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Reconstruction of *Lu*-level cropland areas in the Northern Song Dynasty (AD976–1078)

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Abstract: Based on data on taxed-cropland area and on the number of households in historical documents, a probabilistic model of cropland distribution and a cropland area allocation model were designed and validated. Cropland areas for the years AD976, 997, 1066, and 1078 were estimated at the level of *Lu* (an administrative region of the Northern Song Dynasty). The results indicated that (1) the cropland area of the whole study region for AD976, 997, 1066, and 1078 was about 468.27 million *mu* (a Chinese unit of area, with1 *mu*=666.7m^2), 495.53 million *mu*, 697.65 million *mu*, and 731.94 million *mu*, respectively. The fractional cropland area (FCA) increased from 10.7% to 16.8%, and the per capita cropland area decreased from 15.7 *mu* to 8.4 *mu*. (2) With regard to the cropland spatial pattern, the FCA of the southeast, north, and southwest regions of the Northern Song territory increased by 12.0%, 5.2%, and 1.2%, respectively. The FCA of some regions in the Yangtze River Plain increased to greater than 40%, and the FCA of the North China Plain increased to greater than 20%. However, the FCA of the southwest region (except for the Chengdu Plain) in the Northern Song territory was less than 6%. (3) There were 84.2% *Lus* whose absolute relative error was smaller than 20% in the mid Northern Song Dynasty. The validation results indicate that our models are reasonable and that the results of reconstruction are credible.

Keywords: land use/cover change; cropland area; *Lu*-level reconstruction; spatial–temporal characteristics; Northern Song Dynasty

1 Introduction

Anthropogenic land use and land cover change (LUCC) is an important factor involved in a number of global changes. It influences climate change through both biogeochemical and biogeophysical mechanisms (Ramankutty *et al.*, 2006; Tian *et al.*, 2012a; Tao *et al.*, 2013). In the historical period, LUCC has transformed the Earth's surface and has had a strong impact on global and regional climate and the carbon cycle (Pongratz *et al.*, 2008; Flato *et al.*,

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2013). Therefore, reconstruction of historical LUCC is an important task when modeling climate change and its ecological effects (Brovkin *et al.*, 2004; Strassmann *et al.*, 2008; Kaplan *et al.*, 2012), and has increasingly come to be recognized as a core theme in global climate change research (Gaillard *et al*., 2010; Kaplan *et al*., 2011; Tian *et al*. 2014; Mazier *et al.*, 2015; Santana-Cordero *et al.*, 2016).

In recent years, many studies related to historical LUCC have been carried out. Two representative global-scale LUCC datasets have been developed: a global land use database for the period AD1700–1992 was established by the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin-Madison (Ramankutty and Foley, 1999), and the Historical Database of the Global Environment (HYDE) was established by the Netherlands Environmental Assessment Agency (Klein Goldewijk *et al.*, 2001). HYDE has been updated several times, with HYDE3.1 now covering the period 10000BC–AD2000 (Klein Goldewijk *et al*., 2011). Based on the AD1700 land cover maps of the SAGE dataset, Pongratz *et al.* (2008) reconstructed cropland and pastureland cover for AD800–1700 (hereinafter referred to as the PJ dataset) by using historical population data as a proxy. An anthropogenic land cover change dataset named KK10 (Kaplan *et al.*, 2009, 2011) reconstructed land use from 8000BC to AD1850. However, the accuracy of these global datasets is poor at regional scales, as noted, for example, by Ramankutty *et al*., (2010), Li *et al*., (2012), Klein Goldewijk *et al.* (2013), He *et al*. (2013), and Zhang *et al*. (2013). Based on local historical documents, Chinese scholars have made great progress in the reconstruction of historical LUCC at national and regional scales (Ge *et al*., 2008; Ye *et al*. 2009; He *et al*., 2015; Jin *et al*., 2015; Wei *et al*., 2015; Ye *et al*., 2015; Li *et al*., 2016). However, most research has covered only the last three centuries, and few datasets have covered the whole of the last millennium.

The Northern Song Dynasty dates to the start of the 11th century in China (more precisely, to the period AD960–1127). Cropland area estimation for this period is significant for cropland area reconstruction over the whole millennium in China. In our previous studies (He *et al*., 2012), the cropland area for the mid Northern Song Dynasty(roughly representing AD1078) was estimated at the level of the *Lu* (an administrative region of the Northern Song Dynasty) by analyzing historical taxed-cropland records and related policies. However, because of a lack of historical records, cropland areas were probably underestimated for some *Lus*, including Zizhou *Lu*, Lizhou *Lu*, Kuizhou *Lu*, Guangnandong *Lu*, and Guangnanxi *Lu.* In addition, cropland area estimation was not possible at the *Lu* level for some other periods of the Northern Song Dynasty for which only national-level taxed-cropland records are available.

In the present study, the underestimation of taxed-cropland area in the north and south of the Northern Song Dynasty was analyzed; appropriate ranges of cropland area per household in the Northern Song Dynasty are discussed, and a revised determination is made of the underestimation of cropland area per household for the above-mentioned *Lus*. On the basis of this analysis, we first re-estimate the *Lu*-level cropland area of the mid Northern Song Dynasty. We then estimate the *Lu*-level cropland area for another three periods, based on the calibrated national-level taxed-cropland area data and the allocation method that we have developed. Finally, we analyze the spatial–temporal characteristics of the cropland area changes for the period AD976–1078 and make a comparison with the results of previous studies.

2 Data sources and processing

2.1 Study area

The study area is the territory of the Northern Song Dynasty (Figure 1). It is bounded by the Haihe River in Tianjin, Bazhou in Hebei Province, and Yanmenguan in Shanxi Province to the south, and by Hengshan Mountain in Shaanxi Province, the eastern Gansu Province, the Huangshui River basin in Qinghai Province, Minshan Mountain, and the Dadu River in Sichuan Province to the east. The *Lu* boundaries of the Northern Song Dynasty changed many times during the period AD960–1127. In this study, the 19 *Lu*-level units of the mid Northern Song Dynasty were employed for comparison purposes. Based on historical records, the study area was divided into two regions: the north and the south. The north includes *Lus* numbers 1–6, and the south *Lus* numbers 7–19.

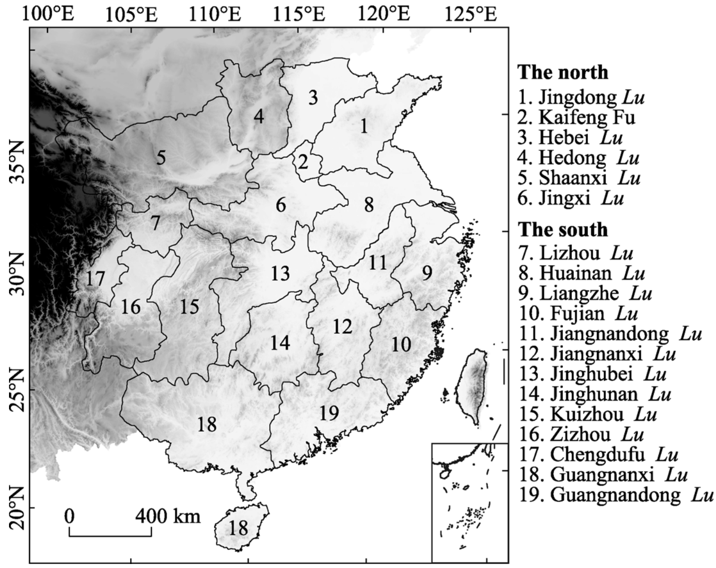

Figure 1 Location of the study area

2.2 Data sources

The data used in this study include taxed-cropland area and the number of households. The data on taxed-cropland area are used as raw materials for estimating cropland area, and the data on number of households are used to estimate population.

Data on taxed-cropland area were obtained mainly from two sources:

1. *Collections of Historical Governmental Archives*: The *Lu*-level taxed-cropland area for AD1078 and the national-level taxed-cropland area for the other five periods (Table 1) were obtained from this document.

Table 1 National-level taxed-cropland area and the number of households in the Northern Song Dynasty

Year	Number of households (10^4)	Taxed-cropland area (10^6 *Song-mu*)
AD976	309.1	295.33
AD997	413.3	312.53
AD1021	867.8	524.76
AD1051	—	228.00
AD1066	1291.7	440.00
AD1083	1721.2	461.66

Song-mu: area unit of the Northern Song Dynasty, 1 *Song-mu*=584.0 m^2 (Wu, 2006).

2. *Xinan Gazetteer*: Data on taxed-cropland area and on the measured cropland area for six counties in Jiangnandong *Lu* for AD1174–1189 are recorded in this document and were employed in this study.

Data on the number of households were obtained from *Collections of Historical Governmental Archives* (Table 1) and the *History of Chinese Population* (Wu *et al.*, 2000). Wu *et al.* calibrated the number of households at the *Lu* level based on a number of historical documents, including the *National Gazette*, *General Condition of Society and Natural Environment in Yuanfeng Term*, and *Monograph on Geography from the History of Song Dynasty*.

2.3 Data processing

2.3.1 Selection of taxed-cropland area data

The taxed-cropland area data in historical documents are not real cropland areas, as has been acknowledged by many researchers. However, they can still reflect the trend of changes in real cropland area (Zhou, 2001). The national-level taxed-cropland area data in Table 1 indicate that cropland area showed an overall increase during the Northern Song Dynasty, which is consistent with the increase in population and the intensification of land use in this period (Qi, 1987; Han, 1993). Note that the taxed-cropland area data for AD1021 and 1051 in Table 1 are quite different from the general trend of changes in cropland area, which casts doubts upon their validity (Qi, 1987). Therefore, only the taxed-cropland area data for AD976, 997, 1066, and 1083 were selected to reconstruct the cropland area at the *Lu* level.

2.3.2 Estimation of population data

We obtained data on the number of households for the Northern Song Dynasty with a resolution at the *Lu* level for AD980–989, 1078, and 1102 from *the History of Chinese Population* (Wu *et al.*, 2000). The time periods of the data on number of households show a mismatch with those for the data on taxed-cropland area. In this study, for AD1066 and 1078, data on the number of households from the *Collections of Historical Governmental Archives* and the calibrated national-level results of Wu *et al.* (2000) were used, respectively. For AD976 and 997, linear interpolation and cross-calibration methods were used, based on the records for AD976 and 997 and the calibrated results for AD980–989 in the *History of Chinese Population* (Wu *et al.*, 2000). Population data were calculated based on the number of households and conversion coefficients of 5.4 for the north and 5.2 for the south (Wu *et al.*, 2000).

3 Reconstruction method

3.1 Method framework

The objective of this study was reconstruction of cropland area at the *Lu* level for the Northern Song Dynasty (Figure 2). It involved two major steps:

1) Estimation of *Lu*-level cropland area for the mid Northern Song Dynasty (AD1078). Based partly on real cropland area data obtained from the projects *Land Measurement and Tax Equalization Law* (方田均税法) for the north and *Land Boundary Survey Law* (经界法) for the south, we calculated the ratios of taxed-cropland area and real cropland area

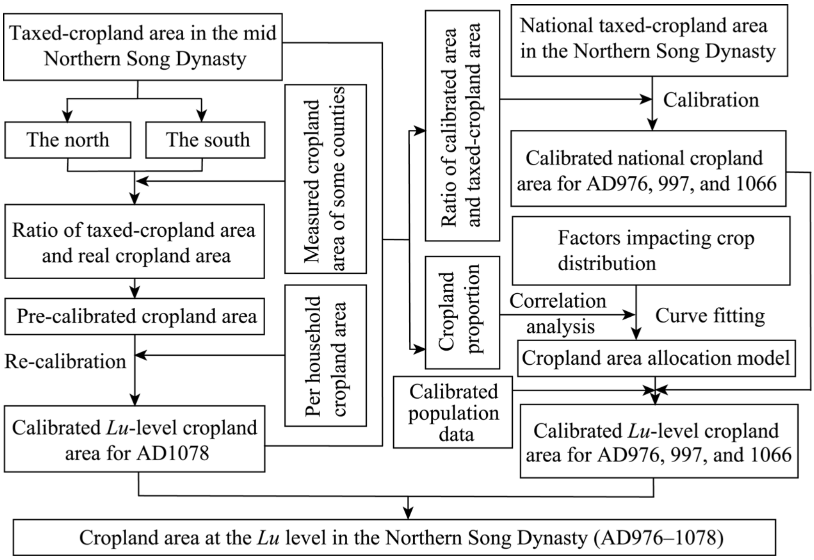

Figure 2 Scheme for reconstruction of cropland area at the *Lu* level in the Northern Song Dynasty

for the north and south. We used these ratios to estimate the real cropland area at the *Lu* level. Subsequently, the results were revised again based on cropland area per household.

2) Reconstruction of *Lu*-level cropland area for other periods of the Northern Song Dynasty, including AD976, 997, and 1066.The national-level cropland area data for the three periods were revised based on the underestimation ratios for AD1078. Then, by analyzing the relationship between crop distribution on the one hand and elevation, slope, and population on the other, we developed a cropland area distribution model. This model was used to reconstruct the cropland area at the *Lu* level for AD976, 997, and 1066. Finally, the changes in cropland area at the *Lu* level for the whole of the Northern Song Dynasty (AD976–1078) were analyzed.

3.2 Estimation of cropland area for the mid Northern Song Dynasty (AD1078)

In the Northern Song Dynasty, land policy featured free land exchange and mergers. As a result, some people used to underreport their cropland area to the government in order to avoid agricultural tax. We analyzed the underestimation of cropland area and re-estimated cropland area for the mid Northern Song Dynasty in our previous research (Li *et al*., 2017). Therefore, only three major steps are described here.

3.2.1 Calibration of cropland area

For the north, we were able to use the results of a huge project conducted by Wang Anshi in AD1072 to measure the real cropland area. Data for five *Lus* in the north (except Jingxi *Lu*) have been preserved in historical records, and, based on these, we calculated the ratio between real cropland area and registered taxed-cropland area, obtaining a value of 2.08. For the south, some cropland data from the *Land Boundary Survey Law* project (Qi, 1984) were preserved in a local gazetteer in Huizhou, and we were able to use these to calculate the ratio between real cropland area and registered taxed-cropland area, obtaining a value of 1.93.

3.2.2 Assessment of the calibrated cropland area

Subsequently, we used per-household cropland area (PHCA) to assess the validity of the calibrated cropland area. Based on historical records of per-worker cropland area and per-household workers (1–2) (Wu *et al*., 2000) in the Song Dynasty, we estimated the PHCA of the Northern Song Dynasty to lie in the range from 20 to 100 *Song-mu* (Figure 3). Based on this estimate, the PHCA in Zizhou *Lu*, Lizhou *Lu*, Kuizhou *Lu*, Guangnandong *Lu*, and Guangnanxi *Lu* is clearly lower than the acceptable range, and therefore we implemented further revisions for these *Lus*.

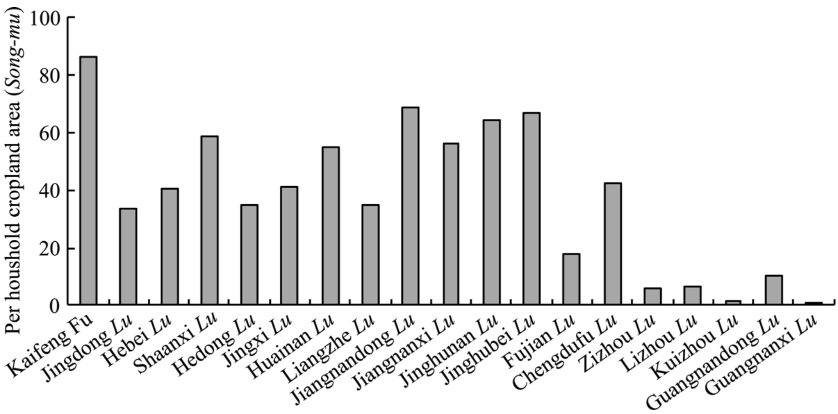

Figure 3 Preliminary revised results for cropland area per household in each *Lu* in the mid Northern Song Dynasty

3.2.3 Revision of the calibrated cropland area

The above-mentioned five *Lus* are located in the southwest of the Northern Song Dynasty. Therefore, we analyzed the grain output per *Song-mu* (Cheng, 2008), the cropping system (Zeng, 2005), and the mean persons in each household recorded in historical documents in the southwest, finding that the basic cropland demand of each household in Zizhou *Lu*, Lizhou *Lu*, and Guangnandong *Lu* was about 20 *Song-mu*, while in Kuizhou *Lu* and Guangnanxi *Lu* it was about 30 *Song-mu.* Based on these results, we revised the cropland areas of the five *Lus* (Table 2).

Table 2 Estimates of cropland area in five *Lus* in the mid Northern Song Dynasty

Lu	Pre-revision results (10^6 *Song-mu*)	Number of families (10^4)	Re-estimated results (10^6 *Song-mu*)
Zizhou	2.84	47.8	9.56
Lizhou	2.49	37.2	7.45
Kuizhou	0.43	25.4	7.63
Guangnandong	6.07	57.9	11.59
Guangnanxi	0.11	23.8	7.15

3.3 Reconstruction of cropland area for AD976, 997, and 1066

3.3.1 Calibration of national-level cropland area

In the earlier periods of the Northern Song Dynasty, the government of the Northern Song also carried out a series of projects to survey the real cropland area of the country, but most of these were not implemented effectively and no records were saved (Qi, 1984). In this study, we used the ratios between taxed-cropland area and estimated cropland area of the mid Northern Song Dynasty to calibrate the national-level taxed-cropland area for AD976, 997, and 1066.

3.3.2 Cropland allocation

To reveal the spatial–temporal characteristics of cropland area changes more clearly, we tried to obtain a cropland area dataset with higher spatial resolution, i.e., *Lu*-level. An approach was developed to convert national-level cropland area into *Lu*-level cropland area.

Generally, cropland distribution is influenced by both natural factors (including topography, heat, water, soil, and vegetation) and social factors (including population, politics, economy, and war). However, the major drivers may be quite different in different regions or at different scales. Our study area is mainly located in the traditional cultivated area of China. Thus, topography (altitude and slope) is the most important natural factor influencing cropland distribution (Lin *et al.*, 2009). In terms of social factors, the need to feed a growing population, especially during the historical period, led to an increasing area being devoted to cropland for grain production. Therefore, population is the major social factor influencing historical cropland distribution. Other factors, including politics and war, will also influence cropland distribution by their effects on population. Thus, the question arises as to whether topography or population is the dominant factor influencing cropland distribution at the *Lu* level.

To identify the dominant factor, we implemented correlation analyses at the *Lu* level between altitude and cropland proportion, between slope and cropland proportion, and between population proportion and cropland proportion. We calculated the average altitude and slope values of each *Lu* based on the 1 km DEM database (http://www.geodata.cn) and ArcGIS 10.1 (http://www.esri.com/software/arcgis/arcgis-for-desktop). The population proportion here is defined as the population in each *Lu* expressed as a proportion of the population of the whole country. Similarly, the cropland proportion is the cropland area in each *Lu* expressed as a proportion of the cropland area of the whole country. The correlation coefficients between altitude and cropland proportion, between slope and cropland proportion, and between population proportion and cropland proportion are −0.183, −0.287, and 0.823, respectively. These results indicate that population is the most important factor influencing cropland distribution at the *Lu* level.

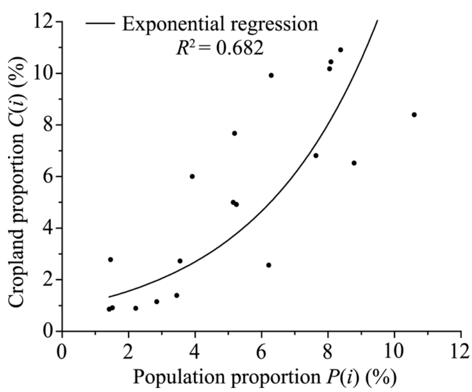

Figure 4 Fitting curve between cropland proportion and population proportion in the mid Northern Song Dynasty

The impact of population on cropland distribution is quantified by fitting the relationship between population proportion $P(i)$ and cropland proportion $C(i)$ in the mid Northern Song Dynasty (Figure 4). The fitting equation is as follows:

$$C(i,t_v) = 0.904 \cdot e^{0.273 \cdot P(i,t_v)} \quad (1)$$

where $C(i,t_v)$ and $P(i,t_v)$ denote the cropland and population proportions, respectively, of *Lu* i in year t_v.

The population proportion can be taken as equivalent to the cropland proportion when the per capita cropland area (PCCA) is similar in each *Lu*. However, we have found great differences in PCCA among the *Lus* in the mid Northern Song Dynasty. To eliminate the impact of PCCA on the allocation result, the fitting equation is modified by the introduction of a PCCA index. The PCCA index of *Lu i* in the mid Northern Song Dynasty is calculated as

$$a(i) = \frac{C_p(i)}{\max(C_p(i))} \tag{2}$$

where $C_p(i)$ denotes the PCCA of *Lu i* in the mid Northerm Song Dynasty and $\max(C_p(i))$ denotes the maximum value of $C_p(i)$. The modified equation, giving the probabilistic model of the cropland distribution, is then

$$\delta(i,t_v) = a(i) \cdot 0.904 \cdot \mathrm{e}^{0.273 \cdot P(i,t_v)} \tag{3}$$

where $\delta(i, t_v)$ denotes the distribution probability of cropland area of *Lu i* in year t_v. Equation (3) shows that the greater the population proportion and per capita cropland resource in one *Lu*, the greater is the cropland distribution probability. The cropland area allocation model is as follows:

$$X(i,t_v) = \frac{\delta(i,t_v)}{\sum_i \delta(i,t_v)} \cdot A(t_v) \tag{4}$$

where $X(i, t_v)$ denotes the cropland area of *Lu i* in year t_v and $A(t_v)$ denotes the national-level cropland area in year t_v.

Note that from the early to the middle period of the Northern Song Dynasty, there was an overall increase in population, and as a result the cropland area also increased. And to the mid Northern Song Dynasty, the cropland area of each *Lu* reached the greatest value of the study period (Qi, 1984). Therefore, when the cropland area in any of the *Lus* exceeded the value in the mid Northern Song Dynasty, the cropland area values of these *Lus* are replaced by their values in the mid Northern Song Dynasty, and with the extra cropland area being allocated to other *Lus* with lower cropland areas than those in the mid Northern Song Dynasty based on Equations (3) and (4).

To validate our reconstruction model, we used it to reconstruct the *Lu*-level cropland area for the mid Northern Song Dynasty, comparing the results with the *Lu*-level data based on historical records (Figure 5). It can be seen that the absolute relative error of our reconstruction at the *Lu* level is low overall. There are 19 *Lus* whose errors are smaller than 30%, and the

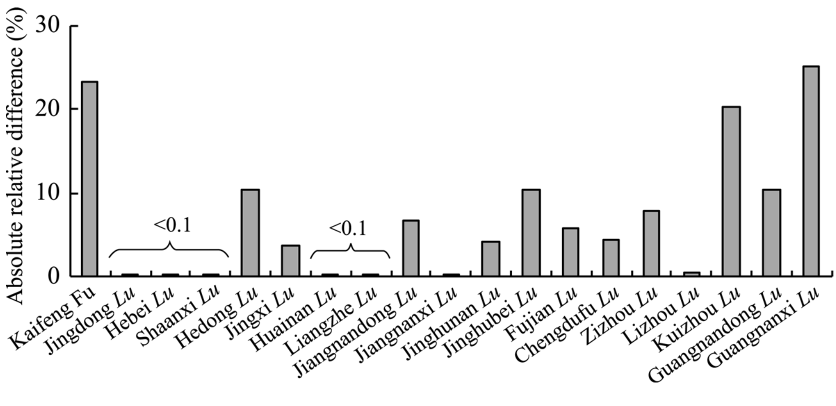

Figure 5 Absolute relative error of our reconstruction results in the mid Northern Song Dynasty

number of *Lus* whose absolute relative error ranges from 0% to 10%, from 10% to 20%, and from 20% to 30% are 13, 3, and 3, respectively. This comparison indicates that our model provides a good transformation from national-level cropland area to *Lu*-level cropland area.

4 Results and analysis

4.1 Trend of changes in national-level cropland area

The national-level cropland area in the Northern Song Dynasty showed a tendency to increase over a 100-year period. Driven by rapid population growth, with an increase from 29.83 million in AD976 to 87.30 million in AD1078, and a series of policies and regulations enacted by government to encourage deserted cropland reclamation, the national-level cropland area increased from 468.27 million *mu* in AD976 to 731.94 million *mu* in AD1078, i.e., an increase of 263.67 million *mu* over 100 years (Table 3). The fractional cropland area (FCA) increased from 10.8% in AD976 to 16.9% in AD1078, an increase of 6%. However, the per capita cropland area decreased from 15.7 *mu* in AD976 to 8.4 *mu* in AD1078.

Table 3 Reconstruction results of cropland area and population for the Northern Song Dynasty

Year	Cropland area (10^6*mu*)	Fractional cropland area (%)	Population (10^4)	Per capita cropland area (*mu*)
AD976	468.27	10.8	2982.7	15.7
AD997	495.53	11.4	3988.5	12.4
AD1066	697.65	16.1	6791.9	10.3
AD1078	731.94	16.9	8730.4	8.4

4.2 Trend of changes in *Lu*-level cropland area

Based on the reconstructed *Lu*-level cropland area and the land area of each *Lu* as provided in the *Historical Atlas of China* (Tan, 1982), we calculated the FCA of each *Lu* for AD976, 997, 1066, and 1078 (Figure 6). It can be seen from Figure 6 that in the early Northern Song Dynasty, the cropland area was distributed mainly in the Yangtze River Plain, the North China Plain, the Guanzhong Basin, and the Chengdu Plain. The FCA in the Northern Song Dynasty then steadily increased and agricultural activities were gradually restored, with reclamation of cropland expanding to the west and south.

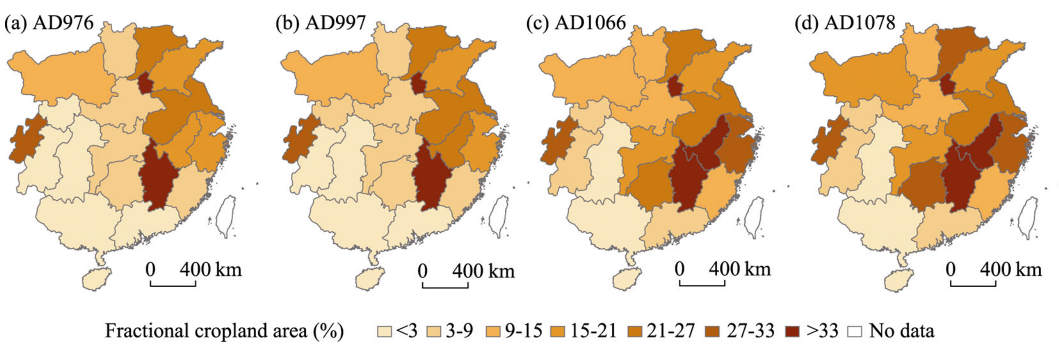

Figure 6 Fractional cropland area for AD976, 997, 1066, and 1078 in the Northern Song Dynasty

Figure 7 illustrates the changes in *Lu*-level FCAs of the Northern Song Dynasty during AD976–1078. Based on the characteristics of FCA changes, we divided the study area into three regions: north, southeast, and southwest. We then analyzed the trends of changes in FCAs of the whole country, of each region, and of each *Lu*.

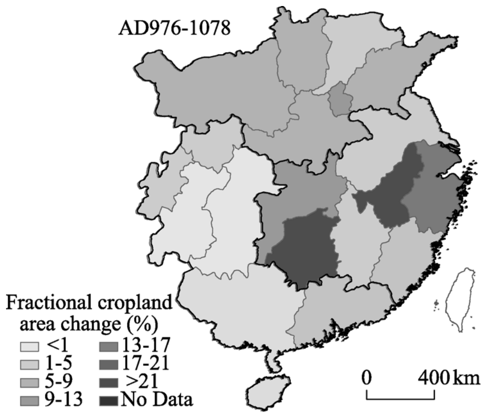

Figure 7 FCA changes in each region of the Northern Song Dynasty during AD976–1078

As the traditionally most widely cultivated region of China, the north has been the main cropland distribution area during the historical period. After the establishment of the Northern Song Dynasty, the population increased and a series of land policies were carried out by the local government, promoting cropland expansion and land intensification. As a result, the FCA for the north increased from 12.7% in AD976 to 17.9% in AD1078 (Figures 6a and 6d; Table 4), and the FCAs of all *Lus* were greater than 10% in AD1078. In particular, the FCA for the North China Plain was greater than 20%.

The FCA of the southeast showed the greatest growth rate of the three regions in this period, increasing from 16.3% in AD976 to 28.3% in AD1078 as a consequence of increased immigration from the north. Agricultural activity greatly intensified and cropland expanded from the North China Plain to the middle–lower reaches of the Yangtze River Plain. At the *Lu* level, the three most obvious *Lus* showing increases in FCA were Jiangnandong *Lu* (a 33.3% increase), Liangzhe *Lu* (16.1%), and Jinghunan *Lu* (22.9%) (Figure 7). In contrast, the FCA only increased by 2.8% in Fujian *Lu*. In the mid Northern Song Dynasty, the FCAs for some regions of the middle–lower reaches of the Yangtze River Plain were greater than 40% (Figure 6d).

In the southwest (except for the Chengdu Plain), agricultural development was greatly restricted by natural conditions. This situation did not change during the Northern Song Dynasty, so the cropland area increased slowly in the southwest. From AD 976 to AD1078, the FCA of the southwest increased from 3.8% to 5.0% (Figures 6a and 6d; Table 4). At the *Lu* level, the FCA increased by 3.3% in Guangnandong *Lu*, 2.8% in Guangnanxi *Lu*, 1.5% in Chengdufu *Lu*, and less than 1% in the other *Lus* (Figure 7). In AD1078, the FCA increased to 32.2% in the Chengdufu *Lu*, while the FCAs of other *Lus* were less than 6% (Figure 6d), with values of only about 2% in Kuizhou *Lu* and Guangnanxi *Lu*.

Table 4 Changes in FCA in each region of the study area during AD976–1078 (%)

Year	North	Southeast	Southwest
AD976	12.7	16.3	3.8
AD1078	17.9	28.3	5.0
Change	5.2	12.0	1.2

4.3 Comparative analysis with existing datasets

The previous land use datasets that have been used for conducting a comparative analysis of the outcome of restructuring historical cropland in the Northern Song Dynasty are primarily HYDE (Klein Goldewijk *et al*., 2011; Klein Goldewijk *et al*., 2001) and PJ (Pongratz *et al*., 2008). HYDE, PJ, and the dataset used in the present study have different temporal intervals and spatial resolutions. In order to facilitate comparison, data related to 19 *Lus* in AD1100 were drawn from HYDE and PJ, and then compared with this study. The results of this comparison indicate that the estimates of the total cropland area for the study area obtained from HYDE and PJ datasets, 565.50 and 492.60 million *mu*, respectively, were both lower than the estimate of 731.94 million *mu* obtained in the present study. The result using HYDE is closer to ours, so we performed another comparison with this dataset, but this time at the *Lu* level. The results show that the differences between the total cropland area of the *Lus* drawn from HYDE and those from this study are greater, with about one-third of *Lus* showing a difference of more than 75%. The cropland areas of Jiangnanxi *Lu*, Jiangnandong *Lu*, and Chengdufu *Lu* drawn from HYDE are less than those from this study by 76.2%, 77.2%, and 79.1%, respectively. In contrast, the cropland areas of Jingdong *Lu*, Zizhou *Lu*, and Guangnanxi *Lu* drawn from HYDE are greater than those from this study by 75.7%, 218.9%, and 410.5%, respectively (Figure 8).

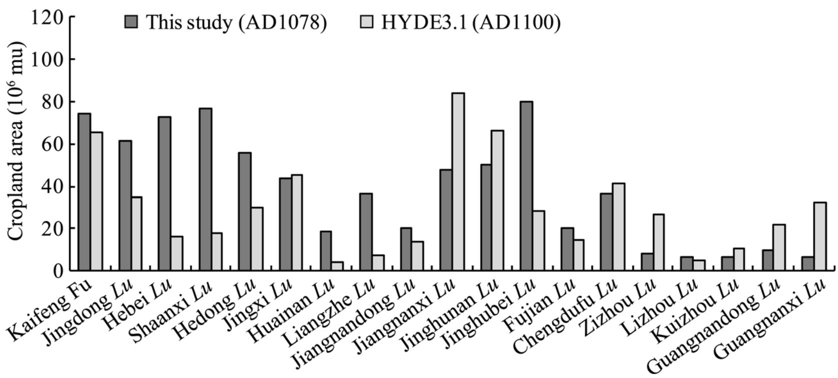

Figure 8 Comparison of reconstructed cropland areas in the mid Northern Song Dynasty at the *Lu* level

5 Conclusions

In this study, we have reconstructed the cropland area in the Northern Song Dynasty. The major findings of the study can be summarized as follows:

(1) Based on historical documents and an analysis of the factors influencing cropland distribution at the *Lu* level, a probabilistic model of cropland distribution and a cropland area allocation model have been developed. The number of *Lus* with absolute relative errors in the ranges from 0–20% is 16, accounting for 84.2% of all *Lus*, which indicates that the model provides a good representation of the spatial distribution of cropland in the Northern Song Dynasty.

(2) The cropland area of the whole country for the years AD 976, 997, 1066, and 1078 was about 468.27 million, 495.53 million, 697.65 million, and 731.94 million *mu*, respectively. The national-level cropland area showed a tendency to increase over a period of 100 years. The population of the whole country for AD976, 997, 1066, and 1078 was about 29.83 million, 39.89 million, 67.92 million, and 87.30 million, respectively. The FCA increased from 10.8% in AD976 to 16.9% in AD1078. PCCA in the Northern Song Dynasty

decreased from 15.7 *mu* to 8.4 *mu*.

(3) In terms of the spatial patterns of cropland change during the period AD976–1078, the FCA of the southeast, north, and southwest regions of the Northern Song territory increased by 12.0%, 5.2%, and 1.2%, respectively. The FCA for some regions in the Yangtze River Plain was greater than 40% in AD1078, and for the North China Plain it was greater than 20%. The FCAs of the *Lus* in the southwest (except for the Chengdu Plain) of the Northern Song territory were less than 6%. The FCA was only about 2% in Kuizhou *Lu* and Guangnanxi *Lu*.

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