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RESEARCH ARTICLE

Irrigation water salinity and N fertilization: Effects on ammonia oxidizer abundance, enzyme activity and cotton growth in a drip irrigated cotton field

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Abstract

Use of saline water in irrigated agriculture has become an important means for alleviating water scarcity in arid and semi-arid regions. The objective of this field experiment was to evaluate the effects of irrigation water salinity and N fertilization on soil physicochemical and biological properties related to nitrification and denitrification. A 3×2 factorial design was used with three levels of irrigation water salinity (0.35, 4.61 and 8.04 dS m^{-1}) and two N rates (0 and 360 kg N ha^{-1}). The results indicated that irrigation water salinity and N fertilization had significant effects on many soil physicochemical properties including water content, salinity, pH, NH_4-N concentration, and NO_3-N concentration. The abundance (i.e., gene copy number) of ammonia-oxidizing archaea (AOA) was greater than that of ammonia-oxidizing bacteria (AOB) in all treatments. Irrigation water salinity had no significant effect on the abundance of AOA or AOB in unfertilized plots. However, saline irrigation water (i.e., the 4.61 and 8.04 dS m^{-1} treatments) reduced AOA abundance, AOB abundance and potential nitrification rate in N fertilized plots. Regardless of N application rate, saline irrigation water increased urease activity but reduced the activities of both nitrate reductase and nitrite reductase. Irrigation with saline irrigation water significantly reduced cotton biomass, N uptake and yield. Nitrogen application exacerbated the negative effect of saline water. These results suggest that brackish water and saline water irrigation could significantly reduce both the abundance of ammonia oxidizers and potential nitrification rates. The AOA may play a more important role than AOB in nitrification in desert soil.

Keywords: saline water, nitrogen fertilizer, ammonia-oxidizing microorganisms, enzyme activity, cotton yield

1. Introduction

Fresh water scarcity is a world-wide problem, especially in arid regions where irrigation is necessary for crop production. To overcome this scarcity, poor quality water, such as brackish or saline water, is increasingly used for irrigation (Feikema *et al*. 2010; Verma *et al*. 2012). An important concern is that continuous application of brackish or saline water can cause salt to accumulate in the soil-plant system. This build-up of salt has a range of adverse effects on soil physicochemical properties, biological processes and plant growth.

Microbial oxidation of ammonia to nitrate (i.e., nitrification) is a key process affecting the N supply to agricultural crops. The transformation of ammonia to nitrate is the first and rate-limiting step of nitrification. This process is carried out by two groups of microorganisms: ammo-

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nia-oxidizing bacteria (AOB) and the recently discovered ammonia-oxidizing archaea (AOA). Soil salinity affects biological processes responsible for N transformations in soil (Aslam and Qureshi 1998). A previous study reported that AOB abundance increased as soil salinity increased, and the archaeal *amoA* genes were more abundant than bacteria *amoA* genes under low salinity conditions (Mosier and Francis 2008). In contrast, Keshri *et al*. (2013) reported that bacterial *amoA* gene copy numbers were two orders of magnitude higher than archaeal *amoA* gene copy numbers in saline-alkaline soil. Wang and Gu (2014) reported that high salinity promoted growth of both AOA and AOB during a 10-d incubation. The authors also suggested that AOA and AOB might have species specificity to salinity. A recent study indicated that AOB abundance was inhibited by high salinity, whereas AOA abundance remained relatively high under saline conditions (Jin *et al*. 2011). Li *et al*. (2012) observed that the abundance of both AOB and AOA was negatively correlated with salinity. These conflicting reports indicate the limitations of current understanding about ammonia-oxidizing microorganisms in agricultural soils.

Nitrogen fertilization is of great importance to crop yield. Proper management of N fertilizer is especially important in salt affected soils where N application might reduce the adverse effects of salinity on plant growth and yield (Villa-Castorena *et al*. 2003; Hou *et al*. 2009). Furthermore, N application can also affect the abundance and activity of ammonia oxidizers (Webster *et al*. 2005). Shen *et al*. (2008) reported that N application significantly increased the abundance and composition of the AOB community in a sandy alkaline soil. In contrast, N application had minimal effect on the composition of the AOA community. Many studies show that AOA generally out competes AOB at low ammonium concentrations (Tourna *et al*. 2008; Höfferle *et al*. 2010; Stopnišek *et al*. 2010; Gubry-Rangin *et al*. 2011; Herrmann *et al*. 2011; Tourna *et al*. 2011). However, Reigstad *et al*. (2008) reported that low ammonium concentrations might limit the growth of AOA. Overall, ammonia-oxidizing microorganisms, essential in nitrification, undoubtedly play an important role in the sustainable development of agricultural ecosystems as well as in environmental protection. The composition and abundance of ammonia oxidizers could be used as an important biological indicator for evaluating the quality of agricultural soil (Bastida *et al*. 2008). However, little is known about the influence of irrigation water salinity and N application on ammonia oxidizers.

Soil enzymes are crucial for nutrient cycling. Soil enzyme activity is also an important bio-indicator of soil fertility and quality. Soil enzyme activities generally decrease as salinity increases; however, the effects vary depending on experimental conditions. For example, several researchers reported that salinity reduced the activity of oxydoreductase more than that of hydrolase (Sardinha *et al*. 2003; Wichern *et al*. 2006; Yuan *et al*. 2007). Others have reported the opposite effect (Garcia and Hernandez 1996). Soil urease, nitrate reductase, nitrite reductase, and hydroxylamine reductase are important indexes for evaluating biochemical processes related to soil N transformation.

We hypothesized that long-term application of brackish or saline irrigation water will have a detrimental effect on the abundance of AOA and AOB, and that AOA are important in alluvial gray desert soils. The objective of this field experiment was to evaluate the effects of irrigation water salinity and N fertilization on (1) soil physicochemical properties, (2) the abundance of AOA and AOB, (3) potential nitrification rates, (4) soil enzyme activity, and (5) cotton growth, N uptake and yield.

2. Results

2.1. Soil physicochemical properties

Soil water content, electrical conductivity ($EC_{1:5}$), and pH were significantly affected by water salinity and N rate, but not their interaction (Table 1). Soil water content and $EC_{1:5}$ both increased as water salinity increased. Soil pH decreased as water salinity increased. Averaged across the three water treatments, soil water content and pH were both higher in the unfertilized plots than in the fertilized plots. Soil $EC_{1:5}$ was greater in the fertilized plots than in the corresponding unfertilized plots.

Soil NH_4-N and NO_3-N were significantly affected by water salinity, N rate and water salinity×N rate interaction (Table 1). Soil NO_3-N concentrations decreased as water salinity increased, and the effects of water salinity were larger in the fertilized plots than in the unfertilized plots. In the unfertilized plots, the NO_3-N concentration in the fresh water (FW) treatment was 18% greater than that in the brackish water (BW) treatment and 54% greater than that in the saline water (SW) treatment. In the fertilized plots, the NO_3-N concentration in the FW treatment was 67% greater than that in the BW treatment and 115% greater than that in the SW treatment. Soil NH_4-N concentrations increased as water salinity increased. The effects of water salinity on NH_4-N were greater in the fertilized plots than in the unfertilized plots; however, the effects on NH_4-N were not as large as those observed for NO_3-N. Specifically, in the unfertilized plots, the NH_4-N concentration in the FW treatment was 12% less than that in the BW treatment and 18% less than that in the SW treatment. The NH_4-N concentration in the FW treatment was 24% less than that in the BW treatment and 30% less than that in the