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Integrated assessment of cropping patterns under different policy scenarios in Quzhou County, North China Plain

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ABSTRACT

Agricultural land use is affected by government policies and leads to different consequences of regional sustainability. In this work, changes in cropping patterns including acreage, cropping locations and management-related environmental impacts were simulated under various policy scenarios for Quzhou County, China. This county is in China's major agricultural region, the North China Plain. Four dominant crop systems were categorized (winter wheat/summer maize, winter wheat/summer maize/spring maize, cotton, and vegetables) and analyzed, following two alternative policy scenarios that either prioritized government funding to subsidize crop production ("subsidy" scenario) or promoted advanced irrigation techniques ("technique" scenario). Input–output coefficients for all four crop systems were determined, mainly irrigation demand, yield, and price of produce, but other factors like a limited area of arable land and scarce regional water resources were also considered. For the simulation, a LINDO Inc. system was linked with the CLUE (Conversion of Land Use and its Effects) model. Temporal changes of crop systems were simulated with the LINDO system, whereas spatial dynamics of cropping patterns were simulated with the CLUE model, based on land suitability maps. The results show that crop patterns changed variably with time under the two scenarios, and water availability was the primary constraint on sustainability of land use. Under the subsidy scenario, winter wheat/summer maize/spring maize became dominant across the entire county, replacing other crop systems. In contrast, the vegetable system gradually occupied farmland surrounding the township under the technique scenario. The different policies produced opposite consequences for regional sustainability. Although a "subsidy" policy contributed to farmers' income, it did not encourage water conservation for sustainable crop production, leading to land abandonment because of water shortage. In contrast, the "technique" policy partially cut direct financial benefits to farmers, but promoted water conservation and made a substantial contribution to agricultural sustainability.

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Introduction

The sustainability of agricultural land systems is an important global issue, relevant to worldwide food supply, availability of freshwater, soil health and others (van Keulen et al., 1998; Foley et al., 2005; Guo et al., 2010). Improper land use may have serious consequences like soil degradation, pollution, or total loss of fertile arable land from uncontrolled urban development (Chen, 2007; Liu et al., 2010; Deng et al., 2011; Su et al., 2011). Agriculture on slopes can result in serious soil erosion and flooding (Shi and Shao, 2000; Feng et al., 2005; Liu et al., 2008), and large inputs of chemical fertilizers, irrigation water and other resources cause significant soil acidification and decline of the groundwater table (Fang et al., 2010; Guo et al., 2010).

The North China Plain (NCP) is the largest agricultural region in China, comprising around 18 million hectares of farmland (18.3% of the national area) (Sun et al., 2010). Before 1970, the major cereal cropping systems (wheat and maize) in this region yielded only three harvests over 2 years, because of low precipitation and poorly developed irrigation (Kröbel et al., 2010). To feed the increasing population, the Chinese government has greatly invested in construction of irrigation facilities in recent decades. The now-abundant groundwater for irrigation has increased the number of harvests to two per year. Additionally, average grain yields have doubled over the past 30 years from about 3 to 6 tons per hectare, and now the NCP delivers about 69% of the wheat, 35% of the maize, and 41% of the cotton produced in China (http://www.stats.gov.cn/tjsj/ndsj/2009/html/M1215e.htm).

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The sustainability of agricultural production on the NCP is challenged by a variety of risks. The most serious problem is water shortage (Mo et al., 2005; Fang et al., 2010). High crop productivity on the NCP relies on irrigation, especially for double cropping (Wang et al., 2001). As irrigation continually increased, the groundwater table fell about 1 m annually over the last 20 years (Yang et al., 2006; Fang et al., 2010). The largest groundwater depression in the world formed over an area of 40,000 km^2 (Li et al., 2008), and the situation will deteriorate as the same land use systems and management practices continue to dominate the region. Another potential risk is the sensitivity of crop production to farm income variations (Zhen et al., 2005). For example, the price of wheat increased 5.6-fold from 1978 to 2006, but that of vegetables increased 15.6-fold over the same period (statistical data from http://tongji.cnki.net). Today, net return is up to 20 times higher from cash crops like cotton and vegetables than from grain production (Zhen et al., 2005), causing a substantial shift away from grain crops among farmers. This land-use change will not only affect regional food security, but aggravates the water shortage because of the much greater water demand of vegetables. Apart from environmental limitations and economic interests, government policies are important in management decisions of farmers and are therefore very relevant for current land use. To maintain food security, Chinese policies support grain production by subsidizing grain farmers and facilitating advanced irrigation techniques. Since funds are always scarce, political decision makers must often decide between options. Such decisions are not easy. Therefore, an integrated assessment tool to predict farmers' responses to policy changes is essential, to find the most effective investment option for achieving long-term environmental and economic sustainability.

Since sustainability encompasses many factors from different research fields, integrated approaches are needed to simultaneously assess effects and interactions of those factors. Modeling is a useful tool to evaluate socioeconomic, political and environmental issues of agricultural systems (Uthes et al., 2010). In Europe, the Dynamic Land Use change Modeling for Common Agricultural Policy impact assessment on the rural landscape (LUMOCAP) policy support system was developed to investigate the relationship between policies, agricultural economics and land suitability, through dynamic simulation of land-use change by integrating four levels of models (van Delden et al., 2010). The system comprises models that simulate the competition for space between land uses in broad categories (agricultural land, residential areas, and others) and also crop-choice decisions for agricultural areas. The System for Environmental and Agricultural Modeling – Linking European Science and Society (SEAMLESS) is designed to focus on agricultural activities like arable cropping, grassland management, livestock husbandry and fruit-growing, along with their interactions with the environment, economy and rural development (van Ittersum et al., 2008). SEAMLESS comprises three levels of models for field, farm and market level analysis. The Land Use Planning and Analysis System (LUPAS) modeling system permits evaluation and optimization of agricultural land use by integrating crop simulation models, expert systems, GIS and multiple-goal linear programming models (van Ittersum et al., 2004; Roetter et al., 2005, 2007). A combination of the Common Agricultural Policy Regionalized Impact model with spatial downscaling module (CAPRI-Spat) and Conversion of Land Use and its Effects (CLUE) modeling framework was proposed to support integrated assessment (Britz et al., 2011). CAPRI-Spat controls global and regional economic modeling of different policy scenarios. CAPRI-Spat results are entered into the CLUE model, which provides land-use change assessment at landscape scale that can in turn be used as an input to assess environmental impacts (Britz et al., 2011). In addition to Europe, the CLUE model has been applied in China to simulate land-use change (Verburg and Veldkamp, 2001). A combination of the Agricultural Production Systems Simulator (APSIM) and ORYZA2000 rice growth model was also used in China to simulate change of crop yield under different scenarios of climate conditions, soil nutrients, variety types and management practices (Liu et al., 2013). The tools described above mainly link several independent models, and usually comprise at least one economic and one explicit land-use simulation model.

A major disadvantage for application of most available systems and tools to assessment of the sustainability of land use systems is that they were developed for European conditions. It is very difficult to simply adopt these models for assessing sustainability of agricultural areas in China. A major challenge is to distinguish the very different natural and socioeconomic situations in East Asia and Europe. A promising solution is using flexible linking between different models, which is very useful to construct custom-made modeling environments for Chinese land-use systems, along with sound model validation.

Our objective here is to study effects of various government policies on the distribution of different cropping systems at the county level, and to analyze the potential socioeconomic and environmental consequences of such policies.

Study area and datasets

Study area

Quzhou County is in the northern part of the NCP. This county is frequently selected for research by scientists because it has conditions typical of the NCP (Chen et al., 2006; Liu et al., 2006; Shen et al., 2009). A research station was established during the 1970s in Quzhou, and much long-term experimental and survey data are available. The county comprises 10 towns and has total area 67,669 ha, of which 75.9% is arable land. Average annual precipitation is 556.2 mm, which mainly falls between July and September. Summer crops include maize, millet and soybeans, which are planted after the winter wheat harvest in June. Cotton is also an annual crop, with planting at the end of April and harvesting in November (Liu et al., 2006). In 2006, winter wheat/summer maize was grown on 49.9% of the county's arable land, cotton on 30.1%, and vegetables on 13.1%.

Data sources

The land-use data used were derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images from the year 2001 (Liu et al., 2006). Original land-use data were of raster type with resolution 15 m, which were classified into seven types: woodlands, orchards, vegetable fields, non-agricultural, cotton fields, water surfaces and wheat/maize fields (Liu et al., 2006). Considering the common field size of ≈1 ha in Quzhou County and computation speed during modeling, land-use data were rasterized to 100 m × 100 m cells using the majority rasterization method (Dendoncker et al., 2008). Since urban settlements, woodlands, orchards and water bodies barely changed in the county, these land-use types were categorized into one type, that of "other" land. Land-use data were ultimately reclassified into only four land-use types (winter wheat/summer maize, cotton, vegetables, and other land).

Land suitability data mainly included soil and groundwater survey data and locations of irrigation facilities. The dataset comprised soil data of 79 sites, which were derived from a national soil survey in 1999 (Ouyang, 2004; Chen et al., 2006). Location of each site was determined by GPS, and three to five topsoil samples (0–20 cm depth) were taken from within 100 m around each site. Soil samples were analyzed for organic matter content, total nitrogen, available phosphorus, and available potassium as important soil nutrients,

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