Changes of phosphate and ammonium nitrogen in irrigated waters of Hani terrace wetlands along the elevation gradients

Huifeng Xu\textsuperscript{a}, Qinggai Wang\textsuperscript{b}, Junhong Bai\textsuperscript{c*}, Rong Xiao\textsuperscript{c}, Haifeng Gao\textsuperscript{c}, Baoshan Cui\textsuperscript{c}

\textsuperscript{a}College of Agriculture, Jilin Agricultural University, Changchun, 130008, P.R. China
\textsuperscript{b}Appraisal Center of Environment and Engineering, Ministry of Environmental Protection, Beijing 100012, P.R. China
\textsuperscript{c}State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, 100875, P.R. China

Abstract

PO\textsubscript{3}\textsuperscript{--}P and NH\textsubscript{4}\textsuperscript{+}-N concentrations were measured in the overlaying waters at different elevations in Hani terrace wetlands on the Yunnan plateau of China in December, 2004, in order to study spatial variations in nitrogen and phosphorous concentrations along the elevation gradients under domestic sewage injection in fallow period. Results showed that there were consistent variations in PO\textsubscript{3}\textsuperscript{--}P and NH\textsubscript{4}\textsuperscript{+}-N concentrations in both terraces with elevation. They were reduced exponentially with decreasing elevations in both terraces and appeared the maximum at the higher elevations where domestic sewage was injected. The goodness-of-fits of the fitting models were more than 0.90 and 0.85 in MP and QFZ terraces, respectively. The retention rates of NH\textsubscript{4}\textsuperscript{+}-N and PO\textsubscript{3}\textsuperscript{--}P from domestic sewage in both terraces in fallow period was 98.7% and 90%, respectively.

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Key words: spatial variation; PO\textsubscript{3}\textsuperscript{--}P; NH\textsubscript{4}\textsuperscript{+}-N; elevation gradient; Hani terrace wetlands; retention rate

* Corresponding author. Tel.: +86-010-58802029; fax: +86-010-58802673.
E-mail address: junhongbai@163.com.
1. Introduction

Wetlands are in use worldwide to reduce concentrations of nutrients in through-flowing water. Many studies at the site scale have demonstrated that wetlands have a high and long-term capacity to improve water quality \([1,2,3]\), with the maximum potential rate of nitrogen (1000 to 3000 kg N ha\(^{-1}\) y\(^{-1}\)) and phosphorous (60 to 100 kg P ha\(^{-1}\) y\(^{-1}\)) removal of wetlands in the temperate zone \([3,4,5]\). Because water quality of rivers or lakes was facing serious deterioration in intensively farmed regions worldwide, nutrient retention of natural wetlands or constructed wetlands was paid more attention to \([3]\). However, little information is available about the purifying functionality of terrace wetland to nutrient loads from domestic wastewater in the plateau area.

Paddy fields account for about 80% of arable land in South China \([6]\). Paddy terrace wetlands or Hani terrace wetlands (named after Hani nationality) are characteristic of eco-agriculture at Yuanyang County on the Yunnan Plateau of China, which enhances infiltration and prevents soil erosion and landslides after constructing terraces. There are strong interactions between agricultural activities, air and water environments in paddy fields \([6]\). Hani terraces were irrigated through all ditches around the hill and persistent flooded all the time except for the rice-harvest period, which was obviously different from the traditional pattern of flooding and drainage in fallow period in plains. Hani terraces were fertilized through rain erosion of forest humus and domestic sewage injection from villages. Spatial pattern of forest-village-terrace-river landscapes along the elevation gradients in this region makes up a meta-ecosystem with high ecosystem services \([7]\). However, little research has been quantitatively done to investigate the impacts of domestic sewage injection on water quality of paddy terraces in this region.

The objectives of this paper were to study spatial variations in NH\(_4\)^+-N and PO\(_3\)^--P concentrations in water samples along the elevation gradients under domestic sewage injection in Hani terraces and to reveal the retention rates of NH\(_4\)^+-N and PO\(_3\)^--P in Hani terrace wetlands.

2. Materials and Method

2.1. Site description

Hani terrace wetlands widely distribute in Honghe district, Yunnan province of Southwest China. The total area of typical Hani terrace wetlands at Yuanyang County was 12667 hm\(^2\), of which 12.8% was prepared to apply for UNESCO World Heritage protection including four core areas such as Malizhai River core area, Niuniaoazhai River core area, Duoyishu River core area and Duo River core area (Fig.1). Yuanyang County is located on the south slope of Ailao Mountain in Yunnan Province (102°40′ and 102°48′E, 23°04′ and 23°12′N) and belongs to one part of the Honghe Autonomous Prefecture for Yi and Hani nationalities. There is a group of large-area rice terraces built on the hillside, which mainly distribute at the elevations ranging from 500 to 2000 m with slope gradients from 15° to 75° (more than 80% slope gradient ranging from 15° to 35°). There are 63958.4 hm\(^2\) forest (including virgin forest and secondary forest) at Yuanyang County, forming the typical landscape pattern of forest-village-terrace-river with decreasing elevations.

It is the subtropic continental monsoon climate and is characteristic of vertical climate in this region, with the mean annual temperatures decreasing from 25°C to 11.6°C with increasing elevations. The mean annual precipitations range from 1500 to 2000 mm, exceeding the annual evaporation (791.8 mm). The wet season is from May to October, and dry season is from November to March. Hani terrace wetlands are predominately planted double-cropping rice (single-cropping rice at higher elevations) and soil type is paddy soil cultivated for several hundred years.
2.2. Field sampling and analysis

Mengpin (MP) and Quanfuzhuang (QFZ) terraces were designed along the increasing elevations from 1350 to 1550 m and from 1650 to 1850 m, respectively. Water samples with five repetitions were collected with 50 m intervals along the elevations in both transects in December, 2004. Domestic sewage was injected at the elevations of 1550 m and 1850 m, respectively. Phosphate (PO$_3$$^-$$^P$) and ammonium nitrogen (NH$_4$$^+$$^-$$^N$) of water samples were determined using a potable multi-parameter water quality monitor. The model fitting were performed using the software package Origin 7.0.

Fig.1 Sampling transect in paddy terrace wetlands at Yuanyang County
3. Results and Discussion

Spatial variations in PO₃⁻-P and NH₄⁺-N concentrations in water samples of MP and QFZ terraces are shown in Figure 2. The consistent variations in PO₃⁻-P and NH₄⁺-N concentrations in water samples of both terraces with decreasing elevations could be observed. They were reduced exponentially with decreasing elevations and appeared the maximum at the altitude where domestic sewage was injected. The exponential models were used to fit the spatial variations of PO₃⁻-P and NH₄⁺-N concentrations in water samples of both terraces, with the goodness-of-fit of more than 0.90 and 0.85 in MP and QFZ terraces, respectively. Generally, NH₄⁺-N concentrations in both terraces are nearly zero at lower elevations.

The application of domestic sewage sludge to agricultural land has become an acceptable method of waste disposal and soil amendment. Some studies have been published which documented the effects of sludge application on contamination of surface water [8]. However, domestic sewage could be purified by filtration of the terrace wetlands in this region, thus protecting water quality of rivers. The decreasing changes of PO₃⁻-P and NH₄⁺-N concentrations in irrigated waters with decreasing elevations testified the purification role of terrace wetlands.

The retention rates of NH₄⁺-N and PO₃⁻-P from domestic sewage in MP and QFZ terraces were 98.7% and 90%, respectively, which could improve soil fertility and protect water quality of rivers. Due to multi-order structure of the terraces, both the water flow and water retention time were lengthened, the pollutants in domestic sewage were purified through sedimentation, adsorption and absorption, transformation etc. soil adsorption and nitrification-denitrification are generally the most important processed for nitrogen removal in fallow period. And the most important mechanisms of phosphorous removal were sedimentation and soil adsorption [3,9,10], since no plant uptake occurred in this period. Meanwhile, water tables were continuously kept 0.3m in the terrace wetlands, which contributed to the sedimentation of pollutants from domestic sewage.
Fig. 2 Changes in PO$_3^-$-P and NH$_4^+$-N concentrations in MP (A) and QFZ (B) terrace wetlands along an altitude gradient. Mean values with standard deviation bars are reported.

4. Conclusions

Hani terraces could efficiently infiltrate PO$_3^-$-P and NH$_4^+$-N from domestic sewage. PO$_3^-$-P and NH$_4^+$-N concentrations in terrace wetlands decreased with decreasing elevations, with the retention rates of more than 90%. Therefore the spatial pattern of forest-village-terrace-river landscapes with decreasing elevations in this region is optimal cultivation style for uplands, which contributing to water quality protection of rivers below the terraces. Changes of other ions concentrations in water environment of the terraces will be investigated to further testify the purifying capacity of the terrace wetlands.

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