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Progress on quantitative assessment of the impacts of climate change and human activities on cropland change

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Abstract: It is important to study the contributions of climate change and human activities to cropland changes in the fields of both climate change and land use change. Relationships between cropland changes and driving forces were qualitatively studied in most of the previous researches. However, the quantitative assessments of the contributions of climate change and human activities to cropland changes are needed to be explored for a better understanding of the dynamics of land use changes. We systematically reviewed the methods of identifying the contributions of climate change and human activities to cropland changes at quantitative aspects, including model analysis, mathematical statistical method, framework analysis, index assessment and difference comparison. Progress of the previous researches on quantitative evaluation of the contributions was introduced. Then we discussed four defects in the assessment of the contributions of climate change and human activities. For example, the methods were lack of comprehensiveness, and the data need to be more accurate and abundant. In addition, the scale was single and the explanations were biased. Moreover, we concluded a clue about quantitative approach to assess the contributions from synthetically aspect to specific driving forces. Finally, the solutions of the future researches on data, scale and explanation were proposed.

Keywords: climate change; human activities; contributions; quantitative; cropland pattern

1 Introduction

Cropland is essential for food production, and also the largest man-made landscape among land use types (Shi *et al*., 2014). Spatial-temporal changes of cropland can largely influence agriculture's ecosystem services, such as grain yield and biodiversity (Müller *et al*., 2013).

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Cropland pattern is sensitive to climate change and other natural factors. Additionally, human activities are also closely related to cropland distributions. Due to the limited area of cropland and the increasing population, identifying the contributions of driving forces of cropland change has become a hot spot in the fields of land use and land cover change, agriculture and food security. Cropland changes are affected by climate change and human activities simultaneously. The quantitative assessment of the contributions of climate change and human activities to cropland spatial-temporal changes is a scientific topic both to the fields of climate change and land surface system sciences.

In recent years, many researchers assessed the impacts of climate change and human activities on cropland change and made great progress (Shi *et al*., 2014; Lambin and Meyfroidt, 2012; Liu *et al*., 2009; Ye *et al*., 2012). Climate change is not the only factor to drive cropland change; human activities (socio-economic factors, policy, etc.) also affect the cropland distribution largely (Shi *et al*., 2014; Ye *et al*., 2012). Lambin and Meyfroidt (2012) found that ecological feedbacks seem to better account for cropland reclamation in Vietnam, while economic factors better explain reforestation. Liu *et al*. (2009) reported that cropland dynamics are driven by policy, economic development and climate warming in China. In the past 300 years, the contradiction between limited land and rapidly increasing population was intensified by extreme climatic disasters in North China. The resultant large-scale reclamation of Northeast China led to the formation of an organic chain of climate-policy-reclama tion (Ye *et al*., 2012).

In the previous studies, combined effects of climate change and human activities were considered synthetically. However, based on the two-variable or multivariable data, most of the studies analyzed the causal relationships between cropland change and driving forces qualitatively. Identifying the contributions of climate change and human activities to cropland change from quantitative aspects can help us to take appropriate actions to intervene and adapt to climate change, which aimed to support rational land use and balance the ecosystem services. Therefore, the contributions of climate change and human activities to cropland change are needed to be assessed quantitatively. In this study, we presented an overview of the methods that identifying the contributions of climate change and human activities to cropland change at quantitative aspects. The progress and the defects in the previous researches were also introduced. Finally, we discussed the perspectives on future researches. This review can provide references for cropland conservation, food security ensuring and climate change adaptation.

2 Methods

Quantitative methods for identifying the contributions of climate change and human activities to cropland change include five main types, i.e. model analysis, mathematical statistical method, framework analysis, index assessment and difference comparison (Table 1).

2.1 Model analysis

Model analysis is one of the classical methods to study the land use and land cover change. It is helpful to well understand the process and mechanism of cropland change. Conversion of Land Use and its Effects Model (CLUE), Slope, Land use, Exclusion, Urban extent, Transportation, Hill shade Model (SLEUTH) and Cellular Automata and Spatial-temporal Markov chain Model (CA_Markov) are the representative models in common use (Yu *et al.*, 2011). In this method, the contributions of climate change and human activities are identified through the cropland pattern simulation. For example, CLUE-S and Environment for Geoprocessing Objects Model (Dinamica EGO) were used to investigate the contribution of each driver of cropland change in China for the period 2000–2005 (Gao and Yi, 2012). In addition, some researchers combined models of land use and farm decision-making to emphasize the importance of human decision-making. Audsley *et al.* (2006) employed the crop

Table 1 Methods for identifying the contributions of climate change and human activities to cropland change

Methods	Study areas	Periods	Models	Literatures
Model analysis	China	2000–2005	CLUE-S, Dinamica EGO	Gao and Yi, 2012
	Europe	2000–2050	ROIMPEL, SFARMMOD	Audsley *et al.*, 2006
	Global	2000–2080	AEZ, BLS	Tubiello and Fischer, 2007
	Vietnam	2007–2030	CLUE, MAGNET	Rutten *et al.*, 2014
Mathematical statistical method	Jamaica	1942–2010	Logistic regression	Newman *et al.*, 2014
	Mississippi, USA	1938–2010	Stepwise logistic regression	Schweizer and Matlack, 2014
	Taibus Banner, China	2008–2009	Logistic regression	Hao *et al.*, 2010
	Jiangsu Province, China	2000–2008	Principal component analysis, linear regression	Du *et al.*, 2014
	Amazon, Brazil	2001–2012	Fixed effects panel regressions	Gollnow and Lakes, 2014
	Fuyang City, China	1999–2006	Random effects model, fixed effects model	Zhong *et al.*, 2011
	Ireland	1993–2007	Random effects model, spatial autoregressive random effects model	Upton *et al.*, 2014
	Bohai Rim	2010	Linear regression, spatial error model, spatial lag model, geographically weighted regression model	Wu *et al.*, 2014
	Jiangxi Province	1988–2005	Mechanism model of land conversion	Zhan *et al.*, 2010
	China	1996–2011	STIRPAT model	Zhang and Chen, 2014
Framework analysis	Swiss	1930–2000	System definition, system analysis, and system synthesis framework	Hersperger and Bürgi, 2009
	Portugal, Sweden	1950–2010	Pressures-Frictions-Attractors-Triggers	Beilin *et al.*, 2014
Index assessment	Northern Iran	1967–2002	Land use change area ratio	Kelarestaghi and Jeloudar, 2011
	Swiss Alps	Past 120 years	Rates of landscape change	Schneeberger *et al.*, 2007
Difference comparison	China	1980–2000	Constant eco-region in the 1980s	Gao and Liu, 2006
	Sahel	1982–2003	Residuals trend of NDVI (NDVI RESTREND)	Herrmann *et al.*, 2005
	South Africa	1985–2003	Rain-Use Efficiency, NDVI RESTREND	Wessels *et al.*, 2007
	Ordos region, China	1981–2000	NPP RESTREND	Xu *et al.*, 2009

yield model (ROIMPEL) and the Silsoe Whole Farm Model (SFARMMOD) to estimate the climate change consequences of cropland.

The contributions of climate change and human activities to future cropland change can be assessed by the difference of cropland pattern simulated by the land use model and economic model (Tubiello and Fischer, 2007; Rutten *et al*., 2014). First, the contribution of socio-economic factor can be evaluated by projecting the future cropland distribution under the economic scenario only, then the future pattern of cropland is projected under both the economic scenario and climate change scenario, contribution of climate change can be evaluated through the difference between the cropland distribution simulated with and without climate change. Coupling an Agro-Ecological Zone (AEZ) model with Basic Linked System (BLS) model, global cropland distributions were simulated with and without climate change over the period 1990–2080, then the contributions of climate change and human activities to cropland change were quantified by Tubiello and Fischer (2007). In Vietnam, Rutten *et al*. (2014) combined a Modular Applied GeNeral Equilibrium Tool (MAGNET) with a spatial land use allocation model (CLUE) to analyze future land use pattern with and without climate change scenarios for the period 2007–2030, and then investigated the relative role of climate change and human activities. Due to the simulation of the potential pattern of current and future cropland, model analysis becomes a powerful tool to investigate the transformation of cropland system (Tang *et al*., 2009). However, application of these models has been largely restricted to the difficulty of parameter acquisition, the sophisticated objective conditions, the absence of validation and criterion, and the hypothesis limitation.

2.2 Mathematical statistical method

Mathematical statistical method is mostly used to analyze the contribution of specific factors from climate change and human activities. The frequently used methods are logistic regression (Newman *et al*., 2014), principal component analysis (Du *et al*., 2014), panel regression (Gollnow and Lakes, 2014) and other mechanism statistical models (Zhan *et al*., 2010; Zhang and Chen, 2014).

Logistic regression is an appropriate tool to analyze the binary dependent variable, and often used to study the driven mechanism of cropland change. The contribution of independent variable is explained by the odds ratio or the marginal effect of the regression. Some are also determined by the hierarchical partitioning analysis, i.e. the difference between the equations with or without certain independent variable (Prishchepov *et al*., 2013). Currently, most of the studies investigated the time-series relationships between dependent and independent variables at the regional scale. For example, Newman *et al*. (2014) determined the climate change and socio-economic drivers of cropland reclamation by using logistic regression in the Cockpit Country, Jamaica. Schweizer and Matlack (2014) used stepwise logistic regression to separate the driving forces' influences in land use change of the coastal plain of Mississippi, from 1938 to 2010. Some logistic regressions were based on panel data, which were mostly from household surveys. Hao *et al*. (2010) used household surveys and binary logistic model to analyze the driving factors of cropland transfer due to differences between farmers in Taibus Banner of Inner Mongolia, China. Nevertheless, the above-mentioned studies can only tell the dependent variables' dependency to independent variable, the explanation of causal relationships still needs the aid of relevant theory. Thus, some scholars selected the co-integration test and Granger causality test to solve it. For Changsha-Zhuzhou-Xiangtan urban agglomerations of China, the internal relationships between the cropland quantity and the major driving forces were verified by the co-integration test and Granger causality test analyses (Liu *et al*., 2010).

The most obvious problem in regression analysis is the co-linearity among variables (Corbelle *et al*., 2012). Researchers are increasingly combining stochastic sampling, correlation coefficient testing, ridge regression and principal component analysis to solve the problem (Du *et al*., 2014; Zhang *et al*., 2012). Du *et al*. (2014) identified the drivers' relative importance of land use change in Jiangsu Province by principal component analysis and general linear model. Principal component analysis summarizes the information from the independent variables effectively, but ill-conceived of the interpretation.

Due to the consideration of variables' heterogeneity and co-linearity eliminating, the panel regression analysis can deal with the dynamic phenomenon better than the time-series data or panel data. For example, fixed effects panel regression was employed to quantify the contribution of cattle and soy production with cropland abandonment in Brazil between 2001 and 2012 (Gollnow and Lakes, 2014). However, the traditional panel regression is deficient in spatial correlation and spatial dependence. Spatial panel regression, which is connected with the dynamic econometric model, including the individual, time and spatial factors, can overcome the false hypothesis and estimation deviation of the model. Thus it is becoming a new choice to explore the attribution of cropland change. Focusing on Ireland, a random effects and a spatial autoregressive random effects model were employed to identify the significant effect of physical, economic and policy factors on cropland conversion (Upton *et al*., 2014). Wu *et al*. (2014) constructed linear regression model, spatial error model, spatial lag model and geographically weighted regression model to explore the relationships between cropland distribution and driving forces in the Bohai Rim.

Furthermore, some scholars developed mechanism statistical models to reveal the sophisticated relationships between climate change, human activities and cropland transformation. Zhan *et al*. (2010) developed an econometric model to explore the driving mechanism of cropland conversion from 1988 to 2005. Based on Stochastic Impacts by Regression on Population, Affluence and Technology Model (STRIPAT) and socio-economic development data of China from 1996 to 2011, the marginal contributions of urbanization process, population, economic development, and technical factors on cropland change were assessed by Zhang and Chen (2014).

Owing to the feasibility and availability, mathematical statistical method is widely used in exploring the attribution of the cropland change. However, the hypotheses between driving forces and cropland change are too simple, and understandings of cropland response to climate change and human activities are still incomplete. These may lead to the contradictions between co-linearity, autocorrelation, non-standardization, comprehensiveness and rationality. By way of mathematical statistical method, we can obtain the contributions of specific factors (such as temperature, precipitation, economic and population) to cropland change, but cannot get the spatial distribution difference of these contributions. Furthermore, this method is incapable of distinguishing the integrated contribution of climate change or human activities.

2.3 Framework analysis

Framework analysis, stemmed from general system theory, is also called conceptual model. Drivers-Pressures-State-Impact-Responses (DPSIR) is the most widely used system framework analysis (Shiferaw, 2011). Based on the framework, a list of driving forces is selected. The authors explore the relationships between driving forces and land use change on the basis of document analysis (i.e. the studies, chronicles, cantonal reports, and archival records from governments); expert interviews are made in order to supplement the document analysis. According to the impacts on land use change, each driving force is assigned a value from 1 to 0. These values are summed up to the important value to determine the contribution. For example, Benini *et al*. (2010) took DPSIR framework to distinguish the contributions of main factors acting on the cropland conversions of Lamone river basin in Northern Italy.

In addition, Bürgi *et al*. (2004) proposed system definition, system analysis, and system synthesis framework. The system definition includes defining the study area, the achievement of the study, the spatial-temporal resolution, and the landscape elements of interest. The system analysis focuses on three parts, i.e., the change and persistency of physical landscape elements, the actors and institutions, the driving forces. The actors, institutions, and driving forces are linked through causal relationships in the system synthesis phase, and their influences on the land use are determined. Based on this framework, Hersperger and Bürgi (2009) built the importance value to quantify the relative importance of socio-economic, political, cultural, technical and natural driving forces of urbanization, agricultural intensification and greening, from various administrative levels and time scales.

Then Slatmo (2011) proposed pressures, frictions, attractors and triggers framework. Pressures are factors that are forcing stresses on land use, such as political, economic, cultural and technical. Frictions are factors that prevent change: resisting, slowing down or changing the direction of land use change. Attractors are site physical characteristics. Triggers are factors that spur land use change in a direct, immediate ways (e.g. the opening of a new road). Beilin *et al*. (2014) estimated the relative importance of international, national and local drivers to cropland abandonment based on this framework in Portugal and Sweden. Compared to other methods, framework analysis has profound theoretical background, and interprets the causality more comprehensively and reasonably. Nevertheless, this method is mostly based on the indicator calculation; the obvious subjectivity may inevitably exist in the weight selecting.

2.4 Index assessment

The authors often select direct indicators representing land use change (rates of landscape change or land use change area ratio), they identify the driving forces (political, economic, cultural, technical and natural) and actor levels (international, national, canton, municipality, planning agency, organization, group, individual and farmer level) to impact on land use change. The interviews, which include free discussion and systematical thoughts, are then taken with farmers, politicians, planners and historians, interviewees are shown graphs with the time-series indicators of land use change. Additionally, historical documents are analyzed in order to supplement the interview. Finally, the contributions of driving forces to land use change are investigated. For instance, in northern parts of Iran, the land use change area ratio was computed to determine spatial patterns of land use changes in relation to physical and socio-economical factors by Kelarestaghi and Jeloudar (2011). Schneeberger *et al*. (2007) reconstructed the rates of landscape change in northern fringe of the Swiss Alps, expert interviews with farmers, politicians, planners and historians helped in identifying the contributions of actors and driving forces to land use change. This method is easy to operate, and can assess the contributions of climate change and human activities to cropland pattern quantitatively. Unfortunately, the spatial difference cannot be reflected in these studies.

2.5 Difference comparison

The difference comparison method is usually used to distinguish the integrated role of climate change and human activities in cropland conversion. First, some indirect indicators are selected, such as Normalized Difference Vegetation Index (NDVI) or Net Primary Productivity (NPP), the potential value of the indirect indicator is simulated with climate change only. Then the differences between observed and potential value of indicator are considered as human activities' impact, the contributions in various periods can be implied by difference trend of these indirect indicators. Based on the constant eco-region in the 1980s, Gao and Liu (2006) analyzed the respective impact degree and direction of changes caused by climate change and human activities to land use in China. This practice inspires the researches on the contribution of cropland change, while the spatial differences of driving forces may be ignored.

Residuals trend of NDVI method (RESTREND) can separate the contributions of climate change and human activities to cropland pattern in arid and semi-arid zones. Furthermore, the contributions can be displayed spatially. The process is that, based on the highly correlated relationships between vegetation and rainfall in arid and semi-arid zone, the regression equation is constructed to estimate the NDVI. It is hypothesized that, the difference between observed and predicted NDVI can be considered as the human impact. Herrmann *et al*. (2005) used this method to investigate the 'human signal' to the cropland change in the Sahel. Moreover, Rain-Use Efficiency (RUE= NPP/Rainfall or ΣNDVI/Rainfall) can also imply the cropland degradation. Wessels *et al*. (2007) tested the RUE and RESTREND to detect the human-induced land degradation in South Africa, results indicated that the RESTREND showed better. The RESTREND method is mainly suitable to arid and semi-arid zones. In such regions, the vegetation growth is correlated with precipitation. So the key issue of this method is to validate the relationships between precipitation and NDVI. Nevertheless, the vegetation is not always significantly related to the precipitation everywhere. Except for the precipitation, other factors, such as temperature and soil quality, should also be involved (Wessels *et al*., 2007).

In Ordos region of China, Xu *et al*. (2009) selected potential NPP and the difference between potential and actual NPP to analyze the relative roles of climate change and human activities in sandy desertification, respectively. Based on the remote sensing images, this method can spatially identify the contribution of land use for a long time and multi-scale analysis. However, the exact causes of the negative trend, e.g. overgrazing by livestock or cultivating, should be explored by the aid of widely field investigation and higher-resolution remote sensing image at the local scale.

3 The contributions to the cropland pattern change

3.1 Climate change

Climate change can substantially induce the variation of regional hydrological cycle and environment, affect cropping systems, crop productivity and land use, subsequently causing considerable variability of cropland pattern (Newman *et al*., 2014; Chen *et al*., 2012; Piao *et al*., 2010; Dong *et al*., 2009). The cropland in Northern China, which is limited by heat, had benefited from the climate warming. The cropping center of rice in Northeast China was 128°52′E, 45°37′N in 1970 and 129°53′E, 46°29′N in 2006, and extended northward about 80 km (Chen *et al.*, 2012). Climate warming had already caused a significant northward expansion of rice cropping boundaries from ~48°N to ~52°N in Heilongjiang Province, the areas extended from 0.22 Mha in the early 1980s to 2.25 Mha in 2007 (Piao *et al*., 2010). With the increasing of annual accumulated temperatures ≥10 °C since the late 1980s, 31.6 Mha of land were transferred from the spring wheat zone to the winter wheat zone (Dong *et al*., 2009). In mountainous areas, temperature change affects the cropland distribution because of the terrain variation (IPCC, 2014). The gravity center of China's cropland was gradually moving upward altitudinally and northward from the late 1980s to 2008. According to latitude (or altitude), the cropland increased areas seemed to be about 0.5°–1° more northward (or 100–200 m higher) than the decreased areas (Shi and Yang, 2010). In parallel, precipitation can also influence the cropland distribution. From 2001 to 2010, with every 100 mm increase of precipitation in the driest month, the deforestation probability of Jamaica increased by 8% (Newman *et al*., 2014). As for the cropland in China from 2000 to 2005, the main driving force of cropland-forest transition was the months whose precipitation > 50 mm (the weight range was 2.065) (Gao and Yi, 2012).

Combined with climate change scenarios, some scholars predicted the cropland response to future climate change. As for the tropical ecosystems, humidity and extreme heat were projected to negatively impact the growing season length and the crop suitability (medium confidence) (Jones and Thornton, 2009). Lane and Jarvis (2007) used projected future climate data for ~2055 and the Ecocrop model to predict the areas suitable for 43 crops. Results indicated that suitable cropland areas are projected to grow, however, the suitable areas for the cold weather crop were likely to decrease significantly, including wheat (18%). By region, Europe was projected to increase by 3.7% in suitable cropland areas, suitable areas in Antarctica and North America would also expand by 3.2% and 2.2%, respectively, suitable cropland areas in Sub-Saharan Africa and the Caribbean were likely to experience a decline (–2.6% and –2.2%, respectively). To 2050, more than 50% of the cropland was projected to be unsuitable for cultivating in most African countries (Burke *et al*., 2009). With the climate projections of the global coupled atmosphere-ocean general circulation model (version 2) by the Meteorological Research Institute of the Japan Meteorological Agency, during the period 2081–2100, rice cultivation area in Japan was projected to move northward from 100 km to 200 km (Ohta and Kimura, 2007). Under the IPCC SRES A1B and A2 climate change scenarios, from 2005 to 2035, cropland area of the Poyang Lake region was projected to increase by 3% and 2.3%, respectively, the cropland area under the B1 scenario was likely to decrease by 1% (Yan *et al*., 2013). Compared to the period 1961–1990, with the 80% and 50% guarantee rates of accumulated temperature, planting boundaries of early and middle maturity varieties were likely to move northward 1.9°–2.3° latitude and 1.2°–2.6° latitude, respectively. For the late-maturity spring maize in Heilongjiang and Liaoning, their planting boundaries would move northward 2.0°–3.9° latitude and 0.4°–1.7° latitude, respectively (Liu *et al.*, 2010).

3.2 Human activities

Globalization, urbanization and industrialization substantially influence the farmers' living and land use, subsequently cause the cropland change. For example, economic development and urbanization can lead to the decrease of cropland area (Li, 1999). From 1978 to 2007, for every 1% increase of urbanization level and local finance revenue, the area of cropland abandonment increased by 0.05% and 0.03%, respectively (Huang *et al.*, 2009). From 1997 to 2008, for every 1% increase of urbanization level of Jiangsu Province, the cropland area decreased by 1800 ha (Meng *et al.*, 2013). Meanwhile, during 1978–2007, the cropland lost 5671.40 ha with every 1% increase of urbanization level of Chengdu (Chen *et al.*, 2010).

Population growth promotes the demand of minerals, land and water resources, and drives the conversion of cropland to non-agriculture use (Newman *et al.*, 2014; Zhan *et al.*, 2010). For every 1% population increase of Jiangxi Province, the conversion of cropland to urban and industrial land raised 0.802%; for every 1% increase of the proportion of agricultural population, the conversion of cropland to forest/grassland increased by 1.131% (Zhan *et al.*, 2010). Zhang *et al.* (2010) found that impacts of non-agricultural population proportion on cropland have exceeded that of total population. For every 1% increase of total population and the proportion of agricultural population, cropland areas reduced by 0.90‰ and 1.33‰, respectively.

Location and transportation are also the important driving forces of cropland distribution. There is general agreement that the probability of cropland abandonment grows with the distance to the settlement (Schweizer and Matlack, 2014). For the provinces of Kaluga, Rjazan, Smolensk, Tula and Vladimir in European Russia (for five provinces in post-Soviet European Russia), from 1990 to 2000, an additional kilometer far from settlements increased the probability of cropland abandonment by 8% (Prishchepov *et al.*, 2013). In the Ongiud Banner of Inner Mongolia, being one additional kilometer closer to the nearest settlement increased the probability of cropland reclamation by 1.6 times (Xie and Li, 2008). Meanwhile, the distances to road and town also have negative effects on cropland abandonment. In Fuyang County of Zhejiang Province, for each 100 m increase in distance to road and town, the risk of being abandoned decreased 0.9802 and 0.9704 times, respectively (Zhong *et al.*, 2011). Forest area impacts the cropland abandonment positively, the distance to forest impacts it negatively. For each hectare expansion of native forest in 1985, the probability of cropland abandonment increased by 0.23%. Also, for every one kilometer closer to Chiloé National Park, the probability of cropland abandonment increased by 0.45% (Díaz *et al.*, 2011). For five provinces in post-Soviet European Russia, the probability of cropland abandonment decreased by 4% for each 100 m increase of distance to the forest edge and increased by 48% for the cropland areas within the forest matrix (Prishchepov *et al.*, 2013). In addition, cropland transition is closely related to its neighboring land use. For Fuyang City in Zhejiang Province, an additional 100 m away from the nearest construction land decreased the probability of being converted by 0.6703 times (Zhong *et al.*, 2011). For Jiangsu

Province, during the period 1998–2008, an additional 1% decrease of adjacent cropland area led to 0.154% decrease of local region (Wen *et al*., 2011).

The land use (or migration) policy differences between regimes or periods impact the farmers' attitude towards the cropland (Zhong *et al*., 2011; Díaz *et al*., 2011). In general, the existence of cropland protection policy restrains the land abandonment. In Southern Chile, the presence of a subsidy reduced the risk of cropland abandonment by 19% (Díaz *et al*., 2011). For the Fuyang City of Zhejiang Province, an additional one unit land protection policy decreased the probability of being converted by 1.0231 times (Zhong *et al*., 2011).

Technology is so important that can solve the livelihood of increasing population with the limited land. However, it is difficult to analyze quantitatively. In the long haul, technical progress may result in the cropland shrinkage (Ewert *et al*., 2007). During the period 1996–2011, for each increase of one unit technical factor, the area of Chinese cropland reduced by 0.003 % (Zhang and Chen, 2014).

Other driving forces are also investigated in literatures. For example, in the five provinces in post-Soviet European Russia, an additional 0.1 t/ha decrease of grain yields in the late 1980s, increased the risk of cropland abandonment between 1990 and 2000 by 11% (Prishchepov *et al*., 2013). Adjustment of agricultural structure also affects the cropland pattern, during the period 1998–2008, the marginal elasticity coefficient of ratio of grain and economic crops on cropland change is 0.069 in Jiangsu Province (Wen *et al*., 2011).

Summary of the integrated contribution of driving forces is helpful to understand the factors that are putting stress on cropland. Based on the hierarchical partitioning analysis, Prishchepov *et al*. (2013) found that 'average grain yields in the late 1980s had the highest explanatory power for cropland abandonment (42.1% of the total variability), whereas 'distance from nearest forest edge' was of secondary importance (19.4%), it was followed by 'isolated cropland within the forest matrix' (11.9%) and 'distance from nearest settlement with more than 500 people' (11.5%), human influences were more obvious than that of climate change. Zhang *et al*. (2014) employed a multi-level statistical model to explore the driving forces of cropland abandonment of Wulong County, Chongqing. The research revealed that 7% and 13% of the cropland abandonment can be attributed to the household and village levels, respectively, while the remaining 80% can be attributed to the land parcel features.

3.3 Integrated contributions of climate change and human activities to cropland change

Integrated contributions of climate change and human activities to cropland change vary with regions. With regard to land use degree excursion intensity, 81% and 85% was caused by climate changes in east-west direction and north-south direction, respectively. The climate change impacts were much greater than human impacts (Gao and Liu, 2006). While for Xinjiang Autonomous Region, from 1981 to 2005, the contributions of climate change in east-west direction and north-south direction were 24% and 40%, respectively, climate change influences were less than that of the human activities (Huang *et al*., 2009). Furthermore, integrated contributions of climate change and human activities to cropland change vary with conversion types and periods. For example, the reversed desertification mainly caused by climate change during 1981–1990 (the contribution was 64.30%) and by human activities during 1991–2000 (the contribution was 91.13%). The expanded desertification was mainly induced by human activities between 1981 and 1990 (the contribution was 89.16%) and by climate change between 1991 and 2000 (the contribution was 79.42%) (Xu *et al*., 2009).

For the contributions of future climate change and human activities to the cropland pattern, the socio-economic factors (economics, technology reform, social development and governmental structure) play more important role to cropland change (Tubiello and Fischer, 2007). To 2080, without consideration of climate change, the cropland in developing countries was projected to rise by 27% (250 Mha), most of these was from Africa (+122 Mha, or +60%) and Latin America (80 Mha, or +45%). On the contrary, croplands of many developed countries were projected to decrease; Western Europe had the largest reduction (−9 Mha, or −11%). With consideration of combined effect of climate and economic changes, under IPCC SRES A2 climate scenario, impacts of climate change on global cropland were projected to be small (+9 to +12 Mha, or +0.5 to +0.7%). Anthropogenic impact was projected to be more significant than that of climate change (Tubiello and Fischer, 2007). Under the influence of human activities, cropland in England and Wales was projected to reduce from 3.48 Mha in the mid-1980s to 2.07 Mha in 2060. While under the climate scenarios from Geophysical Fluid Dynamics Laboratory, Goddard Institute for Space Studies, and United Kingdom Meteorological Office, the cropland areas were likely to be 2.23 Mha, 2.05 Mha and 2.18 Mha, respectively (Hossell *et al*., 1996). Briner *et al*. (2012) found that, for the Visp region in the Swiss Alps, the cropland loss from economic change (147 ha) was projected to be larger than that from climate change (116 ha).

4 Limitations

4.1 Method issue

The methods of identifying the contributions of climate change and human activities to cropland change have their own advantages and disadvantages. Some of these methods investigate the integrated role of climate change or human activities, and some others investigate the relative role of specific factors of climate change and human activities. The integrated role and specific role are seldom considered simultaneously. First of all, we should analyze the integrated role of climate change or human activities; then, we should know what are the particular factors inducing the cropland change. In addition, there are few methods for identifying the contributions of climate change or human activities to cropland change shown at the detailed spatial scale.

4.2 Data issue

Compared with the spatial pattern data for cropland from high resolution remote sensing image, data of driving forces are needed to be more accurate and abundant. For example, data on the discriminate of rain-fed, irrigation and wetland cultivation, crop types, cropping system, pesticide and fertilizer, etc. are not yet accurately and adequately acquired. However, these data are indeed vital important factors relating to research driving forces. Moreover, the socio-economic statistical data (economic, political and technical) are limited to display and mostly collected based on administrative district, which disagree with the cropland pattern data based on the physical characteristics (Yu *et al*., 2013). Except for some population data and national statistical data, the comparable data of driving forces are absent worldwide. Moreover, the existing socio-economic data are mainly from developed countries (IPCC, 2014). All above restrict the deep understanding of driving mechanism of land use changes.

4.3 Scale issue

Land use is an integrated decision of multi-scale and multi-dimension, so the contributions of climate change and human activities to cropland change are different in different spatial-temporal scales and actor scales. The same driving forces impact differently in different regions, and the cropland change could be interpreted by changes at various scales simultaneously (Napton *et al*., 2010). Most of the researchers can realize the time scale, but ignore the treatment of spatial scale, actor scale and classification precision. The differences of the contributions among various scales are scarcely researched, which results in the unilateral understanding of driving forces.

4.4 Explanation issue

The explanation of the relationships between cropland and driving forces is “grey”. Simultaneously, the studies seldom investigate the individual effect of climate change and human activities. Evaluating the contributions of the climate change and human activities systematically is useful to understand the mechanism of reclamation and abandonment of cropland. We should explain the results carefully because of the imperfection comprehension of impacts on cropland system (Yu *et al*., 2013).

5 Perspectives

5.1 Identifying the contributions from integrated role to specific factors

The evaluation of the contributions of climate change and human activities should aim at the spatial quantitative identification. Based on the image interpretation data of cropland, we should refer to the causality between driving forces and cropland pattern in the framework analysis method and also the ideas from difference comparison, and select the suitable model to project the potential distributions of cropland only under climate change. Then, we can compare the potential distributions with the actual changes of cropland, to investigate the influences of human activities, and identify the integrated contributions of climate change and human activities. In addition, combined with the changes of water and heat conditions, questionnaires should be investigated in the reclamation and abandonment areas of cropland, and the spatial choice model should be employed to explore the internal mechanism of the reclamation and abandonment (Yin *et al*., 2010). The contributions of climate change and human activities to cropland spatial-temporal change can be spatially identified. Moreover, the results validation should be considered in the future evaluation.

5.2 Enhancing the comprehensiveness and accuracy of data

We should pay more attention to the collection of high quality cropland data, such as the cropping system, crop types, management (irrigation, fertilization), natural disaster, etc. Meanwhile, we should supplement the socio-economic data from the questionnaire of representative regions, such as the economic level of household, labor structure, migrant laborers, livestock and villages. We should also seek the appropriate model (or method) to mate the socio-economic data with natural environment data, and display the former spatially. Moreover, based on the high-resolution remote sensing images, information of human activities should be extracted to provide the reliable support of establishment and validation of model. In addition, the traditional statistical method requires the normal distribution and linear data (Tsakovski *et al.*, 2010). However, in the self organization theory, knowledge acquiring is self-adaption and fault-tolerant, which can explain the non-linear and macro characteristics of the open complex system. It can be used to solve the complex, multi-dimension and non-linear relationships between cropland use and climate change, human activities.

5.3 Quantitatively synthesizing with multi-scale and multi-dimension

The scales that impact on cropland use include time, spatial and actor scale. As for the time scale, what are the relationships between drivers and cropland use at monthly, annual, decadal and centenary scale respectively? As for the spatial scale, what are the relationships between drivers and cropland use at parcel, local, regional, national and global scale respectively? At the various spatial-temporal scales, what are the contributions of the actors from farmer to the institution scale? All of these questions should be answered by the multi-scale and multi-dimension researches (Cai, 2001). Cropland utilization is the decision of multi-scale action. Multi-scale statistical models would seem to solve the nested structure activity and could be taken as commendable attempt to determine the contributions at different scales (Zhang *et al.*, 2014). First of all, the representative explanatory variables should be collected. For example, the slope, elevation and soil quality represents the variables at parcel scale, agricultural labor amount, labor age and percentage of male laborer represent the variables at household scale, distance to administrative center and land rental rate represent the variables at village scale. The models are constructed by including the explanatory variables at different scales sequentially. Then the contributions of variables at different scales can be determined by the comparison of models.

5.4 Reasonable explaining on the basis of driving force theory

We should realize that the methods are only the tools to understand the complicated relationships between cropland change and its driving forces (Gao and Yi, 2012). In order to discuss the contributions of climate change and human activities to cropland change, the explanation should appeal the co-integration test and Granger causality test analyses to judge the causality firstly. Therefore, we should deepen the comprehension of drivers and avoid analyzing the results just in terms of the simulations or statistical results.

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