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Agricultural land use decouples soil nutrient cycles in a subtropical riparian wetland in China

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ABSTRACT

We examined the impact of human changes in land use on the concentrations and stoichiometric relationships among soil carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in a *Phragmites australis* riparian wetland (Minjiang River estuary, China). We compared a natural (unaltered) wetland with five altered land uses: intertidal mudflat culture and vegetable, flower, fruit and rice cultivations. All these land uses decreased C, N and K soil concentrations relative to those in the *P. australis* wetland. The close relationship between total soil C and N concentrations, under all land uses, suggested that N was the most limiting nutrient in these wetlands. The lower N concentrations, despite the use of N fertilizers, indicated the difficulty of avoiding N limitation in the agricultural land. Croplands, except rice cultivation, had lower soil N:P ratios than the original *P. australis* wetland, consistent with the tendency of favoring species adapted to high rates of growth (low N:P ratio). The release of soil C was less and the soil C:N and C:P ratios higher in the natural *P. australis* riparian wetland than in the croplands, whereas C storage was more similar. The levels of soil C storage were generally opposite to those of C release, indicating that C release by respiration was the most important factor controlling C storage. Cropland soil management promotes faster nutrient and C cycles and changes in soil nutrient stoichiometry. These impacts can further hinder the regeneration of natural vegetation by nutrient imbalances and increase C-cycling and C emissions.

1. Introduction

Anthropogenic activities can strongly alter the nutrient pools of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in soils by many processes including increasing nutrient inputs, N deposition, drought, species invasion or increases in atmospheric CO_2 (Sardans and Peñuelas, 2012; Sardans et al., 2012b; Tian et al., 2010). These shifts are frequently associated to changes in the structure of plant communities and/or in nutrient outputs (e.g. crop harvesting and weathering) (Sardans et al., 2012a). Land-use changes due to agronomic practices and livestock production generate soil stoichiometric shifts in forests (Falkengren-Gerup et al., 2006; Sardans and Peñuelas, 2013), shrublands (Sardans and Peñuelas, 2013), grasslands (Mulder and Elser, 2009) and steppes (Jiao et al., 2013). The status of the C:N:P ratio in wetland soil under different intensities of human disturbance, however, remains unknown.

Recent stoichiometric ecological studies have shown that K is even more associated than is N or P with stoichiometric differences among various plant ecotypes (Sardans and Peñuelas, 2014; Sardans et al., 2012c) or with stoichiometric shifts in response to environmental changes (Rivas-Ubach et al., 2012). The strong link between plant K concentrations and water availability (Sardans et al., 2012c; Yavitt et al., 2004) justifies the study of K and its stoichiometric relationships with other nutrients.

Changes in soil stoichiometry can influence the capacity to regenerate natural vegetation after the abandonment of human activities, delaying it for many decades (Falkengren-Gerup et al., 2006; Jiao et al., 2013). This impact can be especially critical in sensitive diversity-rich ecosystems, such as wetlands, that are severely affected by changes in land use (Ramsar, 2013). The effect of land-use change on the stoichiometry of wetlands has received little attention (Koerselman and Meuleman, 1996). Wetlands occupy 5.7×10^6 km^2 worldwide, are cradles of biodiversity upon which countless species of plants and animals depend for survival and are among the world's most productive environments,

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being a sink of C in the forms of peat and plant matter and providing a wide array of benefits (Mitsch and Gosselink, 2007; Ramsar, 2013). In the current context of global change, wetlands continue to be among the most threatened ecosystems, and yet we lack information about the impact of anthropogenic changes on their abiotic and biotic environments (Mitsch and Gosselink, 2007; Ramsar, 2013). The ability of wetlands to adapt to changing conditions and to the current accelerating rates of global change will be crucial to world biodiversity conservation. A better understanding of the resulting soil C, N, P and K ecological stoichiometries in wetlands submitted to land use changes would provide decision makers with the necessary information for developing effective methods to enhance the potential capacity of these ecosystems to fix C and reduce the impact of emissions of greenhouse gases (Peñuelas et al., 2013). It would also provide information on the impacts of anthropogenic activity on the regenerative capacity of wetlands by determining the cycles and balances of C, N, P and K and the fertility of the soil. We expect that human activities changing nutrient balances (fertilization and harvesting), species composition and water fluxes should exert a great impact on soil elemental composition. This should change C fluxes and hinder further ecosystem restoration processes by shifting soil condition far from the optimum from that of natural wetlands. China has a coastal zone approximately 18,000 km in length, much of which is occupied by tidal wetlands in estuaries, estimated at more than 1.2×10^4 km^2 (Huang et al., 2006). These areas are characterized by rapid economic development, and by the fast replacement of natural undisturbed areas by areas disturbed by crops, livestock and tourism. The loads of N and P to rivers caused by human activities and further transported downstream to the wetlands (Howarth et al., 1996) cause water eutrophication (Anderson et al., 2002) that threatens the health of wetlands (An et al., 2007) and decreases ecosystemic services (Lee et al., 2006). Research in these areas, however, has been scarce, and studies on various spatial and temporal scales are therefore needed.

To solve this lack of knowledge, we aimed to determine: (1) the changes in C, N, P and K concentrations and stoichiometry associated with land-use changes at various soil depths in riparian tidal wetlands, (2) the relationships of soil influencing factors and (3) the capacity of soil to store C with soil C, N, P and K ratio shifts and land-use changes.

2. Material and methods

2.1. Study area and experimental design

This work was conducted in the Difengjiang wetland of the Minjiang River estuary (China) (25°58′53.50″–25°59′46.01″N, 119°17′52.60″–119°20′25.67″E Fig. 1). The climate is subtropical with mean annual temperatures and precipitation of 19.7 °C and 1348.8 mm, respectively. The soil surface of the riparian wetland is submerged across the study site for 1–2.5 h during each tidal inundation. The large perennial grass, *Phragmites australis* (mature height of 2 m at 150 stems m^{-2}), is one of the most important plant species and is typically found from the upstream to the downstream regions of the Minjiang River tidal wetland (Liu et al., 2006).

To determine the associations between different agricultural land-use changes and the concentrations and ratios of soil C, N, P and K, we established plots on a wide range of land uses: natural *P. australis* wetland (control), flower (Jasmine) cultivation (*P. australis* plants removed eight years previously), intertidal mudflat culture (the aerial parts of *P. australis* plants removed 10 years previously), rice cultivation (*P. australis* plants removed 20 years previously), vegetable cultivation (*P. australis* plants removed 30 years previously), and fruit (Longan) cultivation (*P. australis* plants removed 40 years previously). The natural *P. australis* wetland and intertidal mudflat culture plots have not been fertilized. The plots of flower, rice, vegetable and fruit cultivations were fertilized ($N–P_2O_5–K_2O = 16–16–16\%$; Keda Fertilizer Co., Ltd.) with dosages of 225, 235, 150, 300 kg ha^{-1} y^{-1} respectively.

The soil types for *P. australis* wetland and intertidal mudflat culture plots were wetland soil, the soil types for vegetable cultivation, flower (Jasmine) cultivation and fruit (Longan) cultivation plots had changed from wetland to krasnozem soil and the soil types for rice cultivation plots had changed from wetland to paddy soil.

In our study, three plots (1 m^2 each one) were randomly selected at each location. These plots were separated 100 m among them in each site with different land uses. *P. australis* wetland is the control plot of the experiment. *P. australis* wetlands are water sources in the region, and they are protected by the government, so the human influence was very limited. Sampling locations were established in the *P. australis* riparian wetland and at sites of intertidal mudflat culture, vegetable, flower, fruit and rice cultivations (Fig. 1). Soil samples were collected in March 2013. Under natural conditions (without any human activity) all studied sites that currently have a human activity should be a *P. australis* wetland such as the control.

2.2. Collection and measurement of soil samples

Three plots were randomly selected in each of the locations, and soil profiles (width, 1 m; length, 1 m; depth, 0.5 m) were excavated. Samples were collected with a small sampler (length, 0.3 m; diameter 0.1 m) from each of five soil layers (0–10, 10–20, 20–30, 30–40 and 40–50 cm) at the center and on both sides of the soil pits. These three samples from each layer were bulked to form one sample per layer. A

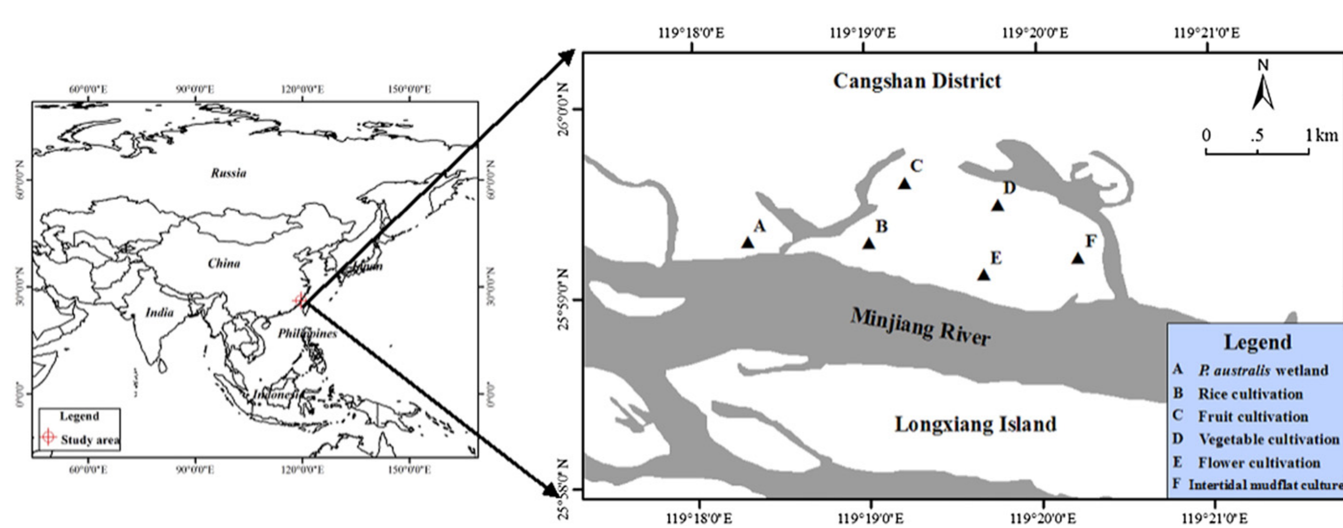

Fig. 1. Location of the five types of land use.