Chin. Geogra. Sci. 2019 Vol. 29 No. 5 pp. 809–819
https://doi.org/10.1007/s11769-018-0983-1

Springer Science Press
www.springerlink.com/content/1002-0063

Spatial and Temporal Changes of Arable Land Driven by Urbanization and Ecological Restoration in China

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Abstract: Since the industrial revolution, human activities have both expanded and intensified across the globe resulting in accelerated land use change. Land use change driven by China's development has put pressure on the limited arable land resources, which has affected grain production. Competing land use interests are a potential threat to food security in China. Therefore, studying arable land use changes is critical for ensuring future food security and maintaining the sustainable development of arable land. Based on data from several major sources, we analyzed the spatio-temporal differences of arable land among different agricultural regions in China from 2000 to 2010 and identified the drivers of arable land expansion and loss. The results revealed that arable land decreased by 5.92 million ha or 3.31%. Arable land increased in the north and decreased in the south of China. Urbanization and ecological restoration programs were the main drivers of arable land loss, while the reclamation of other land cover types (e.g., forest, grassland, and wetland) was the primary source of the increased arable land. The majority of arable land expansion occurred in the Northwest, but the centroid for grain production moved to northeast, which indicated that new arable land was of poor quality and did not significantly contribute to the grain production capacity. When combined with the current 'Red Line of Arable Land Policy' (RAL) and 'Ecological Redline Policy' (EPR), this study can provide effective information for arable land policymaking and help guide the sustainable development of arable land.

Keywords: arable land; spatio-temporal characteristic; agricultural regionalization; driver; China

Citation: WANG Liyan, ANNA Herzberger, ZHANG Liyun, XIAO Yi, WANG Yaqing, XIAO Yang, LIU Jianguo, OUYANG Zhiyun, 2019. Spatial and Temporal Changes of Arable Land Driven by Urbanization and Ecological Restoration in China. *Chinese Geographical Science*, 29(5): 809–819. https://doi.org/10.1007/s11769-018-0983-1

1 Introduction

Almost all anthropogenic activities rely on land resources to meet the needs of a growing population. Arable land resources are possibly the most valuable because they can be used for produce food. Competition over land resources is a global phenomenon. Competing interests may threaten food security when the land is high-quality arable land (Cao et al., 2008). The global population is expected to grow from roughly 7.6 billion in 2016 to 9.2 billion by 2050 (Roberts, 2011; Grafton et al., 2015; Delzeit et al., 2017), which will increase global food demand by 70%–110% (Bruinsma, 2009; Tilman et al., 2011; Kastner et al., 2012). As land use pressure continues to grow, ensuring the stability of arable land for agricultural production is important if food security is to be maintained in the coming century. Across the globe, China possesses 7% of the world's arable land

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Received date: 2017-12-11; accepted date: 2018-04-04

Foundation item: under the auspices of Chinese Academy of Science Services Network Program (No. KFJ-STS-ZDTP-010), Michigan AgBio Research Program

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and 20% of the world's population (Larson, 2013). This means that the amount of arable land per capitia (0.11 ha/person) is well below the global average (0.23 ha/person) (Brown, 1995; Long et al., 2012). Population growth is expected to continue, which means that competition over the already limited arable land resources will increase (Yang and Li, 2000; Nath et al., 2015).

Since the implementation of the 'Reform and Opening-up Policy' in 1978, China has undergone rapid urbanization accompanied by large increases in population and Gross Domestic Product (GDP) (Wang et al., 2012). For example, the speed at which these processes occurred is shown by fact that 50% of the Chinese population were urban residents in 2010, compared to only 17% of the population in 1978 (Tian and Qiao, 2014). It is estimated that the Chinese population will peak at 1.4 billion in 2025 (DeSA, 2013). The increased population and wealth will continue to fuel demand. This has meant that the patterns of Chinese grain production and consumption have become major issues of interest to global markets and trading partners (Lam et al., 2013). Food trade is a potential solution that could be used by highly populated areas to meet their food demands (Grafton et al., 2015). However, commodity price spikes, restrictive tariffs, increasing numbers of extreme weather events (e.g., droughts, floods *etc*.), and biosecurity risks compromise the ability of food imports to meet China's large food demand (Baldos and Hertel, 2015; Kompas et al., 2015; Jiang et al., 2018). Furthermore, a global food security crisis could disrupt international food trade networks, which would disproportionately affect developing countries. Therefore it is important for global food security that China is able to maintain basic food self-sufficiency. The debate over the allocation and protection of arable land in China is important domestically as well as globally (Deng et al., 2015).

Land use change has not only brought tremendous changes to the structure of surface landscapes, but has also affected materials and landscape energy flow (Peng et al., 2017a). Urbanization, is one of the crucial characteristics of human development in the 20th Century (Cui and Wang, 2015; Peng et al., 2017b). It has led to grassland or farmland being converted into construction land, which has meant that the function of the former land uses has been completely lost (Peng et al., 2017b). Another noticeable factor affecting land use change is China's 'Grain for Green Program' (GFGP), which aims to convert farmland on steep slopes to forest or grassland. This has significantly altered ecosystem services. Farmland provides limited regulation and supporting services compared to forest and grassland because primary products are harvested and removed from the land (Wang et al., 2017). Some studies have indicated that the GFGP could help to maintain soil organic carbon levels, reduce soil erosion, and restore other functions (Lei et al., 2012; Rao et al., 2016). According to the Ministry of Land and Resources of China, 0.70 million ha of arable land per year was consumed by other types of land use or destroyed by natural disasters between 1987 and 2000 (Tan et al., 2005). At the same time, land competition between urban development, agricultural production, and environmental restoration has led to arable land use change in most regions of China. As China continues to develop, competition over limited arable land resources will increase (Deng et al., 2006). Therefore, it is crucial that the spatio-temporal dynamics of arable land is understood and its driving forces are identified (Sun et al., 2017). A greater understanding of the potential changes to arable land will help protect high-quality arable land, provide scientific guidance for the long-term planning of arable land, and ensure a domestic food supply (Sun et al., 2015).

Many studies have analyzed the features of arable loss in China resulting from urban land expansion and ecological restoration at different scales. For example, there have been studies on the differences between urban land expansion and the resultant arable land loss in the Beijing-Tianjin-Hebei regions (Tan et al., 2005), land use change in response to rapid urbanization in Hangzhou City (Deng et al., 2009), the effects of urbanization on agricultural activities (Berry, 1978), the impacts of the GFGP on vegetation cover in Shanxi Province (Zhou and Van Rompaey, 2009), and the impacts of the GFGP on agricultural productivity in west China (Feng et al., 2005) and across the whole country (Deng et al., 2006). However, relatively few studies have analyzed the forces driving of arable land change in different agricultural regions in China at the national scale. Therefore, this study explored the patterns and drivers of arable land use change in China from 2000 to 2010 using Remote Sensing and Geographic Information System technology. The aims of this study are to: 1) explore the temporal and spatial characteristics of arable land between 2000 and 2010 in China; 2) analyze the main driving forces of arable land change; and 3) understand the centroid conversion trajectory between arable land and grain production. The results have important implications for the development of land use and sustainable development policymaking in China.

2 Materials and Methods

2.1 Study area

As we all known, agriculture is the foundation of national economy in China. Food security in China is bound to have a significant global implication. Among many factors that influence food production and supply, the availability of arable land is the most crucial one. To identify the spatial and temporal patterns of arable land change between 2000 and 2010 in China, we analyze the change of arable land through using the Chinese comprehensive agricultural regionalization map (Zhou et al., 1981) (Fig. 1). Then, the arable land area in each region was quantified to generate a dynamic transfer matrix of the area, which can indicate the drivers of arable land changes in different regions. In addition, data on grain yields for the regions were obtained from the *Chinese Statistical Yearbook* (2000; 2010).

2.2 Data source

This study used the ecosystem classification system (Ouyang et al., 2016) to measure the change in arable land, which is different from the traditional land use and land cover classification. It is provided by the Institute of Remote Sensing Applications of Chinese Academy of Sciences (CAS).The arable data has a spatial resolution of 30 m, and covers the period of 2000 to 2010. Cropland has been divided into arable land and orchard. In our study, we only considered arable land containing paddy land and dry land so that the impacts of arable land change and its influence on grain production can be emphasized.

2.3 Modeling the centroid for arable land

In this study, the model used to determine the central point of arable land and grain production was based on the model for the center of population distribution. It was used to describe the spatial change in arable land resource and grain production (Wang et al., 2015). The model can be expressed as:

Fig. 1 Chinese agricultural regionalization map (No data in Hong Kong, Macau and Taiwan of China) (Zhou et al., 1981). NEAF: Northeast agricultural-forestry region; HHHA: Huang-Huai-Hai agricultural region; YRAFC: Middle-lower of Yangtze River agricultural-forestry region; SCTAF: South China tropical-agricultural-forestry region; SWAF: Southwest agricultural-forestry region; IMPAF: Inner Mongolia and Great Wall pastoral-agricultural-forestry region; LPAPF: Loess Plateau agricultural-forestry-pastoral region; GXAPF: Gan-Xin agricultural-pastoral-forestry region; TPPAF: Tibetan Plateau pastoral-agricultural-forestry region.

$$X_t = \frac{\sum_{i=1}^{n} C_{ti} \times X_i}{\sum_{i=1}^{n} C_{ti}} \quad (1)$$

$$Y_t = \frac{\sum_{i=1}^{n} C_{ti} \times Y_i}{\sum_{i=1}^{n} C_{ti}} \quad (2)$$

where X_t represents the longitude for the center of arable land in the tth year; Y_t represents the latitude for the center of arable land in the tth year; t means the research year; C_{ti} is the arable land area in the study area (km^2); X_i represents the longitude of the geometric center in the ith year; and Y_i represents the latitude of geometric center in the ith year.

3 Results

3.1 Arable land changes in China between 2000 and 2010

In 2010, there were 173.15 million ha of arable land in China (Table 1). The largest area was in NEAF, which accounted for 20.35% of the total arable land in China, followed by YRAFC (about 18.45%), HHHA (15.55%), and SWAF (15.46%). Arable land area in 2010 had decreased by about 5.92 million ha (3.31%) compared to that in 2000, of which the newly reclaimed arable land area and the arable area loss were 3.78 million ha and 9.70 million ha, respectively. The arable land area increased by 1.67 million ha or 17.78% in GXAPF, and by 0.04 million ha or 0.11% in NEAF, while the arable land area in other seven agricultural regions decreased from 2000 to 2010.

Marked differences exist in the patterns of land use change and their driving forces among the agricultural regions (Liu et al., 2005). Between 2000 and 2010, the arable land area decreased in all agricultural regions located in the southern China. The YRAFC, SWAF, HHHA, and LPAPF regions were responsible for 79.17% of the arable land loss, with decreased areas accounting for 28.14%, 20.10%, 19.69% and 11.24% of the total arable land loss, respectively (Table 2). The total increase in arable land was 1.67 million ha. However, 54.97% was located in GXAPF, the arid region of Northwest China (Fig. 2).

3.2 Changes of Arable land

The areas and spatial patterns of land cover change indicate that the key drivers of arable land loss were urbanization and ecological restoration programs. The area of arable land converted to urban land accounted for 43.71% (4.25 million ha) of the total loss of arable land, and ecological restoration programs accounted for 45.60% (4.52 million ha). Among the ecological restoration programs, 24.46% of the arable land was converted to forests, 13.92% to grassland, and 7.22% to wetland. However, 38.62% of the new arable land was from grassland, 27.78% was from forest, and 23.91% was from wetland (Table 3). Furthermore, arable land losses that occurred in areas characterized by flat or gentle slopes (e.g., 0°–6°) were mainly due to urbanization. About 68.05% of the arable converted to urban land occurred on land with slopes of 0°–2°. This is in sharp contrast to the majority of the areas converted

Table 1 Arable land area and its change in different agricultural regions between 2000 and 2010 in China

Agricultural regions	Arable land (million ha)		Change (million ha)	Change amplitude (%)
	2000	2010		
NEAF	35.19	35.23	0.04	0.11
HHHA	28.71	26.92	–1.79	–6.23
YRAFC	34.14	31.95	–2.19	–6.41
SCTAF	11.15	10.58	–0.57	–5.11
SWAF	28.66	26.77	–1.89	–6.59
IMPAF	13.61	13.52	–0.09	–0.66
LPAPF	16.57	15.53	–1.04	–6.28
GXAPF	9.39	11.06	1.67	17.78
TPPAF	1.65	1.58	–0.07	–4.24
Total	179.07	173.15	–5.92	–3.31

Notes: Meanings of agricultural regions see Fig. 1. Meanings of '–' is decrease.

Table 2 Arable land change in different agricultural regions in China (2000–2010)

Agricultural regions	New reclaimed arable land (million ha)	Rate of increase (%)	Occupied arable land (million ha)	Rate of decrease (%)	Net changes (million ha)
NEAF	0.55	14.55	–0.50	5.15	0.05
HHHA	0.12	3.17	–1.91	19.69	–1.78
YRAFC	0.54	14.29	–2.73	28.14	–2.19
SCTAF	0.24	6.35	–0.81	8.35	–0.57
SWAF	0.06	1.59	–1.95	20.10	–1.89
IMPAF	0.17	4.50	–0.26	2.68	–0.10
LPAPF	0.04	1.06	–1.09	11.24	–1.05
GXAPF	2.04	53.97	–0.37	3.81	1.67
TPPAF	0.02	0.53	–0.08	0.82	–0.06
Total	3.78	100.00	–9.70	100.00	–5.92

Notes: Rate of increase is the increased area as a proportion of total area of arable land increases; rate of decrease is the decreased area as a proportion of total area of arable land decreases

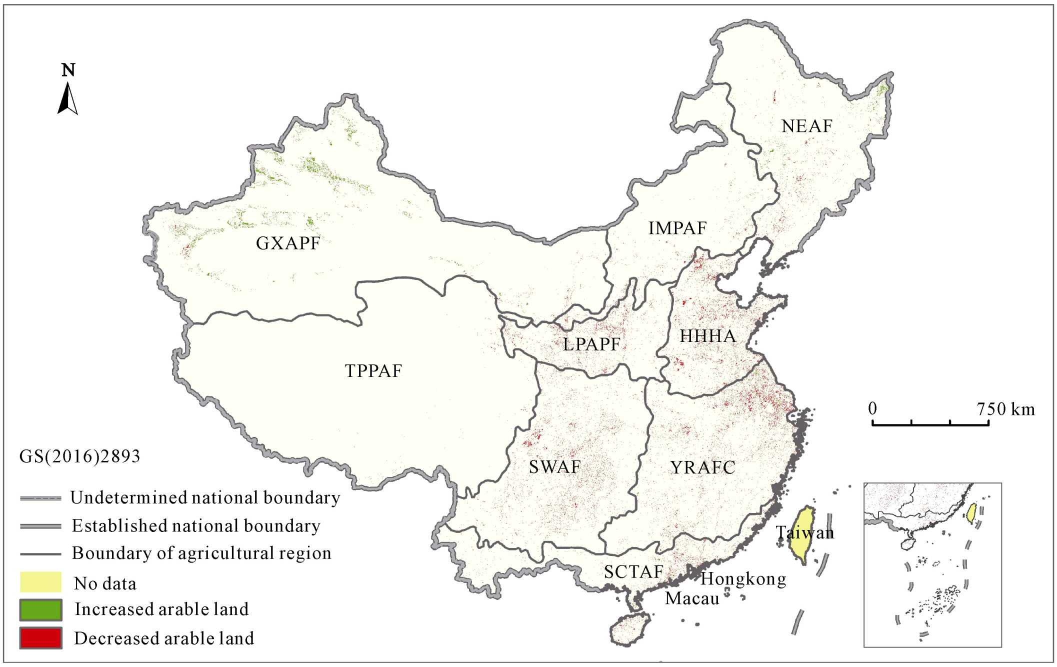

Fig. 2 Arable land change distribution map for China from 2000 to 2010. No data in Hong Kong, Macau and Taiwan of China

from arable land to forest or grassland, which took place on steep slopes (e.g., >15°). Around 68.70% of arable land converted to forest on land with slopes greater than 25° and located in the ecologically fragile areas of the southwestern China and the Loss Plateau (Fig. 3).

The spatial pattern of the arable land that was converted to urban areas showed that it was mainly distributed in eastern China (Fig. 4). Specifically, the arable land converted to urban land accounted for 67.58% and 64.84% of arable land loss in YRAFC and HHHA, respectively (Fig. 5). Regional development policies, such as the 'Western Development Strategy' (Lu and Deng, 2011), the 'Northeast Area Revitalization Plan' (Kuang et al., 2016) and the 'Rise of Central China Plan', accelerated arable land loss in NEAF, IMPAF, and GXAPF where arable land loss was by 39.20%, 31.48% and 30.79%, respectively (Fig. 5).

In contrast, the 'Sloping Land Conversion Program' (SLCP) (Li et al., 2011) and the 'Conversion of Cultivated Land to Wetland Program' (CCWP) (Zhang et al.,

Table 3 Land cover conversions between arable land and other land types

New reclaimed arable land			Conversion of arable land to other land cover types		
Land use types	Area (million ha)	(%)	Land use types	Area (million ha)	(%)
Forest	1.05	27.78	Forest	2.47	24.46
Grassland	1.46	38.62	Grassland	1.35	13.92
Wetland	0.9	23.81	Wetland	0.7	7.22
Bare land	0.2	5.29	Urban land	4.25	43.71
Others	0.1	4.5	Others	0.94	9.69
Total increase	3.78	100	Total loss	9.7	100

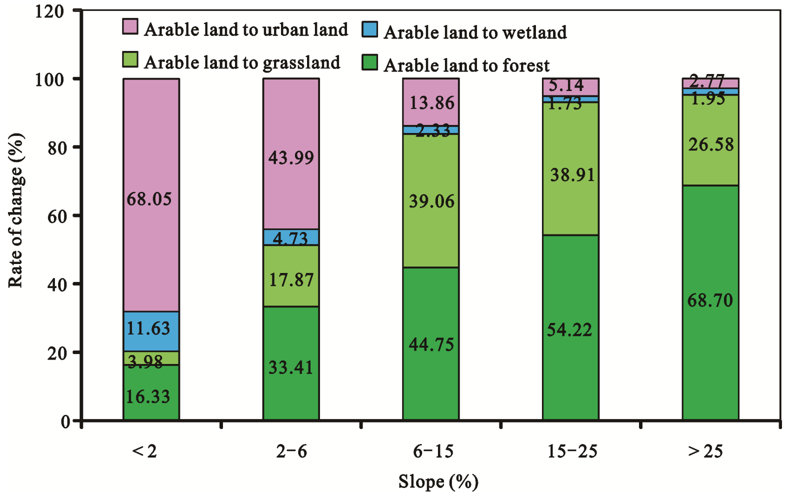

Fig. 3 Conversions from arable land to other land cover types with different slopes. (Rate of change is the area of specific conversion as a proportion of the total area of arable land conversion to other types)

2011) resulted in the conversion of arable land to forest, grassland, and wetland. A total of 4.52 million ha was converted to these land types and this accounted for 45.60% of the area of arable land lost between 2000 and 2010. Around 45.17%, 36.49%, and 32.05% of the arable land in SWAF, TPPAF and HHHA, respectively, was converted to forest. In LPAPF, TPPAF, IMPAF, and GXAPF, 65.82%, 53.90%, 46.44%, and 32.53% of the arable land was converted into grassland, respectively. In NEAF, the proportion of arable land converted to wetland was 26.67% (Fig. 5).

Most of the new arable land was converted from forests and grasslands, which accounted for 90.21% of the total increase in arable land. Most of the new arable land (82.81%) was in GXAPF, NEAF, and YRAFC, which contributed 53.97%, 14.55% and 14.29%, respectively (Fig.6). Large areas of forests were converted to arable land in SCTAF (66.13%) and SWAF (65.16%), while the new arable land in GXAPF (59.07%), IMPAF (48.27%), and LPAPF (35.09%) regions mainly came from grasslands. Finally, large tracts of wetland were converted to arable land in the NEAF (71.37%), HHHA (60.62%) and YRAFC (56.47%) regions (Figs.4, 6).

3.3 Centroid movement of grain production and arable land in China

Total grain yield is determined by arable land area and grain yield per unit area. Overall, during the study period, as arable land in most regions decreased rapidly, it had showed negative contribution to total grain production totally (Chen et al., 2011). In contrast, the grain yield per unit area of newly reclaimed arable land had little effect on total grain production. Fig. 7 shows that the arable land center moved to northwest from the middle of China and the grain production center moved to northeast from the middle of China, which indicated that the northern regions contributed more significantly to the domestic grain supply because they had a high grain yield per unit area. The misalignment between the distribution and trajectory of the main production

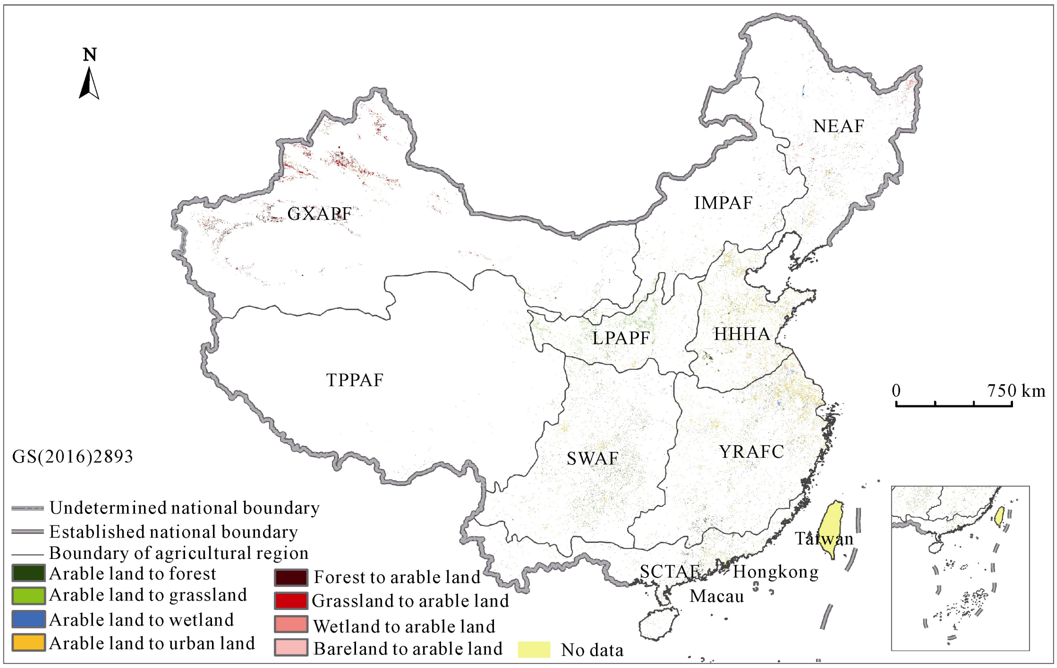

Fig. 4 Land conversion of arable land distribution map in China from 2000 to 2010. No data in Hong Kong, Macau and Taiwan of China

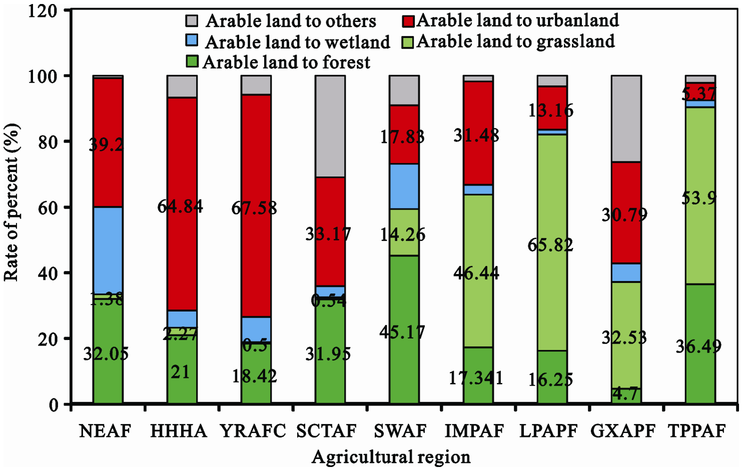

Fig. 5 Conversions from arable land to other land cover types with different agricultural regions

region and the new arable land area indicates that the additional arable land in the Northwest is lower quality than the more productive land in the Northeast. Then, in the occupation-compensation balance for arable land project, it is important that ensure the compensated land has equal quality and quantity with the occupied land.

4 Discussion

Between 2000 and 2010, the arable land area fell by 5.92 million ha or 3.31% overall, which was caused by urbanization and ecological restoration programs. However, some regions, such as GXAPF and NEAF, experienced a net increase in arable land area.

The urbanization of China has been a notable global event (Chen et al., 2016), and was responsible for 43.71% of the total arable land lost from 2000 to 2010. Arable land consumed by urbanization was mainly flat or had gentle slopes, and high quality arable land. However, it was replaced by marginal and lower quality alternatives. As a consequence, not distinguishing between different types of land could result in a reduction

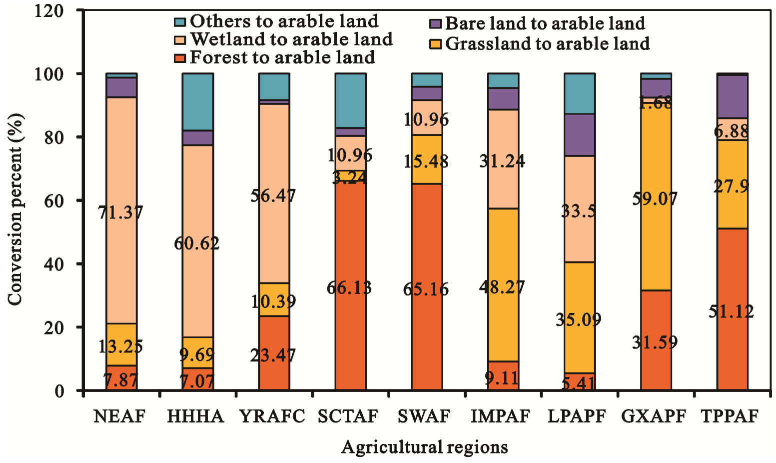

Fig. 6 Conversions from other land cover types to arable land with different agricultural regions

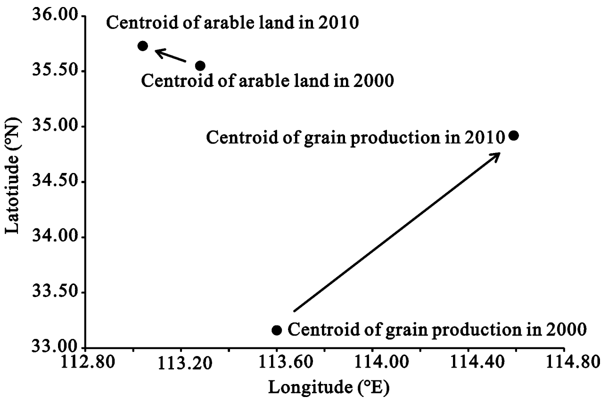

Fig. 7 Centroid conversion of arable land and grain production in China between 2000 and 2010

in production capacity (Yang and Li, 2000; Lichtenberg and Ding, 2008). In addition, the large scale rural to urban migration has weakened rural management because many operators have abandoned their farms (Liu et al., 2014), which has further contributed to the decrease in high quality of arable land. Arable land loss due to ecological restoration programs was mainly located in the SWAF and LPAPF regions and mostly occurred on steeply sloped (> 15°) marginal land. Long term cultivation of these areas has led to severe soil erosion and land degradation (Rao et al., 2014). In light of this, many ecological restoration programs fund farmers to abandon their inferior or marginal land so that it can be restored. In addition, the effect of ecological restoration programs on the national grain supply and demand balance is almost imperceptible (Xu et al., 2004). Furthermore, the restored areas have reduced soil erosion and improved water retention in mountainous areas (Ouyang et al., 2016). There has also been an increased in forest cover (Liu, 2014; Viña et al., 2016) and the number of wildlife habitats (Liu et al., 2016; Tuanmu et al., 2016). It is possible that ecological restoration programs will have positive impacts on agricultural production in downstream regions and contribute positively to food security via ecosystem services.

The new arable land in GXAPF, NEAF, and YRAFC was mainly converted from natural ecosystems, such as forest, grassland, and wetland. Specifically, the new arable land was sourced from wetlands in the Sanjiang area of NEAF, and the coastal wetlands in YRAFC. Further conversion of the natural ecosystem to agriculture produces low grade alternatives, at great ecological cost. These conversions have intensified the conflict between food production and natural resource conservation in China (Grau et al., 2008). Broadly, there has been a shift from growing crops in China's warm and humid south to the less suitable cold and water limited north. The results also showed that China is overusing limited high quality arable to grow ever increasing amounts of food. In order to reduce the conversion pressure on arable land, a new approach is needed to coordinate the pressure between food production, urbanization, and natural resource conservation. In 2006, the Central Government announced a conservation reserve policy called the 'Redline of Arable Line' (RAL). It aimed to reserve roughly 120 million ha (1800 million mu) of arable land for food production (Wen, 2011). However, it was not effective at preventing arable land loss to urbanization. One of the main reasons was because RAL only considered the quantity of arable land, not accounting for the spatial distribution or the quality of the arable land (Li et al., 2009). Eventually a large amount of high quality arable land vanished in clusters around urban areas and coastlines (He et al., 2014; Ma et al., 2014). Therefore, for RAL, high quality arable land must be classified into tracts of land that are for permanent arable use, particularly in developed regions (YRAFC and HHHA) and suitable for grain production region (NEAF). Greater efforts should be made to prohibit the agricultural conversion of marginal land in the northwest. Together, these measures would slow the agricultural shift towards the northwest and buy China some time.

To address conflicts between food production and natural resource conservation, crucial areas particularly, the areas that are highly important wildlife habitats, flood mitigation areas, water resource supplies, or sandstorm prevention areas, should be conserved following the 'Ecological Redline Policy' (EPR) (Yang et al., 2014; Bai et al., 2016). These areas must be protected from conversion to agriculture and urban areas to ensure the provision of ecosystem services. Finally, some continued arable land loss is inevitable and will be driven by rapid urbanization and ecological restoration in future decades. Therefore, China should try to enhance the production capacity of arable land by improving soil fertility, expanding irrigation facilities, controlling soil pollution, and developing highly productive crop varieties.

This study had some limitations. Firstly, the classification of arable land used in this study adopted the ecosystem classification, and this might not be totally consistent with the existing national standard, which is the land use classification system that launched in 2007. Secondly, the modifiable area unit mainly used in ecological and geographical studies. In this study, the agricultural region was selected as the statistical unit to analyze arable land change. In the future, various spatial scales (national, regional, and local) and units (province, city, and county) could be apply to further research.

5 Conclusions

From 2000 to 2010, arable land in China decreased by 5.92 million ha or 3.31%. Arable land increased in the north and decreased in the south of China. With the exception of Gan-Xin agricultural-pastoral-forestry region (1.67 million ha) and Northeast agricultural-forestry region (0.05 million ha), the other seven regions experienced a net decrease in arable land. This study identified urbanization (arable land converted to urban land) and ecological restoration programs (arable land converted to forest, grassland and wetland) as the major drivers of the decrease in arable land. The conversion from arable land to urban land mainly occurred in Huang-Huai-Hai agricultural region (64.84%) and Middle-lower of Yangtze River agricultural-forestry region (67.58%), while arable land converted to forest and grassland were distributed in Southwest agricultural-forestry region (45.17%) and Loess Plateau agricultural-forestry-pastoral region (65.82%), respectively. The reclamation of other land cover types (e.g., forest, grassland, and wetland) was the primary source of the increased arable land. The new arable land was low quality land that did not make the centroid of grain production move the same way as that of arable land. Therefore, we suggest that the government should pay close attention to the change of arable land, consider relevant policies to protect arable land resources, and ensure sustainable development that combines the need for food security, urbanization, and natural assets conservation in China.

Acknowledgments

The authors acknowledge the Institute of Remote Sensing Applications, Chinese Academy of Sciences (CAS) that kindly provided the mapped data to definite the distribution of arable land.

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