Ecological Engineering 106 (2017) 620–628

Contents lists available at ScienceDirect

Ecological Engineering

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

Research paper

Inventory of apparent nitrogen and phosphorus balance and risk of potential pollution in typical sloping cropland of purple soil in China—A case study in the Three Gorges Reservoir region

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ARTICLE INFO

Article history:
Received 2 November 2016
Received in revised form 19 June 2017
Accepted 20 June 2017
Available online 5 July 2017

Keywords:
Purple soil
Sloping cropland
Nutrient balance (N and P balance)
Three Gorges Reservoir region

ABSTRACT

Agricultural non-point source pollution of nitrogen (N) and phosphorus (P) exerts a key influence on aquatic environment safety. Purple soil and sloping cropland make up the highest proportion of all soil types and land-use pattern in the up and middle reaches of Yangtze River. Therefore, a study on nutrients balance for risk assessment in sloping cropland of purple soil will contribute to the understanding of the causes of eutrophication in aquatic environment in China. The Organization for Economic Cooperation and Development (OECD) have developed the soil surface nitrogen balance indicator to estimate potential N pollution through measuring the difference between agricultural inputs and outputs. Based on this indicator, we established a framework, a methodology, and a database for calculating the N and P balance for typical sloping cropland of purple soil in TGR region, and evaluated the impact of nutrients balance on agricultural production and environment. For the basic watershed of Xinzheng unit, which mainly consists of sloping cropland of purple soil, N and P inputs were 755 and 107 kg ha^{-1} a^{-1}, with 68.4% of N and 56.1% of P inputs originating from chemical fertilizer. The N and P outputs were 482 and 60 kg ha^{-1} a^{-1}; the N in crops and P in straw accounted for 23.5% and 45.6% of total outputs, respectively. The N and P surplus intensities were 273 and 47 kg ha^{-1} a^{-1}, much higher than the respective risk thresholds of 180 kg ha^{-1} a^{-1} and 35 kg ha^{-1} a^{-1}, indicating a risk of N and P potential pollution in aquatic environments via cropland discharge. It is essential to utilize proper fertilization methods and improve fertilizer use efficiency in sloping cropland of purple soil in China.

1. Introduction

Nitrogen (N) and phosphorus (P) levels have increased dramatically worldwide from the 19th century due to anthropogenic activities such as N application of fertilizer, livestock and poultry breeding, combustion of fossil fuels (Galloway et al., 2004; Liu et al., 2006). It induces a series of eco-environmental problems such as global warming, acid rain, underground water pollution and surface water eutrophication locally, nationally and globally (Yan et al., 2011; Vitousek et al., 1997). Non-point-source N and P, with the characteristic of random occurrence, among other factors, uncertain in drainage and migration pathways (Zhu et al., 2012), has become a great challenge to the global aquatic environment. Therefore, it is urgent to identify the source, sink and transportation pathways of the pollutants. Furthermore, the calculation of inputs, outputs and nutrient balance is essential to source identification and pollution reduction.

Nutrient balance model, which based on the principle of mass balance, has been used to calculate the inputs and outputs of nutrients in cultivated land, identify nutrient surpluses or deficits, and determine the effects of nutrient inputs on soil fertility, agricultural production and aquatic environments. The surface soil nutrient balance indicator proposed by the Organization for Economic Cooperation and Development (OECD) taking the land plots as its study subjects, has a simple and intuitive structure (OECD, 2001). As one

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http://dx.doi.org/10.1016/j.ecoleng.2017.06.044
0925-8574/

of the most important environmental indicators for agricultural regions in countries belonging to the OECD, it has been used to develop policy guidelines and to estimate N balance in various regions and countries (Salo and Turtola, 2006; Dijk et al., 1996; Máthé-Gáspár et al., 2012; Sassenrath et al., 2013). N and P are considered closely related to eutrophication, yet, emphasizing on N balance, the indicator and related researches have rarely been conducted and applied to investigating P balance (Tittonell et al., 2005; Wang et al., 2014).

Previous studies have been conducted mostly on national, regional, or county scales. Lack of distinction of the balance coefficients among watersheds of different spatial scales might contribute to deviation in estimation results. And different parameters might be employed even when the same object is studied. For instance, (Chen and Chen, 2007) reported that 30% (urban) and 93.7% (rural) of N in human excrement was recycled in cropland, whereas the number reported by Liu et al. (2008) was 40% in the rural area and by Bao et al. (2006) 40% (animal and human). However, according to a preliminary field survey conducted for this study in the small watershed, 85% of human excrement was recycled. Accordingly, precise model parameters which are consistent with the spatial scale are highly required.

Although many studies focused on N balance of cropland in flat terrain such as paddy, red soil and non-irrigated cropland, few studies have been conducted in sloping cropland of purple soil. Purple soil is widely distributed in Sichuan Basin, Yunnan-Guizhou Plateau, the middle and lower reaches of Yangtze River in China. It is the most abundant of all soil types in the upstream of Yangtze River (Zheng and Chen, 2003). Sloping cropland, a kind of agricultural land with a 6°–25° gradient, is characterized by a low yield and a high risk of soil erosion. Sloping cropland of purple soil makes up 78.7% of total cropland area in the Three Gorges Reservoir (TGR) region. It is the major non-point source of agricultural N and P pollution because of its light texture, thin layer and high porosity (Jia et al., 2007; Ge et al., 2007). Given the key role of TGR in the aquatic environment safety of the middle and lower reaches of the Yangtze River in China, the significant amount of non-point source nitrogen (N) and phosphorus (P) pollution produced by the intensive agricultural cultivation within TGR region is a concern as they have adverse effect on the aquatic environment safety (ArandaCirerol et al., 2011). Studies on nutrients balance in sloping cropland of purple soil are very helpful for identifying and managing N and P sources and pathways.

In this study, we focus on nutrients balance in the basic watershed of Xinzheng unit (from hereon, Xinzheng watershed). It represents a typical agricultural land-use pattern in TGR region, with its dominant practice of sloping cropland of purple soil. Household surveys, in-situ experiments, and literature review were employed to acquire the necessary materials and parameters for N and P balance calculations. We calculated N and P inputs and outputs, and estimated the potential risk of pollution from sloping cropland of purple soil, to provide a scientific basis for nutrient balance, and to present some strategies for aquatic environment management and nutrient loss prevention in TGR.

2. Materials and methods

2.1. Study area

The area under study, Xinzheng watershed (Fig. 1; 108°10′E 30°25′N), which is in the town of Shibao (Zhongxian County, Chongqing, China), is located in the center of TGR region. It is characterized by a gently rolling terrain, with a scattering of small flat plots. The region has a sub-tropical southeast monsoon climate, with an average annual temperature of 19.2°C, an annual high temperature of 42.1°C, an average annual rainfall of 1150 mm and a frost-free period of about 320 days per year. Abundant sunshine makes this area suitable for cultivating a variety of crops. The main farm types include orchards at higher elevations, paddies and non-irrigated land at lower elevations, and paddies at the lowest elevations, representing a typical land-use pattern for TGR region. And in this area, the higher, lower and lowest elevation corresponds to the upper, lower and bottom position of the slope, respectively. The navel orange trees (the main fruit trees) are grown in the orchards, and pastures are grown under them in the orchards; maize, wheat, oil rape and vegetables are grown in the non-irrigated cropland; rice is grown in the paddies. The population, area, livestock population, and other information are shown in Table 1.

2.2. Methods

2.2.1. Model construction

According to survey results, indexes of P input and output were added into the OECD soil N balance model. The inputs and outputs of the nutrient balance model are illustrated in Fig. 2. N and P inputs include chemical fertilizer, organic fertilizer (human and animal excrement, straw, and organic waste returned to cropland), seeds, atmospheric deposition, symbiotic and non-symbiotic biological N fixation and parent rock input. N and P outputs include harvested crop (sold crops, subsistence food, and feed), erosion, leaching, runoff, harvested straw (straw returned to cropland, straw fuel, etc.), ammonia volatilization and denitrification. Among them, biological nitrogen fixation, ammonia volatilization and denitrification only exist in the N recycle.

2.2.2. Calculation methods

Apparent N and P levels were calculated as follows:

$$M = \sum_{i=1}^{n} N_{Ii} - \sum_{j=1}^{m} N_{Oj} \quad (1)$$

$$I = M/AL \quad (2)$$

where M is the apparent N or P balance (positive and negative M indicates a surplus and a deficit, respectively); N_I and N_O are N or P input and output amounts, respectively; i is the i^{th} input; j is the j^{th} output; n and m are the number of input and output types; I is the apparent N or P balance intensity; and AL is cropland area.

2.2.3. Calculation parameters

Calculation parameters, indexes and sensitivity coefficients used in the model are shown in Table 2.

The model parameters were categorized into three types (Table 2). The first type was essential data determined by surveys. (i) Human population, permanent resident population, crop types, cultivated area, amount of chemical fertilizer and pesticide, amount of external purchased food and feed, the types, population, and feeding cycle of livestock and poultry were obtained by the watershed scale survey during June and September 2009, with a sample size of 127 households and a survey rate of 97%. The organic fertilizer and treatment methods of organic fertilizer, yield of crop and straw, treatment method of crop and yield were also obtained by the survey during June and September 2009, with a sample size of 127 households and a survey rate of 97%. (ii) The crop yield, straw yield, proportion of straw returned to cropland, proportion of straw used as fuel, seed rate, the amount of self-use and sold crops were further obtained by the survey of plots. Three plots of orchard, five plots of non-irrigated cropland and one plot of paddy were selected randomly according to the survey result of the 127 households. The farming activities of peasants and related infor-