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Land-use changes from arable crop to kiwi-orchard increased nutrient surpluses and accumulation in soils

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ABSTRACT

The potential environmental risk associated to nutrient surpluses after changing arable crops to kiwi-orchards was assessed in the Yujiahe catchment of Shaanxi, China. This was achieved by surveying 242 kiwi-orchards and 21 croplands and determining their nutrient inputs and outputs as well as the soil nutrient status for the over 2 years. The total inputs of nitrogen (N), phosphorus (P) and potassium (K) from fertilizers, manures, deposition, and irrigation in kiwi-orchards were 1201, 268 and 615 kg ha^{-1} yr^{-1}, respectively, which were higher than the rates of 425, 59 and 109 kg ha^{-1} yr^{-1} in wheat-maize fields. The mean annual apparent nutrient surpluses in kiwi-orchards were 1081 kg N ha^{-1} yr^{-1}, 237 kg P ha^{-1} yr^{-1} and 491 kg K ha^{-1} yr^{-1}. Within comparison to the croplands, the soil organic matter (SOM) and total N (TN) in the topsoil (0–20 cm) increased in kiwi-orchards, and soil pH decreased. The average contents of Olsen-P, and available K in 0–20 cm soils of the orchards were 86 mg kg^{-1}, and 360 mg kg^{-1}, which were higher than recommended levels. The nitrate-N accumulation in the 0–100 cm and 0–200 cm soil layers in kiwi-orchards were 466 and 793 kg N ha^{-1}, respectively. The high proportion of nitrate-N in deeper soil profiles of kiwi-orchards poses a great risk for nitrate leaching and subsequent ground water pollution. It is concluded that changing arable crops to kiwi-orchards increased the environmental burden of the catchment due to excessive fertilizer application in kiwi-orchards.

1. Introduction

The agricultural production has increased rapidly since the 1980s in China, greatly reducing food shortages in this populous country (Erismanet al., 2008). This is mainly achieved by increasing crop yield on the same area of land by using synthetic fertilizers, irrigation, and pesticides (Zhang et al., 1996; Fan et al., 2010). At the same time, the rapid growth of China's agriculture comes at a high environmental costs, including emissions of greenhouse gases, loss of biodiversity, and degradation of land and freshwater (Ju et al., 2006; Sutton et al., 2013; Norse and Ju, 2015). Therefore increasing agricultural production while reducing nutrient losses to the environment is a major challenge for China, and other countries with a similar situation.

Nutrient additions to cereal crops in China far exceed those in the United States and Northern Europe (Vitousek et al., 2009; Chen et al., 2014; Davidson et al., 2015). The over-fertilization leads to a reduction in nutrient use efficiency, and an increased risk of environmental pollution (Gao et al., 2012). Ju et al. (2007) reported that substantial mineral nitrogen (N) and available phosphorus (P) and potassium (K) accumulated in the soil and leached down the soil profile. Furthermore, the concentrations of heavy metals increased in soil due to the excessive fertilizer and manure applications (Ju et al., 2007). Over-fertilization also resulted in soil acidification (Cui et al., 2013) and soil salinization (Patriquin et al., 1993; Gao et al., 2012), which may adversely affect plant growth, production, and crop quality.

In recent years, large areas of conventional cereal production in China have been transferred to growing crops with a high economic value (e.g., fruit trees and vegetables). For example, the area under fruit trees has increased from 1.78 M ha in 1980–12.2 M ha in 2013. These crops are associated with excessive nutrient and irrigation application in comparison to cereal crops (Fan et al., 2010; Qiu et al., 2010). The causes for such bad management practices include the low education levels of the farmers, and not enough research work conducted in regard to

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rational fertilizer recommendations for fruit trees, so that existing recommendations are inadequate (Ju et al., 2006; Lu et al., 2012).

The kiwifruit (*Actinidia deliciosa*), a species native to the hills and mountains of Central and Southern China, was domesticated for commercial production in New Zealand early last century (Smith et al., 1994). The domesticated kiwifruit has been commercially introduced to the northern slope region of the Qinling Mountains in Shaanxi since the early 1990s. This region has become the most important kiwifruit production belt in China, accounting for 30% of the total kiwifruit cultivation area in the world and 60% of that in China (Sun and Fu, 2009). In comparison to wheat and maize rotation, which was traditionally grown in the region before the 1990s, the kiwifruit orchards have a greater profit. Therefore, since the 1990s, farmers began to shift arable lands (wheat-maize rotations) to kiwifruit orchards, and applied large amounts of fertilizer and manure to ensure high yields. Now, kiwifruit has become the main crop and is an important source of income for local farmers. Therefore it is important to understand the effects of land-use change from arable land to kiwi-orchards on the soil nutrient budget and their potential associated environmental risks.

Yujiahe catchment was selected as a typical representative of intensive kiwifruit cultivation area in Shaanxi province of China. Our specific objectives were: (1) to investigate the nutrient budgets in grain crops and kiwi-orchards, and (2) to evaluate the potential environmental impacts after converting the cropland to kiwifruit orchards.

2. Materials and methods

2.1. Site description and cropping systems

The study site was in the Yujiahe catchment (33°42′–34°14′ N, 107°39′–108°37′ E), Zhouzhi county, Shaanxi province (Fig. 1a), which is located on the northern slope of the Qinling Mountains. It is characterized by a V-shaped gully topography with about 85% of the arable lands on a 2–15° slope (Fig. 1b). The whole catchment covers an area of 412.4 ha. This region is typical of a warm-temperate sub-humid continental monsoon climate with a mean annual temperature of 13.2 °C and an average annual precipitation of 713 mm (from 1957 to 2012), with 61–84% occurring between July and September.

The main arable crops in the catchment are winter wheat (*Triticum aestivum L.*) and summer maize (*Zea mays L*); and kiwifruit (*A. deliciosa*) vines are main fruit crops. Wheat and maize are sown on sloping land or terraces on the top parts of the catchment, accounting for 20% of the total area of this catchment, where no irrigation system is available and crops depend on rainfall. Winter wheat is usually sown in late September or early October and harvested in early June in the following year; then maize is sown, and harvested in early October. The kiwifruit vines are planted on terraces of the lower parts of the catchment, covering about 40% of the catchment's surface, where they can be irrigated. The kiwifruit vines were mainly established from 1993 to 2010 at a density between 1667 and 2220 vines ha^{-1}. Vines are trained on a T-bar trellis system. Kiwifruit is usually harvested in early October. During the winter of each year, fallen leaves are left in the orchards whereas pruned wood is removed from the orchards. Irrigation frequency of kiwi-orchards depends on the precipitation rate and frequency in each year. There are usually 3–4 irrigation events, with an irrigation depth between 100 and 150 mm each time. The mean precipitation, reference evapotranspiration (ET_0), and irrigation in this catchment between 2012 and 2013 are shown in Fig. 2. The irrigation water in the catchment is pumped from the wells with a depth of 80–200 m. To evaluate the water quality, a total of 19 groundwater samples were taken during the irrigation season in 2015, and water samples were stored in a fridge at 4 °C for analysis. The concentrations of NO_3^--N and NH_4^+-N were measured by a continuous flow analyzer (Bran and Luebbe AA3, Norderstedt, Germany). The concentrations of Ca^{2+}, Mg^{2+}, K^+ and Na^+ were measured by an atomic absorption spectrophotometer (Z-2000, ICP-AES). The information about water quality is shown in Table 3.

2.2. Survey and sampling

To evaluate nutrient inputs and outputs in wheat-maize croplands and kiwi-orchard systems, A total of 242 kiwi-orchards were surveyed in 2012 and 2013, and 21 wheat-maize croplands were surveyed for the period of 2012–2013 (Fig. 1c). The information surveyed included the area of the field, the types and the rates of inorganic and organic fertilizers applied, the age of the kiwifruit vine and fruit yields, and the total biomass of wheat and maize (including grain and straw). The main inorganic

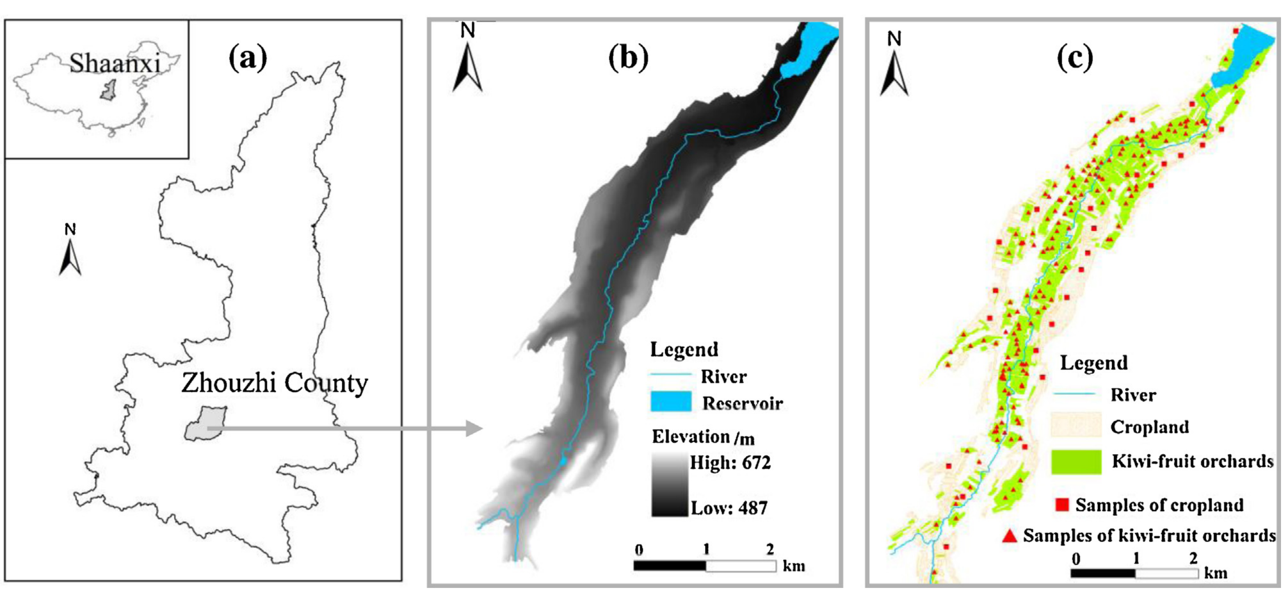

Fig. 1. The location (a), digital elevation model (DEM) (b), land use status, and survey sites of the two cropping systems (c) in Yujiahe catchment.