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Multi-indicator assessment of a water-saving agricultural engineering project in North Beijing, China

Long Liang[a], Rattan Lal[b], Bradley G. Ridoutt[c], Guishen Zhao[a], Zhangliu Du[d], Li Li[a], Dangyang Feng[a], Liyuan Wang[e], Peng Peng[a], Sheng Hang[f], Wenliang Wu[a,*]

[a] College of Resources and Environmental Sciences, China Agricultural University, Beijing, 100193, China
[b] Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH, 43210, United States
[c] Commonwealth Scientific and Industrial Research Organisation (CSIRO), Clayton, Victoria, 3169, Australia
[d] Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, 100081, China
[e] Shanghai Academy of Agricultural Science, Shanghai, 201403, China
[f] Institute of Geographic Science and Natural Resources Research, Chinese Academy of Science, Beijing, 100101, China

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ABSTRACT

The Paddy Land-to-Dry Land (PLDL) program was a 10-year long (2006–2015) agricultural engineering program, initiated jointly by Beijing and Heibei Province, that was designed to increase urban water availability and improve household livelihoods in local farming communities. The program, supported by government subsidy, involved conversion of paddy (*Oryza sativa*) to maize (*Zea mays*). In this study, a range of environmental, social and economic indicators were used to evaluate the program. In relation to its primary goal of saving water, the program was considered successful, with water consumption of maize production 47% lower. The subsidy was also found to be influential in encouraging household participation. However, the small size of household farms and the small proportion of household revenues coming from agricultural production meant that the PLDL program did little to directly improve household livelihoods. Environmental indicators, assessed using life cycle assessment, showed mixed results. Although most indicators improved, some deteriorated, namely acidification and eutrophication potential. This highlights the importance of assessing environmental performance comprehensively to avoid burden shifting. Important environmental impacts could potentially have been reduced if the program had provided additional technological support to farmers. Nevertheless, the aggregated LCA results suggested that overall environmental performance was improved. The PLDL program could also be viewed as a success from the perspective that the monetarized ecosystem service benefits greatly exceeded the subsidy payment. An important spillover benefit was that participating households were able to achieve greater participation in non-farm employment, which contributed to higher household incomes and poverty alleviation. An important finding of this study is that an agricultural engineering program designed to alleviate water scarcity can have wide ranging environmental, economic and social impacts.

1. Introduction

Water resource shortage and water security are important global issues of the 21st century. Food production, social stability and sustainable development can all be impacted by water scarcity and climate change is further exacerbating the problem in many places (Chinnasamy and Agoramoorthy, 2015; Lal, 2015; He and Cai, 2016).While China has 2.81×10^3 billion $m^3\ yr^{-1}$ of freshwater supply, the 6th most in the world (Sun, 2015; Sun et al., 2016), two critical factors that threat China's sustainable development are uneven distribution of water resources and shortage of water per capita. To illustrate, the Yangtze River basin and south China has 36% of national farmland and 80% of national water resources. In contrast, north China, with around 40% of farmland, has a mere 8% of water resources (Sun et al., 2016). The global per capita availability of water resource is 8,800 m^3, but only 2,200 m^3 in China and $< 500\ m^3$ in north China (Huang et al., 2012). The per capita availability of water was $< 100\ m^3$ in 2014 in Beijing (BWA, 2015), which is far below the internationally recognized threshold of 1,000 m^3 (Huang et al., 2012). Water scarcity is threatening China's sustainable development, especially that of north China. Therefore, China must adopt appropriate strategies to address this issue.

* Corresponding author.
E-mail address: wuwenl@cau.edu.cn (W. Wu).

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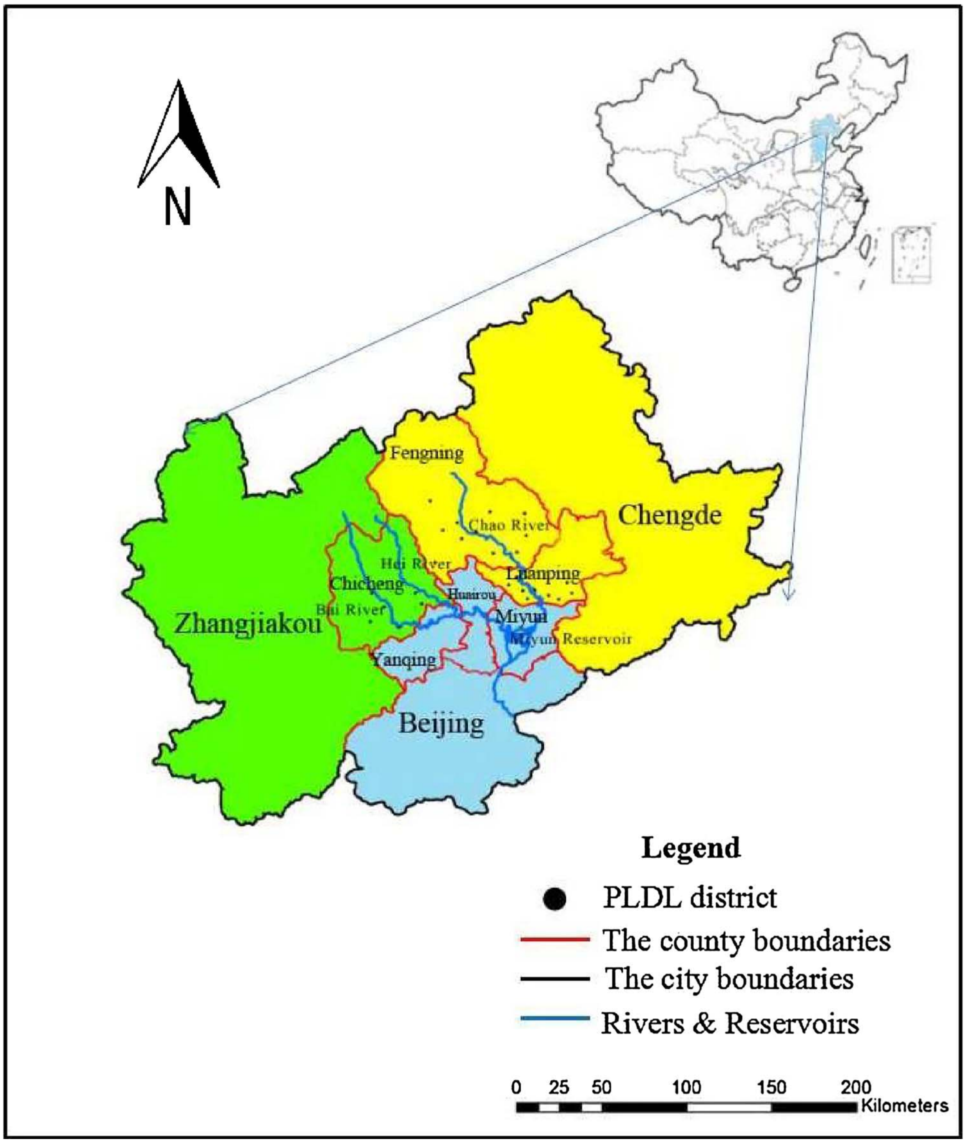

Fig. 1. Geographic location of the PLDL program.

Since 1995, a variety of projects have been implemented in the cities of Zhangjiakou and Chendeng to address water scarcity and improve the livelihoods of the people (Liu, 2012; Zheng et al., 2013; Lin et al., 2016a,b). These cities are located to the north of Beijing and are affiliated administratively with Hebei Province (Fig. 1). These programs include water-saving agricultural practices, sewage treatment, improved watershed management and the Paddy Land-to-Dry Land (PLDL) program, among others. The PLDL program was implemented over ten years (2006–2015), and involved three counties containing 15,213 households and 6,866 ha of farmland.

However, various concerns have been raised about the PLDL program. Farmers were financially incentivized to replace rice cultivation with maize, however the adequacy of the compensation and overall impact on livelihoods has been questioned (Dong and Li, 2007; Liu, 2012; Liang et al., 2013a,b; Cui, 2014; Liu et al., 2015; Lin et al., 2016a,b). Some researchers concluded that the project improved water quantity and quality (Zheng et al., 2013; Dai and Zhang, 2014). However, Liu (2012) and Liang et al. (2013a,b) reported that the implementation of the PLDL program increased loading of N, P and pesticides to water. Zheng et al. (2013) opined that increases in loading of nutrients has resulted in other environmental risks, such as high concentration of nitrates in groundwater, soil acidification, acid rains, greenhouse gas (GHG) emissions, etc. What has been lacking is a comprehensive evaluation of the PLDL program spanning the ten year period and utilizing multiple environmental and economic indicators.

The comprehensive evaluation of the impacts of agricultural ecological engineering projects, covering both the environmental and human dimensions, has become a popular research themes. For example, Sartori et al. (2005) assessed energy use and economics of a 3-year crop rotation for conservation and organic farming in NE Italy. Oudshoorn et al. (2011) explored the sustainability of future organic dairy farming systems in Denmark, by evaluating the economic and environmental consequences of three scenarios at the farm level. Andersson et al. (2015) made a social–ecological analysis of ecosystem services in two different farming systems. Based on the life cycle assessment (LCA) approach, Kamali et al. (2017) evaluated a number of environmental, economic, and social issues for different soybean farming systems in southern Brazil. Wang et al. (2014) used LCA to evaluate two different winter wheat-summer maize rotation models. Synthesis of these and other studies suggested that a comprehensive assessment, combining environmental and economic aspects, can be beneficial (Wang et al., 2014; Wang et al., 2016; Kamali et al., 2017).

The objective of this study was to make a comprehensive assessment of the PLDL program based on multiple-methods and models. Firstly, an energy efficiency analysis was conducted using an input-output methodology. Secondly, LCA was used to estimate environmental effects of