JOURNAL OF ENVIRONMENTAL SCIENCES 46 (2016) 92–100

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JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Reducing nitrogen runoff from paddy fields with arbuscular mycorrhizal fungi under different fertilizer regimes

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ARTICLE INFO

Article history:
Received 6 July 2015
Revised 10 October 2015
Accepted 25 December 2015
Available online 4 March 2016

Keywords:
Nitrogen loss
Runoff
Paddy fields
Arbuscular mycorrhizal fungi
Fertilization
Dissolved nitrogen
Particulate nitrogen

ABSTRACT

Nitrogen (N) runoff from paddy fields serves as one of the main sources of water pollution. Our aim was to reduce N runoff from paddy fields by fertilizer management and inoculation with arbuscular mycorrhizal fungi (AMF). In northeast China, Shuangcheng city in Heilongjiang province, a field experiment was conducted, using rice provided with 0%, 20%, 40%, 60%, 80%, and 100% of the local norm of fertilization (including N, phosphorus and potassium), with or without inoculation with *Glomus mosseae*. The volume, concentrations of total N (TN), dissolved N (DN) and particulate N (PN) of runoff water were measured. We found that the local norm of fertilization led to 18.9 kg/ha of N runoff during rice growing season, with DN accounting for 60%–70%. We also found that reduction in fertilization by 20% cut down TN runoff by 8.2% while AMF inoculation decreased N runoff at each fertilizer level and this effect was inhibited by high fertilization. The combination of inoculation with AMF and 80% of the local norm of fertilization was observed to reduce N runoff by 27.2%. Conclusively, we suggested that the contribution of AMF inoculation combined with decreasing fertilization should get more attention to slow down water eutrophication by reducing N runoff from paddy fields.

Introduction

As the third biggest river in China, Songhua River serves as a major freshwater source for three provinces, including Heilongjiang, Jilin and Inner Mongolia municipality (He et al., 2008). However, the possibility of polluting Songhua River was reported (Guo et al., 2007b). Especially the total nitrogen (TN) load was 113 × 10^4 tons in Songhua River, with 84% caused by anthropogenic activities (Ma et al., 2011) which was aggravated by the long stay of pollutants due to the long icebound season (Guo et al., 2007b). Lalin River is one of the first tributaries of Songhua River and its water quality would contribute directly to the pollution of Songhua River (Guo et al., 2007a). The water quality of upper reaches of Lalin River was better than the threshold value of surface water of Grade I in *Quality Standard of Surface Water Environment of China* (GB3838-2002) while that of the lower reaches was much worse than that of Grade V (Cai and Shang, 2009; Ma, 2006), with high load of TN being one of the characteristics. N runoff from paddy fields was suspected to be one of the factors contributing to the poor water quality of the lower reaches of Lalin River (Kaushal et al., 2011) as rice production was dominated on its middle and lower reaches. In rice production, paddy fields are intensively fertilized for high rice yields (Liu, 2012), contributing the largest amount of N load to the surface water (Kawara et al., 1996; Zhao et al., 2012). In addition, the rice growing season in this area extends from June

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http://dx.doi.org/10.1016/j.jes.2015.12.024

to October and corresponds with the main rainy and hydrologically active period of the year, which makes Lalin River be more vulnerable to be polluted. Furthermore, the shallowly ponded paddy fields (with a depth of 3–10 cm) experience irrigation, artificial draining and random rainfalls, increasing the possibility of N export via runoff (Kim et al., 2006). Collectively, the great contribution of N runoff from paddy fields to the deterioration of water quality was realized but little information of Lalin River is available.

There is growing concern about the environmental impacts of fertilizer applied in agricultural systems on water quality. The fertilization in intensive agricultural areas of China has resulted in serious environmental problems because of atmospheric, soil, and water enrichment with reactive N of agricultural origin (Tian et al., 2007). A number of studies have concluded that the large amount of chemical N fertilizer used in rice production was one of the major sources of N pollutants in water bodies (Kim et al., 2006; Zhao et al., 2012). Furthermore, it was reported that in Taihu Lake Region of China, the current application rate of N fertilizer was excessive (Guo et al., 2004) and the recommended rate could decrease from 10% to 40% to enable optimum economic and ecological results (Xia and Yan, 2012). However, the contribution of fertilizer applied in paddy fields to N runoff from paddy fields has not been well documented in Lalin River basin. The changing dynamics of N runoff, including dissolved N and particle N, during rice growing season is not well characterized in this area either. The lack of this comprehensive information has hampered the development of effective nutrient management policies, which led to the fact that the practice of high inputs of fertilizers is still underway in Lalin River basin while the deterioration water quality of Lalin River continues with little sign of improvement. Therefore, more information on N export via runoff from paddy fields supplied with different levels of fertilizers is required to improve the water quality of Lalin River and then Songhua River.

Besides fertilizer management, developing a safe alternative bio-fertilizer to replace or partly replace chemical fertilizer is another way to relieve water pollution or to prevent water deteriorations. Specifically, arbuscular mycorrhizal fungi (AMF) can be used as such a safe bio-fertilizer since AMF improved the capability of plants for nutrient uptake (Smith and Read, 2010). Potentially beneficial effects of AMF colonization on rice production systems has received much attention in scientific literature and a range of positive responses have been observed even under anaerobic conditions (Purakayastha and Chhonkar, 2001; Wangiyana et al., 2006), including an increase in plant size, tissue nutrient concentration (Solaiman and Hirata, 1996, 1997), photosynthetic rates (Black et al., 2000) and grain yields (Liu et al., 2013). Importantly, these beneficial effects of AMF were persistent until the second year after inoculation (Pellegrino et al., 2011). Although AMF inoculation was hypothesized to slow down the deterioration of surrounding water systems, few research make efforts to estimate the role of practical application of AMF in cutting down N runoff from paddy fields so that there is no conclusive evidence to prove this hypothesis.

The water environment of China suffered seriously and the water quality of many rivers, streams, reservoirs and lakes often does not meet the established standards, with periodic algal blooms occurring in most reservoirs. This implied that further efforts to safeguard the water quality of these water bodies are still needed (Meng, 2009).There is an abundance of evidence demonstrating the negative effect of N runoff due to intensive fertilization in rice production on surface water quality in Korean (Kim et al., 2006), Taihu Lake region of China (Zhao et al., 2012) and Lake Biwa basin of Japan (Kawara et al., 1996). This gave rise to the need for an urgent reduction in fertilizer rate (Xia and Yan, 2012) and application of arbuscular mycorrhizal fungi (AMF) as a safe biofertilizer (Zhang et al., 2010). Our study sought to investigate the dynamics, forms and accumulation of N runoff from paddy fields under different fertilizer regimes, both in the absence and presence of AMF inoculation. We try to address the following questions: Q1: Under the local norm of fertilization, what is the temporal dynamics in two forms and seasonal N runoff from paddy fields in Lalin River basin? Q2: How much N runoff can be cut down by fertilizer management? and Q3: Can N runoff be reduced by AMF inoculation?

1. Methodology

1.1. Site description and experimental design

The experiment site was located on the lower reaches of Lalin River (45°13.82′N, 126°22.61′E) in Songhua River basin, Heilongjiang Province of China. The mean annual temperature at the site is 4.3°C, while the annual temperature range (comparing the average temperature of the hottest and coldest month) is 42.2°C. The frost-free period lasts 135 days and annual rainfall is near 500 mm. The hydromorphic paddy soil contains 26.3 g/kg of organic matter, 125.3 mg/kg of hydrolysable N, 150.6 mg/kg of available phosphorus (P) (Bray-P No.1), and 17.6 mg/kg of available potassium (K) (Zhang et al., 2012). Soil analysis methods used in this study are described in a soil analysis manual (Sparks et al., 1996).

The experimental design was a split-plot design with fertilization (including N, P and K) in main plots and inoculation in split plots. There were two levels for inoculation: inoculated (+M) and non-inoculated (−M) while there were six fertilizer levels, labeled as F0, F20, F40, F60, F80, and F100 which indicated 0%, 20%, 40%, 60%, 80%, and 100% of the local norm of fertilization. Each inoculation and fertilizer combination was replicated three times. The main plots covered an area of 25 m^2 (*i.e.*, each 5 × 5 m) while the split plots covered an area of 1 m^2 (*i.e.*, each 1 × 1 m). A vertical geomembrane (extending 0.5 m above and below ground) was placed around the perimeter of each main and split plot to prevent the movement of surface and ground water.

Each plot, main and split, had one flow entry and one exit. Nutrients added to one plot could not be transferred to its neighbors either by diffusion or by splash. The main water channel ran across the experimental area. All the split plots were provided with water collectors connected with the exits. The runoff collectors were plastic storage boxes (1.5 m × 0.75 m × 0.65 m) fixed beside the main plots to collect runoff water through a piping system. Because the depth of water layer in flooding stage differed from that in artificial draining stage, there were two holes for the collecting