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Nutrition loss through surface runoff from slope lands and its implications for agricultural management

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ABSTRACT

Agricultural land use on slope areas is susceptible to nutrition loss via surface runoff, which would result in negative impacts on downstream waters. However, the linkage between nutrition loss and off-site crop production has been rarely reported. A study was conducted in a small independent agroforestry watershed in subtropical hilly terrain of China. Nutrition loss via surface runoff was measured from cropland, tea garden, citrus orchard, and natural woodland on a slope area. Grain production of rain-fed uplands and irrigated rice paddies were also investigated. Results exhibited that the runoff and associated nutrient loss were substantially affected by land use patterns. In general, the cropland generated the highest runoff and associated nutrient loss, followed by tea garden, citrus orchard, and woodland. Despite of land use patterns, the descending order of nutrient elements losses was: $Ca^{2+} > K^{+} > SO_4\text{-}S >$ TN (total nitrogen) $> Mg^{2+} >$ TP (total phosphorus). Irrigated rice paddies had a higher level of self-sustainability of grain production compared with rain-fed uplands, which should be partially attributed to the nutrients input from irrigated water. The results imply that the runoff harvesting for irrigation, especially the runoff harvesting from agricultural land use patterns, can increase crop production with extra nutrition input by irrigation and reduce nutrition load to downstream waters.

1. Introduction

Hilly areas of South China, with rich water and heat resources, are mainly distributed in the subtropical monsoon region, covering a total area of 134,300 km^2 (Ouyang et al., 2013). These areas abound in timber, fruits, tea, and grain. With continuous growth in population, the demand for agricultural products has become increasingly larger. However, the replacement of natural vegetation by agriculture often results in increase of water erosion (Kateb et al., 2013), a driving force for nutrient migration to surface waters.

Hilly landscape comprises various watersheds in sizes and shapes, where slopes account for a large proportion. Many studies have focused on water erosion on sloping cropland that is highly susceptible to water erosion due to extensive soil disturbance (Bouraima et al., 2016; Reza et al., 2016; Vaezi et al., 2017a; Zhang et al., 2016). However, few studies have been conducted in orchard and tea ecosystems in south of China, and nutrition loss via surface runoff is rarely reported. Land use patterns affect canopy cover, surface litter, and soil physical properties, and consequently affect the runoff and soil erosion processes and associated nutrition loss (Dagnew et al., 2017; Jin et al., 2009; Montenegro et al., 2013; Zuazo and Pleguezuelo, 2008). Therefore, the magnitude of nutrition loss varies according to land use patterns.

The nutrition loss via runoff not only represents an important pathway of soil degradation, but also leads to negative impacts on surface waters (Zhu et al., 2012a). The understanding of hot spots of nutrition loss from agricultural land use patterns will be conducive for non-point source pollution control (Zhu et al., 2012b). For example, runoff harvesting for irrigation can give priority to runoffs which are relatively rich in nutrient content. Increasing efforts have been made to control N and P loss in agricultural land, such as in situ water harvesting techniques (Grum et al., 2017), trench with grass mulch (Panigrahi et al., 2017), contour hedgerow (Xia et al., 2013), grass hedge (Wu et al., 2010), and grass filter (Al-wadaey et al., 2012). However, strategies on farm level or watershed level are rarely reported. Nutrition loss from slope lands may have positive impacts on crop production of irrigated cropland, especially for rice paddies which need extensive irrigation (King et al., 2009; Wu et al., 2017). In general, croplands are located in relatively low and flat places. In hilly terrains, the runoff from slope lands is the main source of irrigation water, and the associated nutrition loss from slope lands may be an important

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nutrition source for irrigated crop. So, integrative strategies on farm level or watershed level are urgently needed to accomplish environmental and agronomic objectives simultaneously.

This study was conducted in a small agroforestry watershed in a subtropical hilly terrain of southern China. The specific objectives of the research are: to quantify the runoff and nutrition loss from different land use patterns; to evaluate crop production of rain-fed uplands and irrigated rice paddies; to understand the linkage between crop production and nutrition loss from slope lands; and thereby to optimize agricultural management practices for crop production and non-point source pollution control.

2. Materials and methods

2.1. Site description

The experiment was conducted at Taoyuan Agro-ecological Experimental Station (28°55′ N, 111°27′ E, altitude 92.2 – 125.3 m), which covers a small watershed in a typical hilly terrain in south of China. The region is characterized by a subtropical humid monsoon climate, with an annual average air temperature of 16.5 ± 0.1 °C and precipitation of 1354 ± 98 mm from 2006 to 2010. The soil is developed from Quaternary red clay. The watershed mainly consists of gentle slopes (< 13 degrees). Generally, rice paddies are located in valleys rich in water resources. In contrast, orchard, tea garden, dry cropland, and natural woodland are in highlands or other places where water resource is inadequate for rice cultivation.

2.2. Experimental design

This study consisted of two parts: (i) surface runoff and nutrition loss from slope with different land use patterns, and (ii) crop production of rice–rice cropping systems and maize–oilseed rape cropping systems.

The runoff observation plots were established in 1995. Each plot extended from the top to the bottom of a slope (11 degrees), covering a horizontal area of 50 m × 20 m. The treatments included citrus orchard, tea garden, cropland, and natural woodland, without replicated plots due to the limitation of the slope area. The citrus orchard was planted with citrus trees, the tea garden with tea trees, the cropland with a rotation of maize–oilseed rape–sweet potato–turnip every two years, and the woodland was mainly covered by natural trees. The citrus orchard, the tea garden, and the cropland were operated under conventional local management practices. The fertilizers used in the runoff observation plots included urea, superphosphate, potassium chloride, and compound fertilizer. The annual amounts of fertilizers used in the cropland were approximately 150 kg N ha^{-1}, 25 kg P ha^{-1}, and 75 kg K ha^{-1}. The annual amounts of fertilizers used in the tea garden and the citrus orchard were approximately 75–96 kg N ha^{-1}, 22–28 kg P ha^{-1}, and 62–80 kg K ha^{-1}.

The rice–rice cropping plots were located in a valley, and were initiated in 1990, with each plot covering an area of 33 m^2. The treatments included unfertilized control (CK-Paddy) and conventional dose of chemical fertilizers (NPK-Paddy). There were three replicated plots for CK-Paddy and NPK-Paddy, respectively. The maize–oilseed rape cropping plots were located in a flat upland, and were initiated in 2006, with each plot covering an area of 46 m^2. The treatments included unfertilized control (CK-Upland) and conventional dose of chemical fertilizers (NPK-Upland). There were three replicated plots for NPK-Upland and one replicated plot for CK-Upland. The fertilizers included urea, calcium superphosphate, and potassium chloride. The annual fertilizing rates were 182 kg N ha^{-1}, 39.3 kg P ha^{-1}, and 198 kg K ha^{-1} for NPK-Paddy, and 341 kg N ha^{-1}, 91.7 kg P ha^{-1}, and 420 kg K ha^{-1} for NPK-Upland. The paddy plots were primarily flooded by irrigation during each rice season. In contrast, the upland plots didn't receive any irrigation. The general soil properties of these sites are listed in Table 1.

Table 1
General soil properties of the experimental soils.

	SOC g kg^{-1}	Total N g kg^{-1}	Total P g kg^{-1}	Total K g kg^{-1}	Available P mg kg^{-1}	pH
Slope [a]	14.1	1.63	0.31	14.3	9.1	4.7
Paddy[b]	14.1	1.78	0.55	12.6	8.7	5.4
Upland[c]	9.7	1.26	0.53	13.7	11.1	5.7

[a] Soil determined in 2000.
[b] Soil determined in 1990.
[c] Soil determined in 2006.

2.3. Surface runoff and nutrition loss

The surface runoff investigation was conducted from 2006 to 2010. There were a cement wall into soil to a depth of 50 cm and an intercepting ditch (10–20 cm in depth) at the bottom side of each plot. Surface runoff was guided by the intercepting ditch into a sedimentation tank (1 m × 1 m × 1 m) and a water tank (3 m × 3 m × 1 m). The other three sides of each plot were surrounded by a cement wall into soil to a depth of 50 cm and above soil at a height of 30 cm. The surface runoff volume was measured after every precipitation event. Water samples were filtered (0.45 μm) and analyzed by an Atomic Absorption Spectrometer (Analytik Jena AG) to determine the concentrations of K^+, Ca^{2+}, Mg^{2+}, and $SO_4{}^{2-}$. Total N and total P were determined by digestion of original water samples using the potassium persulfate oxidation method and the molybdate colorimetric method, respectively. Annual nutrient losses were obtained by multiplying the nutrient concentrations and the corresponding runoff volumes. The crop at maturity stage in each plot was hand harvested. Grain samples were oven-dried at 70 °C and weighed, with the grain yield being was determined on the basis of 14% water content.

2.4. Statistical analysis

All statistical analyses were performed with SPSS 17.0 (SPSS, Inc., USA). The effects of treatments on surface runoff and associated nutrition loss were analyzed using ANOVA with the Student-Newman-Keuls test. As there were no replicated plots for each treatment, the values of each year from 2006 to 2010 were treated as replicated values. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Runoff and nutrition loss from slope lands

Surface runoff volumes variedgreatly due to different land use patterns (Fig. 1). In general, the surface runoff from the cropland plot was the highest (194 m^3 ha^{-1} yr^{-1}), which was 1.83 times that from the tea garden plot, 3.81 times that from the citrus orchard plot, and 13.82 times that from the woodland plot. As with differences in the runoff, the nutrient losses also varied greatly due to different land use patterns (Fig. 2). In general, the nutrient loss in the cropland plot was the highest, followed by that in the tea garden and the citrus orchard plots, the nutrition loss of which was close to each other. The nutrient loss in the woodland plot was the lowest.

Losses of different nutrient elements varied greatly from one another. Under all the treatments, Ca^{2+} loss was higher than all the other five nutrient elements and varied from 0.35 kg ha^{-1} yr^{-1} in the woodland to 4.42 kg ha^{-1} yr^{-1} in the cropland. Total N, K^+, and SO_4-S losses were close to each other. Total N loss varied from 0.15 kg ha^{-1} yr^{-1} in the woodland to 0.83 kg ha^{-1} yr^{-1} in the cropland; K^+ loss varied from 0.20 kg ha^{-1} yr^{-1} in the woodland to 1.36 kg ha^{-1} yr^{-1} in the cropland; SO_4-S loss varied from 0.11 kg ha^{-1} yr^{-1} in the woodland to 1.02 kg ha^{-1} yr^{-1} in the cropland. Total P loss was the lowest among different nutrient elements, and varied from 0.01 kg ha^{-1} yr^{-1} in the