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Synthesis of agricultural land system change in China over the past 40 years

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China's agricultural land system

Understanding the patterns, processes, and causes of land use changes remains the core task and challenge of land system science (Rounsevell et al., 2012; Turner, Lambin, & Reenberg, 2007; Verburg, Erb, Mertz, & Espindola, 2013). While area changes that include agricultural expansion, urbanization, and deforestation have long attracted the most attention in land system science, relatively little research has been conducted regarding the more subtle changes within these broad land use categories, such as modifications of agricultural intensity (Kuemmerle et al., 2013). The spatial patterns and configuration of land use, changes in land tenure, and land use intensification all have profound implications on food security, natural resources, and the environment (Deng, Huang, Rozelle, & Uchida, 2006; Haines-Young, 2009). For example, while the spatial concentration of crops and intensification of agriculture may have positive effects on the agricultural productivity necessary to meet increasing food demand, they also have caused the loss of biodiversity, depletion of water resources, soil exhaustion, surface and groundwater pollution, and increased carbon emissions (Kleijn et al., 2008; Matson, Parton, Power, & Swift, 1997; Searchinger et al., 2008; Tilman, Balzer, Hill, & Befort, 2011). Representing one of the core challenges of sustainable development is the persistent tension between increasing agricultural productivity to feed, clothe, house, and fuel the world's growing population in the near term and ensuring environmental quality and resource sustainability to support humanity's existence in the long term (Swinton, Lupi, Robertson, & Hamilton, 2007; Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). These opposing pressures point to the need for greater evidence-based discourse on competing uses of land, spatial patterns of land use, and their impact on food availability and well-being.

This is particularly so in China, which faces enormous pressure to increase food production and protect depleted natural resources and deteriorated environments. China is one of the largest global producers of agricultural commodities and possesses one of the largest rural workforces. China shares many common issues with other developing and emerging countries, such as extensive land fragmentation in a largely smallholder-based farming system. Yet, China also has a number of unique features that make it a special case, such as its land tenure system. Since the commencement of the rural land reform in China in the late 1970s, under which the croplands

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managed by communal systems were reallocated to individual farm households, the agricultural production, farm structure, and agricultural land use has fundamentally transformed. In addition to the rapid economic growth, with an average 10% annual GDP growth rate, agricultural production has also increased substantially in the past 40 years. Grain production, for example, has more than doubled. What makes this achievement particularly remarkable is that the agricultural production growth did not rely on the expansion of agricultural land, as total cultivated land hovered approximately 135 million hectares over this period (the real number remains elusive, as different estimations are given by multiple sources). The extent of agricultural areas has even decreased in recent years due to urbanization and ecological conservation projects, such as the sloping land conversion project (SLCP) (Liu et al., 2014).

The main drivers of agricultural growth during the past 40 years have been institutional reforms, the adoption of land-saving technologies, financial investment and subsidies to stimulate higher input usage, and other forms of land use intensifications. Yet, China still faces the paramount challenge to guarantee national food security, which continues to be a key goal of the Chinese government. However, ensuring domestic food security is a daunting task given the fundamental supply-side challenges in a country with less than 0.1 ha of agricultural land per capita, which is only approximately 38% of the world average. At the same time, demand-side challenges loom large for China: while the increasing demand was previously driven in part by population growth, dietary shifts towards more animal proteins and processed foods, driven by the rapidly growing affluence and higher rates of urbanization, have caused a much larger land footprint in China (Popkin, Horton, Kim, Mahal, & Shuigao, 2001).

China's achievement in feeding 20% of the world's population with only 7% of the world's agricultural land has been accompanied by increasing social and environmental challenges. The current agricultural intensification comes at the cost of water resource depletion, soil degradation, and air and water pollution (Zuo et al., 2018). It is clearly unsustainable and poses risks not only for China but also for the world. The continuing increase in food demand, especially the rising demand for animal-based protein, is responsible for massive greenhouse gas emissions (Lathuilière, Johnson, Galford, & Couto, 2014). Hence, China faces the double pressure of having to increase production on its limited agricultural land resources while at the same time reducing land use pressure on environmental systems. Such examples include reducing emissions from land use, maintaining biodiversity, and reducing water pollution (Lai et al., 2016; Mukhopadhyay, Thomassin, & Zhang, 2018; Piao et al., 2010).

Agricultural land resources remain the focal point of the Chinese government for maintaining food security and agricultural sustainability. China's agricultural land system has experienced fundamental changes in its land use configurations and intensity despite the stability of agricultural land use overall (Chen, Ye, Cai, Xing, & Chen, 2014; Deng & Li, 2016; Liu et al., 2014). In the past four decades, the rapid urbanization and rural-urban migration have affected China's land use in a way that is unprecedented in scale and speed. Hundreds of millions of rural residents have moved to cities permanently or seasonally. The rural labour force has decreased rapidly and the elderly and women have become the main working force in agricultural production. However, unlike in the transition economies in Eastern Europe and Central Asia, where land abandonment and declining agricultural intensity were prevalent after the demise of the Soviet Union (Lesiv et al., 2018; Rozelle & Swinnen, 2004; Schierhorn et al., 2013), China did not witness substantial amounts of rural land abandonment. Quite the contrary, China experienced a forest transition, i.e. the change from net deforestation to net reforestation, arguably in the early 1980s. However, China's forest transition is the result of a mixture of different pathways, including the economic development pathway, under which forests have been regrowing on marginal agricultural lands in response to the migration of the rural workforce (Chen et al., 2014; Frayer, Sun, Müller, Munroe, & Xu, 2014). At the same time, large-scale ecological conservation programmes have played an important role in the increase of forest cover. Such programmes include the SLCP, which funded efforts to convert marginal agricultural land to forests and grasslands. Additional contributions to China's increased forest

cover were made by state reforestation programmes and schemes that provided monetary incentives to farmers for reforesting marginal agricultural lands (Zhang et al., 2000). However, the ecological quality of the Chinese forest transition has been debated because most of the tree cover increase comes from cash trees, such as for fruits or timber, which provide few ecosystem services beyond provisioning commodities for human consumption (Xu, 2011).

Furthermore, a strict agricultural land protection policy, also known as the 'land red line' policy, intends to safeguard a '1.8 billion mu' (i.e. 0.12 billion ha) area of quality agricultural land. However, in the face of urbanization and infrastructure construction that led to the loss of substantial amounts of fertile agricultural lands in the eastern and coastal regions, maintaining the red line is challenging (Bren d'Amour et al., 2016; Chen, 2007). At the same time, land expansion and reclamation occurring in the northeast and northwest of China is putting further stress on water resources in those regions (Piao et al., 2010).

Land use intensity has also varied over space and time during the transformation. In South China and the lower Yangtze watershed, land use intensity, measured by the cropping intensity index, i.e. the number of times the land is harvested per year, decreased despite favourable climate conditions marked by abundant precipitation and a long growth season. Conversely, land use intensity has increased or remained at high levels in North China and Northeast China, which exacerbated water scarcity (Yu et al., 2018a, 2017).

The economic and demographic transformations and changes also led to substantial alterations in the spatial patterns of crops in terms of crop structure, crop diversity, spatial distribution and concentration, and production intensity (Li et al., 2015; You, 2012). The cultivated area of maize has increased significantly, mainly due to increased feed demand for livestock production. In terms of area, cash crops such as vegetables, oil crops, sugar, and tobacco have also expanded. Cotton, one of the major Chinese cash crops, has been widely cultivated across China; the total harvest area of cotton has increased continuously in the past 40 years, peaking in 2011. It is especially notable that cotton cultivation has increasingly shifted from traditional agricultural zones, namely, the Yellow River Basin and Yangtze River Basin, to the Xinjiang Autonomous Region, an arid region in northeastern China (Hsu & Gale, 2001). The traditional cotton cultivation regions, namely the Yellow River Basin and Yangtze River Basin, continued to see their shares shrink over recent years. According to the recently published data by the National Bureau of Statistics of China (NSBC) (NSBC, 2018), the cotton harvest area in Xinjiang accounted for 74% of the total cotton plantation area and 84% of China's total cotton production in 2018. More importantly, the intensity of cotton production has also increased. In addition to strategies and technologies such as plastic mulching, seedling transplanting, and double cropping, China has widely adopted a genetically modified cotton, *Bacillus thuringiensis* (Bt), that was found to have positive effects on yields while reducing pesticide and labour inputs. (Dai & Dong, 2014; Huang, Hu, van Meijl, & van Tongeren, 2004; Huang et al., 2010a). The concentration of farming in the highly productive Xinjiang region combined with intensified cultivation has led to a continued increase in total production, despite the decrease in area occurring since 2012. While the total cultivated area remained largely stable or slightly decreased, cultivated areas of wheat and rice, the two main staple crops for the Chinese population, have slightly decreased (Huang, Yang, & Rozelle, 2010b). Soybean plantations have shrunk and become increasingly concentrated in Northeast China; however, most of China's soybean consumption for oil and animal feed is imported, particularly since China's entry to the WTO in 2001 (Ali, Huang, Wang, & Xie, 2017; Lathuillière et al., 2014). The analysis of virtual land and virtual consumption shows that food imports, and especially soybean imports, have eased land competition among crops within China. This has allowed China to dedicate much of its agricultural land to growing other major staple crops and cash crops. As such, globalization plays a considerable role in the crop structure and spatial patterns of land use in China (Ali et al., 2017; Dalin, Konar, Hanasaki, Rinaldo, & Rodriguez-Iturbe, 2012; Qiang, Liu, Cheng, Kastner, & Xie, 2013).

Land tenure relations and the security of land tenure are important components of agricultural land systems that have manifold implications for farm structure and land use patterns. China's rural

reform, namely, the establishment of the household responsibility system in 1978, was credited for about half of the agricultural output growth in the early stages after the reform was implemented (Lin, 1992). However, the small-scale farming structure with family farms smaller than one hectare, on average, and high land fragmentation has hindered the improvement of agricultural productivity through mechanization (Tan, Heerink, & Qu, 2006). Economic growth and rural demographic changes caused by massive emigration to urban areas have undermined the viability of the small-scale farming system, which is too labour-intensive. Moreover, the incomes generated on small family farms are not competitive with salaries offered in the off-farm sector. Various land policy reforms, such as the extension of long-term contractual rights, land titling, and the 'three rights separation' (three land rights: land ownership, contract rights under the household responsibility system, and land use rights) have fostered land transfers in recent years (Wang & Zhang, 2017). The latest statistical data by the Ministry of Agriculture of China shows that by the end of 2016 approximately 31.3 million hectares of agricultural land, accounting for 35.1% of the overall contracted land in China, had been transferred in various forms. These land tenure and farm structure changes are deemed to bring transformative change to China's agricultural land system (Jin & Deininger, 2009).

In summary, China presents a particularly intriguing case for the study of land system dynamics with its spatial patterns of cropland and crops, crop structure and diversity, land transfer and consolidation, and land use intensity changes against the backdrop of its rapid socio-economic transformation, globalization, and environmental challenges. Moreover, after 40 years since the commencement of China's Economic Reform and the de-collectivization of agriculture, it is a good time to review and reflect how China's agricultural land systems have been transformed.

2. Contributions to this special section

This special section consists of four papers that all contribute to the understanding of the spatio-temporal dynamics of agricultural land use in China from different perspectives and with various methodological approaches.

Yin et al. (2018) quantify and map the spatial concentration of cropland and five major crops (rice, maize, wheat, soybean, and potato) in China from 1980 to 2011. While the spatial disparity of cropland and crops is well documented in China, few quantitative research studies have been conducted measuring the degree of spatial concentration and its change over time. This research approaches the problem from a systematic way with quantitative statistical methods, including exploratory spatial data analysis (ESDA) and generalized entropy index (GEI). The application of GEI in studying crop disparity among regions is especially innovative. Given that most of the published research consists of local and short-term studies, due to the lack of national-level, fine-scale datasets covering long time spans, the usage of long-term, fine-scale spatial data at county level makes this research stand out among similar studies. The authors reveal an increasing spatial concentration of overall cropland over time, particularly individual crops. The authors argue that increasing the observed spatial concentration may infringe upon food security and the resilience of food production in particular, due to higher production risks associated with weather extremes and plant disease that may outweigh the positive effect on agricultural productivity. Assessing the spatial concentration in crop production is thus relevant for Chinese land use policies.

In the same vein, Ji et al. (2018) assess the spatial patterns of land use, with a focus on vegetable production. China is the world largest producer, consumer, and exporter of vegetables, and vegetables are one of the most important cash crops for millions of farmers. Vegetable production and supply is, therefore, an issue of paramount importance for the Chinese food system. The well-known 'Vegetable Basket' project initiated by the Chinese central government in 1988 aimed to improve the production and circulation system of vegetables. Here, Ji et al. (2018) show where the vegetables have been produced across China: the authors report an increasing concentration of

vegetable production in North China and in the Yangtze Basin from 1995 to 2015. Furthermore, they estimate a spatial panel model, a cutting-edge econometric method, to assess the drivers of area changes in vegetable cultivation at the provincial level. One of the surprising findings is that climate conditions, such as temperature, do not matter in the distribution of vegetable production. The authors argue that the wide-use of greenhouses and irrigation explain this pattern. We believe the spatial panel model presented in this research will be increasingly applied when analysing determinants and drivers of land use changes.

Yao et al. (2018) presented an agent-based simulation model in studying land use change in a suburban region in the North China Plain, an important grain production region in China. Agent-based models (ABMs) have gained great popularity in studying land cover and land use changes in the past 20 years (Magliocca, Brown, Ellis, & Huerta-Quintanilla, 2014; Matthews, Gilbert, Roach, Polhill, & Gotts, 2007; Parker, Manson, Janssen, Hoffmann, & Deadman, 2003). Relatively few Chinese researchers have taken on this method in land use studies, except for a few groups focusing on cellular automata-based modelling, often with a focus on urban land use change (Li & Yeh, 2002). Particularly intriguing for all other ABM modellers is the integration of Repast, an ABM software platform, GIS software, and the creative method to initiate agents that are presented in this paper. The emergence of horticulture (in this case, grassland for urban greening purposes) land use in traditional agricultural areas shows an example of how urbanization asserts its impacts on agricultural land uses via demand. The authors warn that such development may threaten food security and further aggravate water resource depletion despite the high economic return from horticulture.

Last but not least, Yu et al. (2018b) outline a generalized causal chain framework for analysing the causal relationships in land use change after comparing and synthesizing three seminal frameworks, namely the framework of proximate and underlying drivers (Geist & Lambin, 2002), of actors-drivers (Hersperger, Gennaio, Verburg, & Bürgi, 2010), and of environmental cognitions (Meyfroidt, 2013). The authors demonstrate how such frameworks support the study of farmers' land transfer decisions in Northeast China. This research reflects the importance of actors and, hence, the paradigm shift from a 'pixel-based' approach to an 'agent-based' approach in land system science. This trend is in line with the increasing usage of ABMs in land use science. The research of Yu et al. (2018) will further fuel the development of models that support the analysis of land use decision-making using ABMs.

In summary, the four papers featured in this special section quantify changes in crop structures, map spatial patterns of cropland and crops, examine increasing concentration patterns of major crops, analyse the driving factors of those changes, simulate future land use changes, and illuminate decision-making of farmers in land transfers. These contributions provide a glimpse into the highly dynamic and complex agricultural land systems in China. Many challenges remain in analysing land system changes in China, with other compelling topics and unanswered questions revolving around the rapid land and food system transformation. Nevertheless, these papers contribute to the synthesis of existing knowledge, highlight important research gaps, and help chart a path for future inquiry of spatio-temporal dynamics of land use in China. All in all, the land system dynamics of China have great implications for the rest of the world, and the knowledge and lessons learned in China can shed light on the dynamics observed in other emerging countries. We want to use this special section to mark China's 40th anniversary of Chia's major rural reform and the introduction of the household responsibility system, which fundamentally transformed the China's agriculture and land systems. We hope this special section will motivate more discussions of land system change in China-related discussions in the *Journal of Land Use Science*, an important platform for land use science (Müller & Munroe, 2014) and more.

Disclosure statement

No potential conflict of interest was reported by the authors.

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