Sustainable Environment Research 26 (2016) 124–130

Contents lists available at ScienceDirect

Sustainable Environment Research

journal homepage: www.journals.elsevier.com/sustainable-environment-research/

Original research article

Estimating the gross budget of applied nitrogen and phosphorus in tea plantations

Chi-Feng Chen [a], Jen-Yang Lin [b, *]

[a] Department of Natural Resources, Chinese Culture University, Taipei 11114, Taiwan
[b] Department of Civil Engineering, National Taipei University of Technology, Taipei 10608, Taiwan

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form
9 November 2015
Accepted 8 January 2016
Available online 12 April 2016

Keywords:
Best management practices (BMPs)
Fertilizers
Nitrogen and phosphorous distribution
Tea plantations

ABSTRACT

To increase crop yield, high fertilizer application rates have generally been used. The residual fertilizers potentially become a source of diffused pollution, and degrade soil and water quality. Such nonpoint source pollution is a major threat to reservoir eutrophication. The best management practices (BMPs) are usually used to prevent eutrophication; however, the environmental distribution of the applied fertilizers has not been understood properly. This could lead to a biased assessment of the rational quantity of nitrogen and phosphorous applied and the selection of BMPs. A field investigation of 32 plantations and 4 forests in the Feitsui Reservoir watershed, Taiwan, was conducted. Storm runoff water and soils were sampled, and a mass balance was used to demonstrate the gross nutrient budget. The results showed that when applying fertilizers of 2700 kg ha^{-1} in tea plantations only 18.3% of applied nitrogen and 5.5% of applied phosphorus were utilized by tea plants. Less than 5% of applied phosphorus was released in storm runoff, and more than 90% remained in the field. Approximately 30% of the nitrogen was lost through storm runoff, and 52% was stored in the soil mass. Therefore, reducing fertilizer application was recommended as the principal BMP, and collecting and treating storm runoff was suggested for controlling nitrogen pollution. The current management of soil erosion is an efficient measure for controlling phosphorus pollution.

1. Introduction

Nonpoint source pollution control is a key issue in watershed management, especially for avoiding eutrophication in reservoirs and lakes. Nonpoint source pollution is diffuse pollution and is dominated by type of land use. Storm events trigger nonpoint pollution, as pollutants accumulate during dry days are flushed away and transported to the receiving water body by surface runoff. The characteristics of accumulated pollutants are dependent on the type of land use. For example, heavy metals might accumulate on urban roads, sediment from soil erosion of construction sites, and nutrients are flushed from agricultural and urban lands. Among the different types of land, croplands where fertilizers are applied are of particular concern [1–3].

To increase crop yield, high fertilizer application rates have generally been used. However, a high fertilizer application rate does not always increase crop yield proportionally, and residual nutrients might accumulate in soil and distribute in the environment [4]. Frequent fertilization can lead to the excessive application of nutrients, which either flow out with runoff or remain as surplus in the soil, potentially leaching into the groundwater. Nutrient leaching can degrade soil and water quality [5–9]. Tea requires a particular growth environment that includes acidic soil and high moisture [10]. In Taiwan, tea plantations are located in the upper regions of watershed, and some are located in areas that are a drinking water source. Therefore, the impact of nonpoint source pollution from tea plantation on water quality must be taken into consideration.

Many studies have confirmed the relationship between the use of fertilizers on tea plantations and polluted water and soils. For example, Nagumo et al. [8] studied cases in Japan and concluded that increasing the area devoted to tea resulted in a significant increase in the total nitrogen (TN) concentration in the basin. In China, Liu et al. [7] suggested replacing conventional chemical

* Corresponding author.
E-mail address: jylin@ntut.edu.tw (J.-Y. Lin).
Peer review under responsibility of Chinese Institute of Environmental Engineering.

http://dx.doi.org/10.1016/j.serj.2016.04.007
2468-2039/

fertilizers with organic or slow-release fertilizers in the tea fields to reduce N and P losses. In Kenya, Maghanga et al. [9] also verified that fertilizer application on tea plantations contributed to high nitrate levels in the receiving river. In addition to surface water, Han et al. [6] tested tea soils and found high nitrogen application is the cause of nitrate in tea soils. Sainju et al. [4] reviewed studies and concluded that nitrogen fertilization can increase soil organic carbon and nitrogen concentration. Both surface runoff pollution and land or soil pollution present significant potential for damaging water quality. However, such associated sampling is always neglected and the base data are still rare [5,11]. The causal relationship between fertilizer application and surface water or soil pollution is realized, but the complete picture of the distribution of the fertilizer nutrients is not understood. The fraction of applied nitrogen and phosphorus in storm runoff, soil, or plants has not been estimated. Owing to the lack of information, nonpoint source pollution cannot be controlled completely. The performance of best management practices (BMPs), especially the structural BMPs, is often assessed solely by the improvement in quality of runoff, and the residual pollutants remaining in the environment are ignored. This assessment might be biased and not accurately reflect the actual situation.

Nonpoint source pollution contributes to more than half of the pollution in most upstream watersheds in Taiwan [12–14]. The Feitsui Reservoir supplies drinking water to more than 5 million people in Taipei, the capital city of Taiwan. The primary objective in managing the quality of its water is to avoid eutrophication, and in this watershed, potential pollution from tea plantations is the target [11,13,14]. This study aimed to clarify the water and soil quality affected by tea plantations and to capture the distribution of nitrogen and phosphorus fertilizers. A large-scale sampling scheme was implemented, and the use of fertilizers, the amount of tea yields, and tea leaf analysis were surveyed to clarify the mass flow. The understanding of pollution distribution of applied nitrogen and phosphorus should be beneficial in assisting and advancing the efficiency of nonpoint pollution BMPs.

2. Materials and methods

2.1. Study area

Over the past several years, the water quality in Feitsui Reservoir has been controlled to eliminate eutrophication. However, increasing levels of total phosphorus (TP) imply that nonpoint source pollution remains a challenge that needs to be overcome. Nonpoint source pollution from tea plantations is of particular concern because the tea industry is important to the economy in this area [14,15]. Approximately 6.6% of the land is dominated by tea plantations [16], and most of these plantations are located in 3 subwatersheds: the Baishin, Jingualiao, and Daiyujue watersheds, where export TP loadings are high [17]. The land use in the 3 subwatersheds is listed in Table 1. The most prevalent type of land use in the 3 subwatersheds is forest, with agricultural lands occupying less than 10%, and 75% of the agricultural lands are tea plantations. The subsequent sampling tasks in this study were performed in these subwatersheds.

Table 1
The land use of major subwatersheds in the Feitsui Reservoir watershed.

Land use	Subwatershed		
	Baishin (ha)	Jingualiao (ha)	Daiyujue (ha)
Forests	10,638 (77.9%)[a]	2164 (89.5%)	4658 (91.0%)
Waterbodies	900 (6.6%)	11 (0.4%)	57 (1.1%)
Crop land	1317 (9.6%)	182 (7.5%)	258 (5.0%)
Tea plantations	1135 (8.3%)	145 (6.0%)	157 (3.1%)
Urban	258 (1.9%)	20 (0.8%)	52 (1.0%)
Grassland	546 (4.0%)	41 (1.7%)	94 (1.8%)
Total area	13,658 (100%)	2418 (100%)	5119 (100%)

[a] Percentage of land area.

In this area, tea is harvested twice a year and usually in spring and winter and the total harvest amount is approximately 2700 kg ha^{-1}. The nitrogen, phosphorus, and potassium contents in tea leaves are 4–6, 0.25–0.4, and 1.5–2.1%, respectively [18]. Several fertilizers are applied in this area; No. 1 (Taiwan Fertilizer Co.) and No. 42 (Taiwan Fertilizer Co.) compound fertilizers are the most commonly used. The percentages of nitrogen, phosphorus, and potassium in No. 1 and 42 compound fertilizers are 20, 5, 10% (20-5-10) and 23, 5, 5% (23-5-5), respectively. In addition to the compound chemical fertilizers, organic fertilizers have been promoted in recent years.

2.2. Sampling methods

2.2.1. Soil sampling and analysis

Forty soil samples were collected from 32 tea plantations, and four from 4 forests. Fig. 1 depicts the sampling site locations. The samples from forests were used as background data. Among the 32 tea plantations sampled, storm water was also sampled at 4 sites. All soil samples were collected after the application of fertilizers in May and August, 2009.

The soil sampling procedure followed the standard operating procedure provided by Council of Agriculture (COA), Executive Yuan, Taiwan. One soil sample was collected from each site; it was taken from the center of the diagonals of a tea plantation assuming soil homogeneity in the site. However, in sites where storm water also was simultaneously sampled, 3 soil samples were collected, i.e., two additional samples were taken along the diagonal line. One kg of soil was collected at a depth of 0–10 cm, and > 500 g of soil was sampled to a depth of 0–20 cm. All soil samples were sealed and delivered to a certified laboratory on the same day. Eleven soil parameters were analyzed: pH, cation exchangeable capacity, organic content, texture, water content, available phosphorus (PO_4^{3-}), TP, ammonia (NH_4), nitrate (NO_3), TN, and exchangeable potassium.

2.2.2. Sampling and analysis of storm water runoff

Runoff from four tea plantations were sampled in 2009, and each site collected a total of 5 storm events and 1 dry day event. In the four tea plantations, soils were sampled as well. In order to increase the runoff sample data, the results of water quality monitoring in 2008 was complemented to the runoff analysis. In 2008, 8 tea plantations were sampled; in each field, samples were collected on 5 storm days and on 4 dry day events. The dry day samples were used as contrast data. Storm runoff was collected when the cumulative rainfall reached 5 mm. Random sampling of storm water runoff was conducted during rainfall periods at the outlet of the onsite drainage channel. Because the tea plantations are private properties, it is difficult to set up equipment to measure runoff flow. When calculating the mass flow of nitrogen and phosphorus, runoff is obtained from rainfall data and the rational equation is used. The details are explained in Section 2.3.

Several properties of the collected water samples were analyzed, including suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and different types of nitrogen and phosphorus compounds. The pH of the runoff was tested in the 2009 program to assess acidification. Because our experience in 2008 indicates that BOD was less in runoff, we retained COD analysis but excluded BOD analysis in the 2009 samples.