Journal of Cleaner Production 156 (2017) 41–49

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Effects of irrigation on the ecological services in an intensive agricultural region in China: A trade-off perspective

Ruihua Li [a, b], Hua Lin [c, *], Haipeng Niu [a], Yuqi Chen [b], Suxia Zhao [a], Liangxin Fan [a]

[a] School of Surveying & Land Information Engineering, Henan Polytechnic University, Jiaozuo 454000, China
[b] Key Laboratory of Land Use, Ministry of Land and Resources, China Land Surveying & Planning Institute, Beijing 100035, China
[c] School of Architectural & Artistic Design, Henan Polytechnic University, Jiaozuo 454000, China

ARTICLE INFO

Article history:
Received 13 December 2016
Received in revised form
5 April 2017
Accepted 5 April 2017
Available online 10 April 2017

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Irrigation
Ecological service trade-off
Nitrogen leaching
Nitrous oxide emission
Soil organic carbon

ABSTRACT

The quantification of the effect of irrigation on crop yields and other non-marketed ecological services (ESs) is crucial to maintain a steady increase in agricultural production while minimizing negative environmental effects. We use the modified ES trade-off concept frame to analyze the interrelationships between crop yield income and nitrogen leaching, nitrous oxide emission, and soil organic carbon (SOC) sequestration by simulating crop output and other non-marketed ESs with a process-based denitrification–decomposition model. Results show that positive trade-offs and synergies exist between crop yield income and nitrogen leaching, nitrous oxide emission, and SOC sequestration at the loam site before the irrigation index reaches 0.7. Similarly, a positive trade-off exists between crop yield income and nitrogen leaching at the sandy soil site, and a positive synergy occurs between crop yield income and SOC sequestration at the loam site as the irrigation index increases from 0 to 1. The extended ES trade-off concept frame is a beneficial approach for optimizing current agricultural irrigation management strategies to maintain sustainable agricultural development.

1. Introduction

Intensive agricultural management is being rapidly developed to address the food demand of the increasing population. With insufficient water supply (Poch-Massegú et al., 2014), irrigation has become an essential input to maintain intensive agricultural production. Cropland equipped with irrigation facilities is predicted to reach 277 million hectares worldwide by 2050 (Hannam et al., 2016) and will contribute approximately two-thirds to food increase in the future (Jamali et al., 2015). By contrast, irrigation is an important interference to agro-ecosystems, and irrigation-related environmental problems, such as nitrogen (N) leaching (Chilundo et al., 2016), nitrous oxide (N_2O) emission (Hou et al., 2016), and soil organic carbon (SOC) sequestration (Hannam et al., 2016), must be prevented. The ecological service (ES) trade-off conceptual frame provides a promising option to determine beneficial agricultural management strategies by quantifying the economic and ecological effects of irrigation to avoid or mitigate negative environmental effects. However, the trade-offs and synergy effects among ESs caused by irrigation remain unknown. Therefore, the identification of trade-offs or synergies between crop yield income and other ESs is essential to develop sustainable agricultural management strategies (Balbi et al., 2015).

A steady increase in agricultural production is necessary to address the food demands of the large population in China (Xuejun and Fusuo, 2011). The decrease in rainfall and the high drought frequency have rendered irrigation the basic support for agricultural production (Zhang et al., 2015), particularly in the North China Plain (NCP), where 73% of the cropland is equipped with irrigation facilities (Li et al., 2014). However, irrigation has been considered the main cause of N loss, groundwater contamination (Cui et al., 2012), and greenhouse gas emission from cropland (Jia et al., 2014; Qiu et al., 2011). Irrigation may deteriorate the negative effect of N fertilizer application; hence, exploring the effects of irrigation on N leaching, N_2O emission, and SOC sequestration may provide a promising direction to improve crop yield or farmer income while minimizing negative environmental effects (Molina-Herrera et al., 2016).

Numerous recent studies have examined the effect of combining N application and irrigation on nitrate leaching and N_2O emission

* Corresponding author.
E-mail address: hpu_lh@126.com (H. Lin).

http://dx.doi.org/10.1016/j.jclepro.2017.04.031
0959-6526/

given the importance of N application and irrigation in intensive agricultural production (Gholamhoseini et al., 2013; Hu et al., 2008). The proposed countermeasures concentrate on three aspects: (1) to reduce the amount of irrigation and N application (Jamali et al., 2015; Molina-Herrera et al., 2016), (2) to optimize the combination of irrigation and N application (Gholamhoseini et al., 2013; Jia et al., 2014), and (3) to change the irrigation method (Poch-Massegú et al., 2014; Zhang et al., 2016). Despite positive results in several site-specific fields, crop yield and income can remain insufficient when the proposed method is applied to other fields (Chilundo et al., 2016). Therefore, solving the old question "how much N and irrigation do I need to apply to my crop" in a broader field by determining the specific combination of irrigation and N application is difficult. Single irrigation optimization can improve crop yield income (Woli et al., 2016); hence, the solution may be more applicable if the old question is transformed into "which irrigation strategies do my crops require" (Liu et al., 2015). However, few studies have focused on increasing crop yield or income while minimizing N leaching and N_2O by improving irrigation management strategies.

Irrigation induces two opposing SOC change processes in an agro-ecosystem. The first process is increasing crop yield and residue, which promotes SOC accumulation. The second process is increasing microbial activity, which accelerates the mineralization of carbon (C) compounds and consumes the SOC stock. These processes can neutralize each other; therefore, SOC increase has a relatively low magnitude and is even negligible in irrigated cropland compared with that in rain-fed cropland (De Bona et al., 2008). Nonetheless, Giubergia et al. (2013) discovered that SOC significantly increased in irrigated cropland. The effects of irrigation on SOC dynamics remain inadequately addressed (Li et al., 2016b), and the influence of irrigation on SOC sequestration requires further validation.

A win–win strategy between agricultural income and environmental protection must be identified to achieve sustainable agricultural development. The ES trade-off and synergy conceptual frame is a good approach to increase crop yield income while achieving environmental protection (BenDor et al., 2017). When irrigation promotes crop yield at the cost of environmental degradation, such as global warming induced by the emission of greenhouse gases and groundwater pollution caused by N leaching (Chilundo et al., 2016), a negative trade-off relationship occurs. By contrast, if crop yield improves environment quality, then a positive synergy relationship exists (Wei et al., 2009). The ES trade-off and synergy conceptual frame is beneficial for synthetically understanding interrelationships among ESs, which is crucial for developing sustainable agricultural management strategies (Wei et al., 2009). Therefore, the ES trade-off approach has been extensively advocated and is regarded to be promising in developing sustainable agricultural management strategies (Antognelli and Vizzari, 2017). However, although the trade-off among ESs has been a focal topic in ecology research (Lautenbach et al., 2017), the simultaneous quantification of various ESs remains a challenge. Denitrification–decomposition (DNDC) is a process-based model that provides an opportunity to overcome the aforementioned problem. Embedded with detailed N and C biochemical transformation equations (Qiu et al., 2011), the DNDC model exhibits an advantage to simulate the effects of farm management options on the dynamics of N and C in agro-ecosystems (Li et al., 2014). After extensive validation in numerous agricultural fields worldwide (Qiu et al., 2011), the DNDC model is recognized as a useful tool that provides N and C change information for efficient agricultural management strategies (Cardenas et al., 2013).

On the basis of simulated ESs using the DNDC model in an intensive agricultural region (i.e., NCP, China), we continuously pursue alternative agricultural management strategies instead of currently increasing N application to enhance agricultural yield income while minimizing negative environmental effects. This study aims to identify the effects of irrigation on N leaching, N_2O emission, and SOC dynamics, as well as to quantify trade-off or synergy relationships between crop yield income and N leaching, N_2O emission, and SOC sequestration. This study is expected to provide useful information for developing sustainable agricultural strategies.

2. Study area and methods

2.1. Study area

The study area is located in Xinzheng County, an intensive agricultural region in NCP (Fig. 1). This region features a semi-arid, sub-humid, warm temperate, continental monsoon climate. The annual average temperature is 14.1 °C, and the annual average precipitation is 713.8 mm (Soil census office of Xinzheng county, 1983). On the basis of basic principles, such as high input and output of energy and matter, monotonous crop systems, and the objective of increasing intensive agriculture yield (Lares-Orozco et al., 2016), the study area is a typical intensive agricultural region with an average N fertilizer rate of 265.5 kg N/ha·year, an agricultural mechanical power of 17.13 kw/ha, and an irrigated land area accounting for 90% of the total cropland area. The study area has two main types of soil (loam and sandy) and two general cropping systems (winter wheat–maize and wheat–peanut). At present, N fertilizer and irrigation input are the primary approaches used to obtain high crop yield (Zhang et al., 2015).

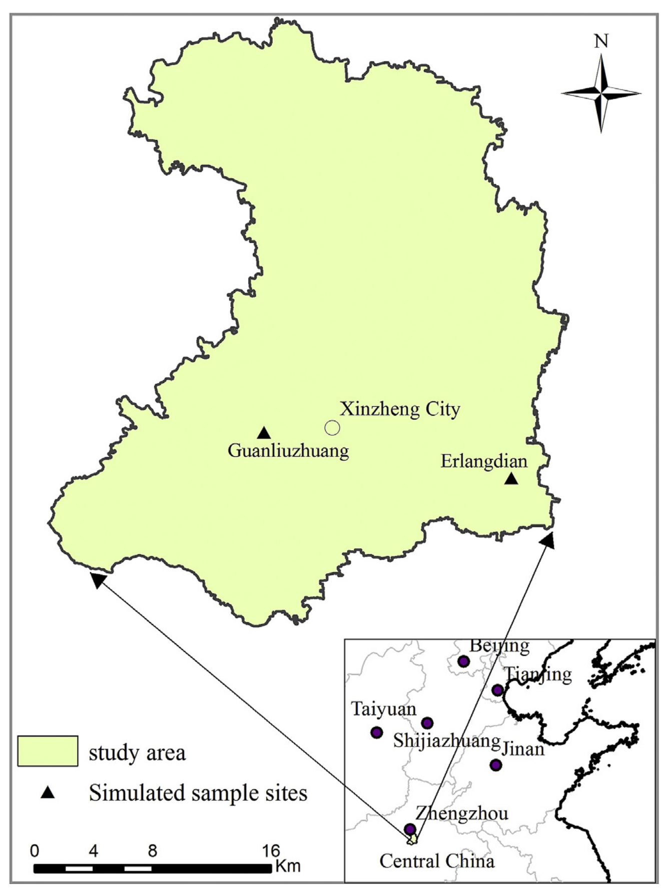

Fig. 1. Location of the study area.