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Protection Methods to Reduce Nitrogen and Phosphorus Losses from Sloping Citrus Land in the Three Gorges Area of China

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ABSTRACT

The increased application of chemical fertilizers in citrus orchards and the non-point source nitrogen (N) and phosphorus (P) diffusion threaten the fresh water quality of the Three Gorges Reservoir area of China. A 10-year field trial on sloping citrus lands was conducted to evaluate five protection methods for reducing N and P losses: 1) intercropping with perennial white clover (CW); 2) straw mulching of the soil surface (CS); 3) intercropping with yellow daylily contour hedgerows (CH); 4) an impermeable membrane buried in the soil along the contour lines (CM); and 5) intercropping with a rotation of wheat and peanut (CWP). An area of conventional citrus management was also maintained as the control (CK). The results showed that CM and CH were the most effective methods for reducing surface runoff. The sediment yield were reduced at the highest rate by CW and CH and was also significantly reduced by CS. Reduced runoff volume and sediment yield were the crucial mechanism for the reductions in N and P losses. Compared with the control, CW, CS, CH, and CM reduced annual runoff by 9%, 13%, 25%, and 30%, sediment yield by 77%, 55%, 71%, and 28%, N loss by 10%, 23% 36%, and 37%, and P loss by 39%, 31%, 27%, and 25%, respectively. CW, CS, CH, and CM were effective in reducing N and P losses from the sloping citrus land. However, over the long-term, surface soil nutrient accumulation in CW, CS, and CH diminished the benefit of those methods in reducing N and P losses. In addition, CWP increased soil erosion and nutrient loss, which showed that citrus intercropping with other crops was an unsuitable method for citrus sloping land in the Three Gorges area.

Key Words: contour hedgerows, impermeable membrane, intercropping, runoff, sediment, straw mulching

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INTRODUCTION

The Three Gorges area (TGA), covering an area of 55 800 km^2, extends along the Yangtze River from Yichang in Hubei Province to Chongqing, China, across middle and low mountains, with elevations ranging from 175 to 2 797 m. TGA is located in a subtropical zone with a continental monsoon climate. In the area with elevation below 500 m, the annual average temperature is 17–19 °C, the average available temperature ($\geq$ 10 °C) totals about 5 000–6 000 °C, and the annual precipitation ranges between 1 140 and 1 200 mm. The major soil type on arable land of TGA is purplish soil developed on folded silicoclastic rocks and classified as Inceptisol according to the USDA Soil Taxonomy. The vegetation varies with altitude, and the typical vegetation below 500 m in elevation is evergreen broadleaf forest, evergreen coniferous forest, and deciduous coniferous forest. The ecological conditions are favorable for citrus, which is also a traditional agricultural product in this region. However, a dense population and shortage of arable land in this region have resulted in deforestation and utilization of unsuitable areas for crop production. From the 1950s to the 1990s, many lands with steep slopes were put into use for growing rice, wheat, corn, and sweet potato due to the demands for food production. Intensive farming with frequent tillage has caused heavy soil erosion and serious deterioration of the sloping land (Wei *et al.*, 2008). Consequently, more than 20% of the arable land had a gradient > 25° and about 54.6% of the eroded area was covered with soils less than 25 cm in depth (Xu, 2007). Since the start of the Three Gorges Project in the 1990s, substantial attention has been paid to eco-environmental protection of this region and the economic situation of the inhabitants. One of the important initiatives is to identify the best way to increase and stabilize employment for the residents and to opti mize the agricultural land use. To avoid frequent tillage, large areas of slopping land below 500 m in ele-

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vation were converted to citrus orchards, an increasingly profitable business for many migrants in TGA in recent years. The total area of citrus production around the reservoir is now approaching 200 000 ha.

In general, the citrus production not only ensures continuous vegetation on the land, but also results in less soil erosion than crop production (Zheng and Zhang, 2006). However, Geißler *et al.* (2012) claimed that during rainfall events, the tree canopy drops were even more erosive than the rain drops of standard size, which would increase the runoff volume and sediment yield. Another concern is that nutrients may migrate from the citrus orchards to the nearby reservoir due to regional increasing total input of chemical nitrogen (N) (Xu *et al.*, 2009), which may have already contaminated the nearby fresh waters in TGA (Zheng and Zhang, 2006; Lin *et al.*, 2010). Since the closure of the dam in 2003, annual algae blooms have been observed in some tributaries (Cai and Hu, 2006; Li *et al.*, 2008), and large amounts of sediment entering the TGA were trapped in flood seasons (Xu and Milliman, 2009). Therefore, measures must be taken to prevent soil and nutrient losses from citrus orchards. Some proven effective measures for food cropping in sloping land include terraced fields, contour hedgerows, and straw mulching (Xia *et al.*, 2007a; Lin *et al.*, 2009; Liang, 2010). Recently, a two-year experiment has been conducted to explore whether soil mulching (straw or plastic film mulch) methods reduce soil and nutrient losses from sloping citrus land at Danjiangkou Reservoir near TGA (Liu *et al.*, 2012). However, there is no comprehensive report about the effect of the protection methods for sloping citrus land, nor do reports consider this issue over a more extensive period of time. This study was conducted in a citrus orchard to analyze the efficacy of protection measures for reducing rainfall runoff, sediment, and N and phosphorus (P) losses, in order to understand the mechanisms of reduction in soil and nutrient losses and to improve management practices in citrus orchards to minimize soil and nutrient losses.

MATERIALS AND METHODS

Site description

This study was carried out at the Zigui Eco-Environmental Monitoring Station (ZEMS), one of the main stations of the Three Gorges Project Ecology and Environment Monitoring Network, located at Shuitianba Town (31°4′ N, 110°41′ E, 220 m above sea level), Zigui County, Hubei Province, Central China. Approximately 50 km upstream of the Three Gorges Dam, ZEMS is located near the reservoir. The mean annual temperature is 18.2 °C, with extremes of −3.0 and 42.9 °C. The mean annual precipitation is 940.3 mm, with 80% falling between April and October. Zigui County is a typical citrus-producing county with 14 000 hm^2 citrus orchards on sloping land and a citrus production of 200 000 t $year^{-1}$. With an increasing percentage of the land being used for citrus cropping, the amount of chemical fertilizers applied increases at a correspondingly brisk rate in the last decade, exacerbating the risk of agricultural non-point source pollution. Since 2003, as one of several tributaries of the Yangtze River in Zigui County, the Xiangxi River has been suffering from eutrophication and algal blooms (Cai and Hu, 2006; Li *et al*, 2008). Observations as part of a typical citrus-growing catchment program of ZEMS revealed that the total runoff N concentration was 3–18 mg L^{-1} and the total runoff P concentration was 0–2 mg L^{-1}, which may be mainly due to non-point source N and P diffusion from citrus sloping land. Therefore, reducing soil and nutrient losses from the citrus sloping land is crucial for sustainable management of the fresh water systems of the Yangtze River in TGA.

Experimental design

Six treatments plots were set up in a representative area with a 25° slope in TGA in 2000; each plot was 5 m in width and 10 m in slope length. Single parcels were separated by precast cement plates. All parcels were filled with a 60 cm-layer of the same soil and were allowed to settle for 1 year. The soil used was a silt loam developed from purple rock. Organic matter, total N, and total P contents were all very low, but total potassium (K) content was high (Table I). At the low end of each plot, an outlet was installed to form a 1-m^3 collection tank equipped with a vertical scale meter.

In 2001, navel citrus trees were planted in each plot in three rows along the contour lines with two trees per row (3.0 m× 2.5 m). The treatments included: 1) interplanting with perennial white clover (CW); 2) straw mulching of the soil surface (CS) with wheat straw applied evenly in June after the wheat harvest at an average annual rate of 27.3 Mg hm^{-2} $year^{-1}$; 3) intercropping with yellow daylily contour hedgerows (CH) in three 20-cm-wide rows at intervals of 3 m from the bottom of the plot; 4) an impermeable membrane (CM) buried 60 cm in the soil along the contour lines between navel trees to prevent soil water loss by lateral seepage; 5) intercropping with a rotation of wheat and peanut (CWP), where wheat was sown in November and harvested in May and peanut was sown in June