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Spatial distribution of soil total phosphorus in Yingwugou watershed of the Dan River, China

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ABSTRACT

P is an essential and commonly limiting element for plants. P losses from agricultural production systems are known to contribute to accelerated eutrophication of natural waters. In this study, soil total phosphorus (STP) concentration and STP mass were estimated from a soil survey of a small watershed of the Dan River, China, after which the spatial heterogeneity of STP distribution and impacts of land-use types, elevation, slope and aspect on STP were assessed. A total of 190 sites were sampled, and 539 soil samples from a soil profile of 40 cm were collected by field sampling in a 100 m × 100 m grid. The results indicated that classical kriging could successfully interpolate STP concentration in the watershed. The STP concentration showed a downward trend with increasing soil depth. The STP variability in the three soil layers was moderate, and there were significant differences among soil layers ($p < 0.01$). Statistical analysis by ANOVA indicated that land use had a great impact on STP concentration, and the spatial variation of STP concentrations among the land use types was significant ($p < 0.05$). The STP mass of different land-use types followed the order of forestland > cropland > grassland. On average, the mean STP masses of forestland, cropland and grassland at a depth of 0–40 cm were 0.39, 0.35 and 0.28 kg/m^2, respectively. The topographic factors of altitude and aspect exerted the greatest influence on STP concentration, and the STP concentration increased with decreasing altitude; however, STP concentration and slope showed no significant correlation. The soil bulk density also played a very important role in the assessment of STP mass. In conclusion, the soils in the source area of the middle Dan River would increase STP with conversions from cropland to forest.

1. Introduction

Phosphorus (P) is an essential and commonly limiting element for plants. Variation in soil P content influences the biogeochemical cycle of elements including carbon and nitrogen (Walker and Syers, 1976; Bronson et al., 2004; Wang et al., 2012). Moreover, P is most often the element limiting eutrophication because many blue-green algae are able to utilize atmospheric N_2 (Pote et al., 1996). Therefore, P losses from agricultural production systems are known to contribute to accelerated eutrophication of natural waters (Sims et al., 1998; Toor et al., 2003; Lang et al., 2013). In the United States, P has been the major nutrient affecting fresh water quality (US Environmental Protection Agency, 2003; Huang et al., 2012). It has been estimated that over 70% of total P discharged into rivers originated from agricultural land (Yu et al., 2006). Approximately 3–4.3 × 10^6 tons of phosphorus is lost from soil to water annually worldwide (Foy and Withers, 1995).

Plants primarily acquire the P needed for their growth from soil P reserves. Soil P content is mainly affected by factors such as parent material, climate, organisms and biogeochemical processes in soil, and its distribution has large spatial heterogeneity (Stewart and Tiessen, 1987; Gardner, 1990; Kooijman et al., 2005; Lane et al., 2011). Soil total phosphorus (STP) in surface runoff is primarily transported in particulate form bound to sediment particles, but can also be lost as P in solution (Haygarth et al., 2000). P loadings in surface runoff are influenced by topography, precipitation (intensity and duration), temperature, land use, and other field management practices (Yu et al., 2006; Zhang et al., 2012). Estimating soil P content under different land uses can help evaluate the impact of patterns of land utilization conversion on soil P reserves (Wang et al., 2008; Roger et al., 2014). Understanding the content of soil P is essential to controlling non-point pollution. However, few estimates of soil P reserves have been made to date (Smil, 2000). Moreover, such estimates have been made at the global and regional scale (Lerman et al., 1975; Pierrou, 1976); thus, estimates of

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spatial variation, influential factors, and density of STP in small watersheds are scarce. The nutritive substances carried by runoff and sediment can cause eutrophication and water-quality degradation of rivers and lakes; thus, research regarding STP in small watersheds is of vital importance.

The Dan River originates from the Minjiahe watershed in Shangzhou, Shaanxi Province, China. The drainage area of the river is about 1.68×10^4 km^2 and its length is 443 km. The Dan River is the source of water from the middle route of the South to North Water Diversion Project (Xu et al., 2013). Water pollution control is vital for maintaining good water quality in the middle route. However, water-quality indexes of some watershed tributaries in the Dan River exceed the National Environmental Quality Standards for Surface Water Class II, and total P levels are significantly beyond the recommended limits. These water quality issues are closely related to agricultural area-source pollution in the Dan River Basin (He et al., 2012). The present study investigated the spatial distribution of STP in the Yingwugou Watershed of the Dan River with geostatistical methods.

The purpose of the present study was to: 1) investigate STP content and reveal the spatial heterogeneity of STP in the Yingwugou watershed in the source area of the middle Dan River; 2) assess the impact of land use, elevation, slope and aspect on STP; and 3) estimate the vertical variability of STP concentration and mass in Yingwugou watershed.

2. Materials and methods

2.1. Description of study area

The study was conducted in the Yingwugou Watershed (110°53′38″–110°55′18″E, 33°31′23″–33°30′35″N), which is located in the Dan River Basin, 2 km southeast of Shangnan County, Shaanxi Province, China (Fig. 1). The watershed has an area of 1.86 km^2 and an altitude that ranges from 470 m to 600 m.a.s.l. The watershed is characterized by an average annual temperature of 14 °C and a mean annual precipitation of 814 mm, half of which occurs between July and September. Local topography is characterized by low mountains and hills, and the region is primarily underlain by yellow brown soil (Haplumbrepts). Limestone accounts for a very small part of the parent material, and is mainly distributed on the north side of the basin outlet. Forestlands, grasslands and croplands have average slopes of 22°, 21° and 10°, respectively. The trees in the area primarily consist of pine *(Pinus tabuliformis* Carr.) and Chinese chestnut (*Castanea mollissima* Blume.), while peanut (*Arachis hypogaea* L.), corn (*Zea mays* L.) and wheat (*Triticum aestivum* Linn.) comprise the dominant crops. The primary land-use types in the watershed are croplands (61.84%), forestlands (28.83%) and grasslands (9.33%), with croplands primarily distributed in the valley bottoms of the watershed and forest and grass communities in the middle and upper parts of the slopes (Fig. 1C, D).

2.2. Soil sampling and analysis

Soil samples were collected from 100 m × 100 m grids (Fig. 1) in the Yingwugou watershed during December 2011 using a hand auger with a diameter of 5 cm. Samples were collected from depths of 0 to 40 cm (0–10 (A1), 10–20 (A2) and 20–40 cm (A3)). Overall, 198, 186 and 163 samples were collected from the 0–10 cm, 10–20 cm and 20–40 cm soil layers. Land-use type, slope, aspect, altitude, soil type, and vegetation species and coverage were evaluated to identify correlations between these factors and spatial variations in soil nutrients. Overall, 71, 30 and 89 forestland, grassland and cropland samples were collected, respectively. STP concentration was determined using an Auto Discrete Analyzer (ADA, CleverChem200, Germany). Each STP measurement was made in duplicate.

Additionally, 26 40-cm deep soil profiles were prepared, after which samples were collected from each horizon and dried in an oven. The cropland, grassland and forestland profiles were 12, 6 and 8, respectively. Additionally, a can was inserted into the soil pit in each horizon, after which surrounding soil was removed using a trowel and the intact soil peds were extracted. Finally, the cores were weighed, then oven dried at 105 °C for 24 h and weighed again, after which the bulk density was calculated.

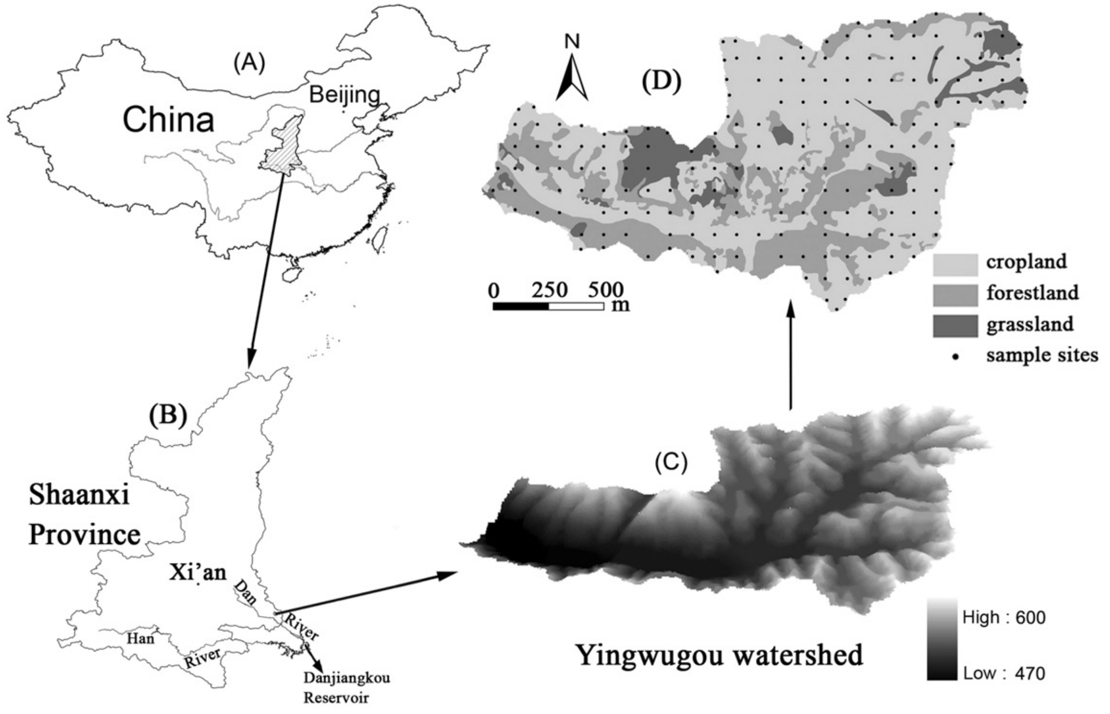

Fig. 1. Location of the study area in Shaanxi Province, China (A, B); digital elevation model (C); land use (D) of the watershed.