation (below 250 mm), mean annual

temperature from -2 to 19 °C [45], and annual evapotranspiration with a range from 225 to 285 mm [7]. The main land cover types in this region consist of temperate evergreen forest (i.e., *Picea* spp., *Abies sibirica*, etc.), temperate deciduous forest (i.e., *Populus*, *Betula*, etc.), temperate shrub land (i.e., *Haloxylon*, etc.), grassland (i.e., alpine meadow, desert steppe), cropland (i.e., oasis, etc.), built-up lands, bare land, and basins [4]. The natural landscape changes from east to west from forest and typical grassland, to a grassland-desert and desert; vegetation cover shows a gradually decreasing trend.

Fig.2 Here

Data sets and pre-processing

a. Land-use category and area

We used a land-use dataset for 1995, 2005, and 2015, derived from Land Cover (LC) project of the European Space Agency (ESA) Climate Change Initiative (CCI) Climate Research Data Package (CRDP)(<https://www.esa-landcover-cci.org/>), with a spatial resolution of 300 m. The Land Cover Classification System (LCCS) proposed by the Food and Agriculture Organization (FAO) of the United Nations was adopted. The land-use dataset was used as follows: (1) The original 22 land-use types were grouped into six land categories, after land use classification of the Chinese Academy of Science: cropland, forest, grassland, water, built-up land, and other land (Zhang *et al.*, 2014) (see table S1). (2) Two land cover transition matrixes were derived from three periods (1995, 2005, and 2015) of land use images (Fig.S1) for the purpose of

calculating the area of cropland reclamation and transfer during 1995-2005 and 2005-2015 (see table S2). (3) The spatial analysis tool “overlay” in Arcgis 10.2 was used to visualize and analyze the distribution of cropland reclamation and transfer for periods 1995-2005 and 2005-2015 (Fig.3).

b. Annual area of cropland change

Land use data acquired from remote sensing images can reflect the spatial and temporal patterns of LUCC, but not the annual area of LUCC [42]. Therefore, in this study, a series of provincial statistical yearbooks (<http://data.cnki.net/>; see table S3) with high temporal frequency were combined with remote sensing data with high spatial resolution to obtain the annual cropland reclamation and transfer area in five northwestern provinces from 1995 to 2015; these data could replace the single data source of LUCC to improve the accuracy of carbon budget estimations.

The annual cropland reclamation and transfer area in the study period was calculated using the following equations:

$$\Delta S = (S_1, S_2, S_3, \dots, S_n) \quad (1)$$

Where ΔS is annual area change of cropland (ha), S_i is annual cropland area (ha), $i=1 \dots n$.

$$\Delta S_{IC} = (\Delta S_1, \Delta S_2, \Delta S_3, \dots, \Delta S_{n-1}) \quad (2)$$

Where ΔS_{IC} is the annual increase in area of cropland, $\Delta S_{IC_i} = \Delta S_{i+1} - \Delta S_i$ (ha), $i=1 \dots n-1$; Considering that ΔS_{IC} may be < 0 , and cropland reclamation area must be in

principle ≥ 0 , it was necessary to smooth and revise the annual increase in cropland area, and the relative annual increase in cropland area was calculated with the following equation (ΔS_{IC}):

$$\Delta S_{IC}' = (\Delta S_1 + |\Delta S_{IC\min}|, \Delta S_2 + |\Delta S_{IC\min}|, \Delta S_3 + |\Delta S_{IC\min}|, \dots, \Delta S_{n-1} + |\Delta S_{IC\min}|) \quad (3)$$

$$P_{IC} = (\Delta S_{IC_1}' / \text{sum}(\Delta S_{IC}'), \Delta S_{IC_2}' / \text{sum}(\Delta S_{IC}'), \dots, \Delta S_{IC_{n-1}}' / \text{sum}(\Delta S_{IC}')) \quad (4)$$

Where P_{IC} (%) is the coefficient of annual increase in cropland area. Calculation

method of P_{DC} (%) is similar to P_{IC} , except that the formula (2) is changed to the following:

$$\Delta S_{DC} = (\Delta S_1, \Delta S_2, \Delta S_3, \dots, \Delta S_{n-1}) \quad (5)$$

Where ΔS_{DC} is the annual decrease of cropland area, $\Delta S_{DC_i} = \Delta S_i - \Delta S_{i+1}$ (ha). The subsequent calculation method is the same as in formulas (3) and (4).

The annual area of cropland reclamation or transfer (ha) was obtained by multiplying P_{IC} (%) or P_{DC} (%) and cropland reclamation or transfer area (ha) for years 1995-2005 and 2005-2015.

Calculation of changes in carbon storage induced by cropland change

Carbon storage induced by cropland change was calculated with the following equation [18]:

$$\Delta C = \Delta VC + \Delta SOC \quad (6)$$

Where ΔC (Tg) represents the change in carbon storage caused by cropland change;
 ΔVC (Tg) represents change in biomass carbon storage; ΔSOC (Tg) represents the
change in soil organic carbon (SOC).

a. Calculation of change in biomass carbon storage

We obtained vegetation carbon density information for each land use type (Table 1) from published literature [8, 20]. Changes in biomass carbon storage caused by cropland change was calculated with the following formula (IPCC, 2006):

$$\Delta VC = \sum_i^i [(VD_{Afteri} - VD_{Beforei}) \times \Delta A_{To-otheri}] \quad (7)$$

Where VD_{Afteri} and $VD_{Beforei}$ ($t\ C\ ha^{-1}$) represent carbon density in vegetation for land-use i after and before the conversion; $\Delta A_{To-otheri}$ (ha) represents the area of land-use i converted to another land type.

Table 1 Here

b. Calculation of changes in soil carbon storage

We obtained soil carbon density of each soil type from the 1:1,000,000 soil type map of the China Second National Soil Survey (Table S4). Based on soil carbon density and the impact factors for soil carbon change [19] (Table 2), we applied Tier 1 method from IPCC (2006) to calculate soil carbon storage caused by cropland change using the following formula [18]:

$$\Delta SOC = \sum_{i,s} (SD_{i,s} \times F_{impactis} \times \Delta A_{to-otheri,s}) \quad (8)$$

Where $SD_{i,s}$ represents soil carbon density for land-use type i with soil type s ;
 $\Delta A_{To-otheri,s}$ represents the transformed area of land use type i with soil type s ; $F_{impact,s}$
represents the impact factors of SOC change during cropland change (Table 2) [19].

Table 2 Here

Results

Spatio-temporal dynamics of cropland change

a. Temporal dynamics of cropland change

Table 3 Here

Northwest China has experienced continuous cropland changes during the period from 1995 to 2015 (Table 3). Overall, total area of cropland in Northwest China increased by 1.48×10^6 ha (4.2%) between 1995 and 2015, in that, the area of cropland reclamation and transfer increased by 3.58×10^6 and 2.11×10^6 ha, respectively, from 1995 to 2015. Separately, the increase in 2005-2015 was 1.01×10^5 ha more than in the previous period. However, the area of cropland reclamation and transfer decreased by 29.33 and 50.79%, respectively, from 2005 to 2015. Cropland reclamation was mainly from other land and grassland, contributing respectively 56.68 and 39.88% of the reclaimed cropland. Meanwhile, conversion to grassland made up the largest proportion of cropland transfer, followed by built-up land, other land; the three LUCCs respectively accounted for 67.44, 14.86, and 10.58% of the area of cropland transfer. Except for the increase in conversion of built-up land to cropland, and

cropland to built-up land, the conversion of other land uses showed a decreasing trend in 2005-2015 over the previous period.

The trend in cropland reclamation was opposite of the trend in cropland transfer (Fig. 3). The area of cropland reclamation exhibited a downward trend from 1995 to 2002 (-1.68×10^5 ha), a gradual increase from 2002 to 2009, with a peak in 2009 (6.71×10^5 ha); since then, the area of cropland reclamation has been on a downward trend. However, the area of cropland transfer gradually increased from 1995 to 2002 (2.12×10^5 ha), then gradually decreased after 2002, and reached an all-time low in 2009 (1.32×10^4 ha); since then, the area of cropland transfer fluctuated. The trend in cropland reclamation was consistent with the trend in other land and in grassland reclamation, while the trend in cropland transfer was consistent with the trend of cropland to grassland conversion from 1995 to 2015.

Fig.3 Here

b. Spatial variability in cropland change

Cropland change across Northwest China exhibited spatial variability (Fig. 4). Between 1995-2005, cropland change in Xinjiang (1.06×10^6 ha), Qinghai (6.22×10^4 ha), and Ningxia (5.48×10^4 ha) provinces exhibited increasing trends, respectively, while that in Shanxi (-1.47×10^5 ha) and Gansu (-3.41×10^5 ha) provinces showed decreasing trends. Qinghai province exhibited an increase in the early period, and then a decrease (-4.72×10^4 ha) in the later period, while trends in other provinces remained steadily increasing or decreasing between 2005 to 2015.

The spatial distribution of cropland change was similar for both periods (Fig. 5). The most dramatic change took place in Xinjiang province, especially in its northern part. Cropland change in Qinghai province, which is mainly covered by grassland, occurred mainly within that cover type. Additionally, cropland changes were notable in the northern part of Ningxia and Shanxi provinces in both periods. Cropland change in Gansu province occurred mainly in the southeastern part.

Fig.4 Here

Fig.5 Here

Effects of cropland change on carbon storage

a. Changes in carbon storage over time

Calculated changes in carbon storage suggested that during 1995-2015, cropland change led to about 12.46 Tg (9.50 Tg in 1995-2005 and 2.96 Tg in 2005-2015) of total carbon accumulation, including 2.28 and 10.18 Tg increase due to, respectively, soil and vegetation carbon storage, corresponding to an increase in storage rates of approximately 0.67 Tg C year⁻¹. Meanwhile, carbon storage due to cropland reclamation increased by 2.76 Tg from 1995 to 2015, which corresponded to a decrease of 3.16 Tg in soil and an increase of 5.92 Tg in vegetation. Moreover, carbon storage induced by cropland transfer increased by 9.71 Tg from 1995 to 2015, in which carbon storage in soil and vegetation increased by 5.45 and 4.26 Tg, respectively.

On the whole, the trend in carbon storage caused by cropland change in northwestern China was affected by the trend in cropland transfer and reclamation (Fig.6). Therefore, carbon storage caused by cropland changes showed an increasing trend from 1995 to 2002, reached a maximum in 2002 (1.27 Tg), gradually decreased after 2002, reached a second, small peak in 2009 (0.73 Tg), and fluctuated since then. Specifically, the trend in carbon storage caused by cropland reclamation or transfer was affected by the trend in vegetation and soil carbon storage. In the background of cropland reclamation, the trend in carbon storage change was consistent with that of vegetation carbon storage from 1995 to 2015. Specifically, total and vegetation carbon storage caused by cropland reclamation both exhibited a downward trend from 1995 to 2002, a gradual increase from 2002 to 2009, a maximum in 2009 (0.71 and 1.27 Tg), and a gradual decrease since then. In the background of cropland transfer, the trend in carbon storage caused by cropland transfer was greatly affected by the trend in vegetation carbon storage from 1995 to 2005, and by soil carbon storage from 2005 to 2015. Specifically, during 1995-2005, total and vegetation carbon storage caused by cropland transfer both showed an increasing trend from 1995 to 2002, reached a maximum in 2002 (1.25 and 0.67 Tg), and gradually decreased from 2002 to 2005; during 2005-2015, total and soil carbon storage caused by cropland transfer both showed a decreasing trend from 2005 to 2009 with a minimum in 2009 (0.02 and 0.03 Tg), and stabilized since then.

Fig.6 Here

b. Carbon storage in different types of cropland conversion

Effects on carbon storage differed across different types of reclamation in Northwest China (**Fig.7a**). The increase in carbon storage was mainly from grassland, water, built-up land, and other land reclamation, while forest reclamation led to a decrease in carbon storage. Specifically, the reclamation of other land had the greatest impact at 8.92 Tg increase in carbon storage, accounting for 47.60% increase in carbon storage due to cropland reclamation. Carbon storage induced by the conversion of forest land, grassland, water, and built-up land to cropland changed by -7.99, 1.74, 0.059 and 0.03 Tg.

Effects on carbon storage differed across different types of cropland transfer in Northwest China (**Fig.7b**). The increase in carbon storage was mainly from cropland to forest and grassland; the transfer of cropland to water, built-up land, and other land led to a decrease in carbon storage. Specifically, the transfer of forest to cropland had the greatest impact at 11.16 Tg increase in carbon storage, accounting for 62.33% increase in carbon storage caused by cropland transfer. Carbon storage changed upon conversion of cropland to grassland, other land, built-up land, and water by 2.65, -2.03, -2.02 and -0.046 Tg, respectively.

Fig.7 Here

c. Spatial variability in carbon storage

The trends in area and carbon storage caused by cropland changes were relatively consistent in spatial characteristics for both periods of study (**Fig.8**). In general,

highest carbon storage was found in Xinjiang (8.41 Tg), followed by Shanxi (1.61 Tg), and Qinghai (1.41 Tg) provinces, while the lowest one in Gansu (0.84 Tg) and Ningxia (0.19 Tg) provinces. All provinces except for Shanxi, retained carbon accumulation during the second period, but the increase in carbon storage was less than that in the first period. Specifically, the largest increase in carbon storage in Xinjiang province was 5.35 Tg from 1995 to 2005, and 3.06 Tg from 2005 to 2015. A minimal amount of carbon storage occurred in Ningxia province with an increase of 0.18 Tg from 1995 to 2005, and 0.004 Tg from 2005 to 2015. Additionally, vegetation carbon storage in Shanxi and Qinghai province increased in the first period and decreased in the second, but the increase in total carbon storage remained almost unaffected.

Fig.8 Here

Discussion

Characteristics of cropland change from 1995 to 2015

Over the last several decades, the area and distribution of cropland in Northwest China has changed as a result of social and economic transition (e.g., urbanization, population growth, etc) [49, 50]. Our results indicated that the area of cropland in Northwest China increased by 1.48×10^6 ha during the period of 1995-2015, with a mean increase of 7.4×10^4 ha per year. This indicated that agricultural land development in Northwest China was likely to increase during the study period (Fig.3). Reclamation and transfer resulted in fluctuation in cropland area. During the

first period from 1995 to 2002, cropland was mostly transferred; with rapid urbanization and expiration of new land contract period, cropland occupation became more prominent causing land encroachment by urbanization; meanwhile, farmers transferred land use rights to other farmers or economic organizations, also contributing to a decrease in cropland area [5, 49]. During the second period from 2002 to 2009, cropland was reclaimed at a large-scale; the Chinese government successively established the strict red line of cropland (1.8 billion mu), and increased protection of cropland. At the same time, advanced technologies (e.g., sprinkler and drip irrigation) improved the utilization efficiency of water and soil resources [40], enabling a gradual increase in cropland area from 2002 to 2009. Finally, with the improvement of cropland protection policy and ecological engineering programs (promoting the conversion of cropland to forest and to grassland) [24], the change in cropland area stabilized when cropland reclamation and transfer reached an equilibrium from 2009-2015. In summary, considering the role of socio-economic factors in different stages of cropland change together with a numerical evaluation can more accurately reflect the change characteristics of a cropland area.

Effects of cropland change on carbon storage

In arid and semiarid regions, cropland change has been shown to have an important effect on carbon storage in both the biosphere and the pedosphere [23]. Our results demonstrated that cropland change from 1995 to 2015 resulted in a cumulative carbon sequestration of 12.46 Tg or 0.62 Tg a^{-1} , of which 2.28 Tg and 10.18 Tg were

in soil and vegetation, respectively; this was consistent with other studies that have demonstrated that northwest China is a sink for carbon as a result of cropland change [48]. Meanwhile, carbon storage caused by cropland reclamation and transfer increased by 2.76 and 9.71 Tg from 1995 to 2015, respectively. However, two other studies showed that northwestern China experienced a relatively small soil carbon loss induced by cropland reclamation, and a loss of total carbon storage (0.54 Tg a^{-1}) [10, 46]. The reason for these differences results mainly from the differences in vegetation density data and data processing.

Carbon sequestration caused by cropland change in Northwest China was due mainly to the reclamation of other land into cropland, and the conversion of cropland to forest and grassland (Fig.7). On the one hand, in our study, 2.03×10^6 ha of other land was converted to cropland, accounting for the main increase in carbon storage (8.92 Tg) in cropland reclamation. Generally, desert-grassland, sandy, and other lands occupy a large fraction of the area of Northwest China; with their low carbon density, these land types were reclaimed into cropland, changing the carbon cycle of desert ecosystem and increasing carbon reserves [37, 47]. On the other hand, the area of cropland (1.42×10^6 ha) was mainly converted into grassland, resulting in a 2.64 Tg increase in regional carbon storage. Meanwhile, only 1.41×10^5 ha of cropland was converted to forest, becoming the main source of increase in carbon storage (11.16 Tg) in cropland change. These changes can be attributed to the implementation of a series of ecological engineering programs by the Chinese government in Northwest China, including the Natural Forest Conservation Program and Grain for Green Program.

These programs promoted the conversion of cropland to forest and to grassland, and significantly affected carbon storage [25, 50]. This indicates that the implementation of ecological engineering programs in Northwest China can promote the development of land cover types with high carbon density (forest and grassland) increasing regional carbon storage.

However, 3.13×10^5 ha of cropland was occupied by built-up area, with a loss of approximately 2.02 Tg (0.10 Tg a^{-1}) of carbon storage. A preliminary estimate suggested that the occupied cropland was the main cause of carbon storage loss during the process of built-up land expansion, resulting in a loss of 0.07 Tg a^{-1} of carbon storage in Northwest China [6]; this was similar to our main result but slightly different because of the soil carbon loss was not considered in Chuai's study. However, the indirect emission effects of urbanization (such as waste products, population migration, and land degradation) caught our attention more than the variability in carbon storage caused by the expansion of built-up land into cropland [3]. In addition, the conversion of forest with high carbon density to cropland has also resulted in a major decline in carbon storage of about 7.99 Tg. Thus, if measures are taken to control urban expansion and deforestation in specified regions, the rate of carbon loss could be reduced. We propose that the capacity for carbon sequestration in our study area will benefit from the optimization of land-use structure with land use policies; this can be accomplished especially by increasing the area converted from cropland to high carbon land-use such as forest, limiting or decreasing deforestation, and

restricting the transfer of cropland to low carbon density land use such as built-up land.

With respect to the temporal evolution, the increase or decrease in regional carbon storage is determined only by the type of land use change, and its dynamics are affected by the annual area of cropland reclamation and transfer [42]. Our study reflected that cropland reclamation and transfer dominated different periods, resulting in fluctuations in the temporal evolution of carbon sequestration (Fig. 6, 7). At the beginning, the increasing trend of total carbon sequestration from 1995 to 2002 was accompanied by an increase in the area and carbon storage of cropland transfer, also reaching the maximum in 2002, of which transfer of cropland to forest was the main source of this increase in carbon storage. Subsequently, the decreasing trend of total carbon sequestration after 2002 was accompanied by a decrease in the area and carbon storage of cropland reclamation, and then reaching a small peak in 2009, of which reclamation of other land to cropland was the main source of this increase in carbon storage. Finally, cropland reclamation and transfer reached equilibrium, and changes in carbon storage were relatively stable. These results demonstrated that the temporal evolution of carbon sequestration was usually higher when cropland reclamation (mainly other land to cropland) and transfer (mainly cropland to forest) was at a maximum. Therefore, we conclude that rapid urbanization, the existing cropland protection policy, and other ecological policy affecting cropland reclamation or cropland transfer should aim to balance transfer and reclamation of cropland to allow for a steady increase in carbon storage.

With respect to the provincial pattern, our study also revealed distinct differences in the direction and quantity of carbon storage caused by cropland change among the five provinces in Northwest China (Fig.8). Xinjiang province, characterized by vast desert area and distinctive natural environment, has experienced enormous land development, mainly reflected in the reclamation of other land to cropland. Here, an increase of 0.42 Tg a^{-1} in carbon storage was facilitated by cropland change, and it was the highest increase in carbon storage among the five provinces. This result was in agreement with a previous study that found that an increase of 0.69 Tg a^{-1} of carbon storage in Xinjiang was due to cropland reclamation and transfer [42]. In Qinghai province, which is mainly occupied by grassland, grassland reclamation (2.16×10^5 ha) and cropland to grassland transfer (9.29×10^4 ha) dominated during the two periods of study, thus, resulting in a decrease in vegetation carbon storage in the second period. Additionally, Shanxi province had experienced an increase (2.53 Tg) during 1995-2005 to decrease (-0.91 Tg) during 2005-2015, and the main reason was the decline of the area of cropland return to forests. Gansu and Ningxia province experienced minor changes in carbon storage changes (0.84 and 0.19 Tg), respectively. In a word, the spatial variability in carbon storage in different provinces was mainly related to natural geographical features in these regions, which limited the types and areas of cropland conversion.

Strengths and limitations of this study, and future work

We also simulated future changes in cropland using CA-Markov models based on the historical transition rules (Supplement material, Fig.S2, Table. S2), and calculated the potential impact of changes in cropland on carbon storage in Northwest China. Overall, total area of cropland in Northwest China increased by 3.45×10^6 ha between 2015 and 2025, resulting in a $0.91 \text{ Tg} \cdot \text{a}^{-1}$ increase in regional carbon storage, with an increase of 51.78% compared with 1995-2015 ($0.60 \text{ Tg} \cdot \text{a}^{-1}$). This suggested that the effect of cropland change on carbon storage was likely to increase in the short term. Briefly, 4.81×10^6 ha of other land is expected to be converted to cropland, and become the main source of increase in carbon storage (24.79 Tg). In addition, a total of 4.18×10^4 ha of cropland is expected to be converted to forest, also leading to a notable increase in carbon storage (3.07 Tg) over the previous period. However, in arid and semiarid area, water resources are the main natural factors restricting the utilization of land resources, and the development of agriculture and forestry [39]. Although the expansion of forest and other land reclamation to cropland are the most important sources of carbon sinks in cropland changes, potential effect of an increase in vegetation cover on water demand need to be considered. Thus, in the future, there is a need to consider how to make cropland changes result in reasonable carbon sinks within the confines of limiting water resources. Cropland changes over long-term can be simulated based on water resources limitation scenarios other than historical transition rules, which can provide valuable information for decision-making process involved in land use change.

We used a novel approach of combining land use data, carbon density data, and statistical yearbooks to assess the impact of cropland change on carbon storage. First, this is the first attempt to evaluate carbon storage due solely to cropland change in Northwest China. Second, this approach clearly illustrates a gradual cropland area change, and is promising in applications which guide agricultural land-use management. More importantly, the results of this study can provide a reference for rational land use management and decision-making based on objective assessment of regional carbon storage, which is conducive to future stable and sustainable development in arid and semi-arid regions.

Though our study has improved the accuracy of estimation and revealed spatial variability and temporal characteristics of carbon storage due to cropland change, our results have some potential uncertainties and limitations. Remote sensing data with spatial detail and statistical data with temporal frequency were used to obtain the annual area of cropland reclamation and transfer; this may not accurately reflect the annual area and trends in cropland change. Thus, obtaining high-resolution land-use data with shorter time intervals may be a more effective method. In addition, time interval of 10 years used in this study may be insufficient to detect changes and stabilization in soil carbon density. For future research, the time interval of 20 years is needed to support calculations of carbon storage.

Conclusions

We combined land use data, carbon density data, and statistical yearbooks with

IPCC method to investigate carbon storage caused by cropland change (reclamation and transfer) between 1995 and 2015 in Northwest China. The method used in our study showed a clear temporal evolution of cropland change and provided promising applications in guiding agricultural land-use.

Our results showed that cropland changes acted as a carbon sink in Northwest China, with a total carbon sequestration of 12.46 Tg, in which the conversion of cropland to forest (11.16 Tg) and other land reclamation to cropland (8.92 Tg) affected by ecological engineering programs and characteristics of ecological environment were the main sources of an increase in carbon storage. Spatial variability in carbon storage in different provinces was mainly related to natural geographical features in these regions, which limited the types and areas of cropland conversion. Cropland reclamation and transfer dominated different periods, resulting in fluctuations in the temporal evolution of carbon sequestration. These results indicate that to increase carbon sequestration in cropland change, it is essential to promote development of land cover types with high carbon density, or the conversion of low carbon density lands to cropland. Meanwhile, we propose that a balance should be sought between the transfer and reclamation of cropland to allow for a steady increase in carbon storage over time.

Our results also indicate that carbon sequestration will likely continue in the future in this area. However, considering the importance of water resources in arid and semi-arid regions, there is a need for considering water resource limitation

497 scenarios for carbon storage in the future. In summary, the results of this study
498 provide a reference for rational land use management and decision-making regarding
499 objective assessment of carbon storage in Northwest China, and for sustainable
500 development in arid and semi-arid regions.

Abbreviations

LUCC: Land use and cover change; SOC: soil organic carbon.

Acknowledgments

The authors thank the editors and anonymous reviewers for their valuable comments and suggestions on this manuscript.

Authors' contributions

JK wrote the first draft of the manuscript and contributed to data analysis; LC and JD designed the study and led the field data collection; ZH and RY supported all aspects of the research. All authors read and approved the final manuscript.

Funding

This work was jointly supported by the Second Tibetan Plateau Scientific Expedition and Research (STEP) program (No. 2019QZKK0303), the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA23060301, XDA23060302), the National Key Research and Development Program of China (No. 2019YFC0507403) and the State Key Program of National Natural Science of China (No. 41630861).

Availability of data and materials

Land-use dataset is derived from LC-ESA through <https://www.esa-landcover-cci.org/>.

The annual area of cropland is derived from available a series of provincial statistical

519 yearbooks (<http://data.cnki.net/>; Table S3). Vegetation and soil carbon density data
520 are shown in Table 1 and Table S4.

521 **Competing interests**

522 The authors declare that they have no competing interests.

523 **Author details**

524 ¹ Linze Inland River Basin Research Station, Chinese Ecosystem Research Network,
525 Key Laboratory of Eco-hydrology of Inland River Basin, Northwest Institute of
526 Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000,
527 China. ² University of Chinese Academy of Sciences, Beijing 100049, China.

References

1. Albanito F, Beringer T, Corstanje R, Poulter B., Stephenson A, Zawadzka J, et al. Carbon implications of converting agricultural cropland to bioenergy crops or forest for climate mitigation: a global assessment. *Glob Chang Biol Bioenergy*. 2016;8:81-95.
2. Arshad A, Ashraf M, Sundari RS, Qamar H, Wajid M, Hasan M. Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. *Int J Disast Risk Re*.2020;46:101468.
3. Bai X, Shi P, Liu Y. Society: Realizing China's urban dream. *Nature*. 2014; 509: 158.
4. Chen Y, Luo G, Maisupova B, Chen X, Mukanov BM, Wu M, et al. Carbon budget from forest land use and management in Central Asia during 1961-2010. *Agric For Meteorol*. 2016;221:131-141.
5. Chuai X, Huang X, Lu Q, Zhang M, Zhao R, Lu J, et al. Spatiotemporal Changes of Built-Up Land Expansion and Carbon Emissions Caused by the Chinese Construction Industry. *Environ Sci Technol*. 2015;49:13021-13030.
6. Chuai X, Huang X, Lai L, Wang W, Peng J, Zhao R. Land use structure optimization based on carbon storage in several regional terrestrial ecosystems across China. *Environ Sci Policy*. 2013;25:50-61.

- 547 7. Deng X, Liu Y, Liu Z, Yao J. Temporal-spatial dynamic change characteristics of
- 548 evapotranspiration in arid region of Northwest China. *Acta Ecolog Sinica*.
- 549 2017;37:2994-3008 (in Chinese).
- 550 8. Fang J, Guo Z, Piao S, Chen A. Terrestrial vegetation carbon sinks in China,
- 551 1981–2000. *Sci China Ser D Earth Sci*. 2007;50:1341-1350.
- 552 9. Fu C, Yu G, Fang H, Wang Q. Effects of Land use and cover change on terrestrial
- 553 carbon balance of China. *Prog Geog*. 2012;31:88-96 (In Chinese).
- 554 10. Ge Q, Dai J, He N, Pan Y, Wang M. Land use changes and their relations with
- 555 carbon cycles over the past 300 a in China. *Sci China Ser D-Earth Sci*.
- 556 2008;51:871-884.
- 557 11. Guo H, Li S, Wong F L, Qin S, Wang Y, Yang D, et al. . Drivers of carbon flux in
- 558 drip irrigation maize fields in northwest China. *Carbon Bal Manage*. 2021;16:12.
- 559 12. He Q, Zeng C, Xie P, Liu Y, Zhang M. An assessment of forest biomass carbon
- 560 storage and ecological compensation based on surface area: A case study of
- 561 Hubei Province, China. *Ecol Indic*. 2018; 90:392-400.
- 562 13. Hirsch AI, Little WS, Houghton RA, Scott NA, White JD. The net carbon flux due
- 563 to deforestation and forest regrowth in the Brazilian Amazon. *Glob Chang Biol*.
- 564 2010;10:908-924.
- 565 14. Houghton RA, Hackler JL. Emissions of carbon from forestry and land-use

566 change in tropical Asia. *Glob Chang Biol.* 1999;5:481-492.

567 15. Houghton RA, House J, Pongratz J, Van Der Werf G, DeFries R, Hansen M, et al.
568 Carbon emissions from land use and land-cover change. *Biogeosciences.*
569 2012;12:5125-5142.

570 16. Houghton RA, Nassikas AA. Global and regional fluxes of carbon from land use
571 and land cover change 1850–2015. *Global Biogeochem Cycles.*
572 2017;31:456-472.

573 17. IPBES (2019): Global assessment report on biodiversity and ecosystem services
574 of the Intergovernmental Science-Policy Platform on Biodiversity and
575 Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors).
576 IPBES secretariat, Bonn, Germany. p.28.

577 18. IPCC, 2006. Good Practice Guidance for Land Use, Land-Use Change and
578 Forestry, IPCC Guidelines for National Greenhouse Gas Inventories (Prepared
579 by the National Greenhouse Gas Inventories Programme).

580 19. IPCC, 2003. Good practice guidance for land use, land use change and forestry.
581 Institute for Global Environmental Strategies. p. 617.

582 20. Kerang LI, Wang S, Cao M. Vegetation and soil carbon storage in China. *Sci*
583 *China Ser D Earth Sci.* 2004;47:49-57.

584 21. Johnson BG, Zuleta GA. Land-use land-cover change and ecosystem loss in the
585 Espinal ecoregion, Argentina. *Agric Ecosyst Environ.* 2013;181:31-40.

- 586 22. Lembi RC, Cronemberger C, Picharillo C, Koffler S, Sena PH, Felappi JF, et al.
587 Urban expansion in the Atlantic Forest: applying the Nature Futures Framework
588 to develop a conceptual model and future scenarios. *Biota Neotropica*.
589 2020;20:e20190904.
- 590 23. Lal R. Soil carbon dynamics in cropland and rangeland. *Environ Pollut*.
591 2002;116:353-362.
- 592 24. Lichtenberg E, Ding C. Chapter 5: Assessing Farmland Protection Policy in China.
593 *Land Use Policy*. 2008;25:59-68.
- 594 25. Lu F, Hu H, Sun W, Zhu J, Liu G, Zhou W, et al. Effects of national ecological
595 restoration projects on carbon sequestration in China from 2001 to 2010. *Proc*
596 *Natl Acad Sci U.S.A.* 2018;115:4039-4044.
- 597 26. Molotoks A, Stehfest E, Doelman J, Albanito F, Smith P. Global projections of
598 future cropland expansion to 2050 and direct impacts on biodiversity and carbon
599 storage. *Glob Chang Biol*. 2018;24:5895-5908.
- 600 27. Nadal-Romero E, Cammeraat E, Pérez-Cardiel E, Lasanta T. How do soil organic
601 carbon stocks change after cropland abandonment in Mediterranean humid
602 mountain areas? *Sci Total Environ*. 2016;566:741-752.
- 603 28. Oelbermann M, Voroney R. An evaluation of the century model to predict soil
604 organic carbon: Examples from Costa Rica and Canada. *Agrofor Syst*. 2011;82:
605 37-50.

- 606 29. Pavelka M, Acosta M, Kiese R, Altimir N, Brümmer C, Crill P, et
607 al. Standardisation of chamber technique for CO₂, N₂O and CH₄ fluxes
608 measurements from terrestrial ecosystems. *Int Agrophys*. 2018;32:569-587.
- 609 30. Qin ZC, Zhuang QL, Zhu XD. Carbon and nitrogen dynamics in bioenergy
610 ecosystems: 1. Model development, validation and sensitivity analysis. *Glob
611 Chang Biol Bioenergy*. 2015;6:740-755.
- 612 31. Qiu L, Wei X, Zhang X, Cheng J, Gale W, Guo C, et al. Soil organic carbon
613 losses due to land use change in a semiarid grassland. *Plant Soil*.
614 2012;355:299-309.
- 615 32. Seto KC, Kaufmann RK. Modeling the drivers of urban land use change in the
616 Pearl River Delta, China: Integrating remote sensing with socioeconomic data.
617 *Land Economics*. 2003;79:106-121.
- 618 33. Shi Y, Shen Y, Kang E, Li D, Ding Y, Zhang G, et al. Recent and Future Climate
619 Change in Northwest China. *Climatic Change*. 2006;80:379-393.
- 620 34. Shi L, Sun J, Lin J, Zhao Y. Factor decomposition of carbon emissions in Chinese
621 megacities. *J Environ Sci*. 2019;75:209-215.
- 622 35. Sitch SB, Prentice IC, Arneth A, Bondeau A, Cramer W, Kaplan JO, et
623 al. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon
624 cycling in the LPJ dynamic global vegetation model. *Glob Chang Biol*.
625 2010;9:161-185.

- 626 36. Sperow M. What might it cost to increase soil organic carbon using no-till on US
627 cropland? Carbon Bal Manage. 2020;15: 1-13.
- 628 37. Su Y, Yang R, Liu W, Wang X. Evolution of soil structure and fertility after
629 conversion of native sandy desert soil to irrigated cropland in arid region, China.
630 Soil Sci. 2010;175:246-254.
- 631 38. Tian H, Melillo JM, Kicklighter DW, Pan S, Liu J, Mcguire AD, et al. Regional
632 carbon dynamics in monsoon Asia and its implications for the global carbon
633 cycle. Global Planet Change. 2003;37:201-217.
- 634 39. Wang T. Review and prospect of research on oasisification and desertification in
635 arid regions. J Desert Res. 2009;29:1-9 (In Chinese).
- 636 40. Wang X, Hao L, Qin H, Su L, Liu Z. Textual quantitative analysis of cultivated
637 land ecological management and protection policies in China from the
638 perspective of policy tools. China Land Sci. 2018;32:15-23(In Chinese).
- 639 41. Wang Y, Qin D. Influence of climate change and human activity on water
640 resources in arid region of Northwest China: an overview. Clim Change Res.
641 2017;13:483-493 (In Chinese).
- 642 42. Wang Y, Luo G, Zhao S, Han Q, Li C, Fan B, et al. . Effects of arable land change
643 on regional carbon balance in Xinjiang. Acta Geograp Sin. 2014;69:110-120 (In
644 Chinese).
- 645 43. Xiao G, Yin K, Feng M, Ma Q, Ping L, et al. Changes in soil organic carbon,

- 646 nutrients and aggregation after conversion of native desert soil into irrigated
647 arable land. *Soil Till Res.* 2009;104:263-269.
- 648 44. Xu Y, Mcnamara P, Wu Y, Dong Y. An econometric analysis of changes in arable
649 land utilization using multinomial logit model in Pinggu district, Beijing, China.
650 *J Environ Manage.* 2013;128:324-334.
- 651 45. Yang R, Su Y, Kong J. Effect of tillage, cropping, and mulching pattern on crop
652 yield, soil C and N accumulation, and carbon footprint in a desert oasis farmland.
653 *Soil Sci Plant Nutr.* 2017;63:1-8.
- 654 46. Yang X, Jin X, Xiang X, Fan Y, Liu J, Shan W, et al. Carbon emissions induced by
655 farmland expansion in China during the past 300 years. *Sci China Earth Sci*
656 2019;62:423-437.
- 657 47. Yang P, Xia J, Zhang Y, Hong S. Temporal and spatial variations of precipitation
658 in Northwest China during 1960-013. *Atmos Res.* 2017;183: 283-295.
- 659 48. Zhang M, Huang X, Chuai X, Yang H, Lai L, Tan J. Impact of land use type
660 conversion on carbon storage in terrestrial ecosystems of China: A
661 spatial-temporal perspective. *Sci Rep.* 2015a;5:10233.
- 662 49. Zhang Y, Li C, Wang T, Cai C, Bao Y. County-level patterns of cropland and their
663 relationships with socio-economic factors in northwestern China. *Agr Ecosyst*
664 *Environ Res. Letters.* 2015b;203:11-18.
- 665 50. Zhao M, He Z, Du J, Chen L, Lin P, Fang S. Assessing the effects of ecological

666 engineering on carbon storage by linking the CA-Markov and InVEST models.
667 Ecol Indic. 2018a;98:29-38.

668 51. Zhao S, Liu S, Sohl T, Young C, Werner J. Land use and carbon dynamics in the
669 southeastern United States from 1992 to 2050. Environ Res Lett.
670 2013;8:575-591.

671 52. Zhao Y, Wang M, Hu S, Zhang X, Ouyang Z, Zhang G, et al. Economics-and
672 policy-driven organic carbon input enhancement dominates soil organic carbon
673 accumulation in Chinese croplands. Proc Natl Acad Sci U.S.A.2018b;115:
674 4045-4050.

675

Figure list

Fig.1 Research framework for calculations of carbon storage induced by cropland changes

Fig.2 Location of Northwest China and its administrative divisions

Fig.3 Temporal dynamics of cropland reclamation and transfer

Fig.4 Provincial area of cropland change from 1995 to 2005 (a), 2005 to 2015 (b)

Fig.5 Spatial distribution of cropland change from 1995 to 2005 (a), 2005 to 2015 (b)

The red fields represent cropland reclamation and transfer, the last fields represent other types of land use change. Others represent the lands remaining unchanged.

Fig.6 Changes in soil, vegetation and total carbon storage over time

Fig.7 Changes in carbon storage due to different cropland conversion types

Fig.8 Carbon storage due to cropland change in each province from 1995 to 2005 (a), 2005 to 2015 (b)

Fig.1. Research framework for calculations of carbon storage induced by cropland changes

Fig.2. Location of Northwest China and its administrative divisions

Fig.3. Temporal dynamics of cropland reclamation and transfer: (a) Cropland reclamation, (2) Cropland transfer

Fig.4. Provincial area of cropland change from 1995 to 2005 (a), 2005 to 2015 (b)

Fig.5. Spatial distribution of cropland change from 1995 to 2005 (a), 2005 to 2015 (b).

Fig.6. Changes in soil, vegetation and total carbon storage over time

Fig.7. Changes in carbon storage due to different cropland conversion types

Fig.8. Carbon storage due to cropland change in each province from 1995 to 2005 (a), 2005 to 2015 (b)

Table list

Table 1 Vegetation carbon density in each land cover type

Table 2 The impact factors of SOC change in cropland change

Table 3 Changes in cropland area and type in Northwest China for different time periods ($\times 10^2$ ha)

Table 1 Vegetation carbon density in each land cover type

Land use type	Forest	Grassland	Cropland	Water	Built-up land	Other land
vegetation carbon density (t C ha ⁻¹)	79.22	3.46	5.70	0	0	0.55

Table 2 The impact factors of SOC change in cropland change

Items	Forest	Grassland	Other land	Cropland
Forest	-	-		-27%
Grassland	-	-		-20%
Other land				80%
Cropland	90%	100%	-20%	-

721 **Table 3** Changes in cropland area and type in Northwest China for different time periods

722 ($\times 10^2$ ha)

Type	1995-2005	Proportion/%	2005-2015	Proportion/%	1995-2015	Proportion/%
Forest to Cropland	656.15	3.13	408.85	2.76	1065.00	2.97
Grassland to Cropland	8527.23	40.63	5757.72	38.82	14284.95	39.88
Water to Cropland	64.20	0.31	39.12	0.26	103.32	0.29
Built-up land to Cropland	12.51	0.06	50.35	0.34	62.86	0.18
Other land to Cropland	11725.91	55.87	8575.27	57.82	20301.18	56.68
Cropland reclamation	20986.00	100.00	14831.31	100.00	35817.31	100.00
Cropland to Forest	1125.01	7.97	291.65	4.20	1416.66	6.73
Cropland to Grassland	10144.49	71.88	4056.76	58.42	14201.25	67.44
Cropland to Water	47.83	0.34	33.78	0.49	81.61	0.39
Cropland to Built-up land	1064.67	7.54	2064.12	29.72	3128.79	14.86
Cropland to Other land	1730.52	12.26	498.38	7.18	2228.90	10.58
Cropland transfer	14112.53	100.00	6944.70	100.00	21057.23	100.00
Net increase	6873.48		7886.61		14760.08	

723

Figures

Figure 1

Research framework for calculations of carbon storage induced by cropland changes

Figure 2

Location of Northwest China and its administrative divisions Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its

authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Temporal dynamics of cropland reclamation and transfer

Figure 4

Provincial area of cropland change from 1995 to 2005 (a), 2005 to 2015 (b)

Figure 5

Spatial distribution of cropland change from 1995 to 2005 (a), 2005 to 2015 (b) The red fields represent cropland reclamation and transfer, the last fields represent other types of land use change. Others represent the lands remaining unchanged. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 6

Changes in soil, vegetation and total carbon storage over time

Figure 7

Changes in carbon storage due to different cropland conversion types

Figure 8

Carbon storage due to cropland change in each province from 1995 to 2005 (a), 2005 to 2015 (b)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryInformation.docx](#)