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Nitrous oxide emissions from fertilized, irrigated cotton (*Gossypium hirsutum* L.) in the Aral Sea Basin, Uzbekistan: Influence of nitrogen applications and irrigation practices

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Abstract

Nitrous oxide emissions were monitored at three sites over a 2-year period in irrigated cotton fields in Khorezm, Uzbekistan, a region located in the arid deserts of the Aral Sea Basin. The fields were managed using different fertilizer management strategies and irrigation water regimes. N_2O emissions varied widely between years, within 1 year throughout the vegetation season, and between the sites. The amount of irrigation water applied, the amount and type of N fertilizer used, and topsoil temperature had the greatest effect on these emissions.

Very high N_2O emissions of up to 3000 $\mu g\ N_2O\text{-}N\ m^{-2}\ h^{-1}$ were measured in periods following N-fertilizer application in combination with irrigation events. These "emission pulses" accounted for 80–95% of the total N_2O emissions between April and September and varied from 0.9 to 6.5 $kg\ N_2O\text{-}N\ ha^{-1}$. Emission factors (EF), uncorrected for background emission, ranged from 0.4% to 2.6% of total N applied, corresponding to an average EF of 1.48% of applied N fertilizer lost as N_2O-N. This is in line with the default global average value of 1.25% of applied N used in calculations of N_2O emissions by the Intergovernmental Panel on Climate Change.

During the emission pulses, which were triggered by high soil moisture and high availability of mineral N, a clear diurnal pattern of N_2O emissions was observed, driven by daily changes in topsoil temperature. For these periods, air sampling from 8:00 to 10:00 and from 18:00 to 20:00 was found to best represent the mean daily N_2O flux rates. The wet topsoil conditions caused by irrigation favored the production of N_2O from NO_3^- fertilizers, but not from NH_4^+ fertilizers, thus indicating that denitrification was the main process causing N_2O emissions. It is therefore argued that there is scope for reducing N_2O emission from irrigated cotton production; i.e. through the exclusive use of NH_4^+ fertilizers. Advanced application and irrigation techniques such as subsurface fertilizer application, drip irrigation and fertigation may also minimize N_2O emission from this regionally dominant agro-ecosystem.

Keywords: Denitrification; Irrigation; Nitrogen; Soil moisture; Arid climate; Greenhouse gases; Climate change; Emission pulse

1. Introduction

The role of irrigated agriculture in food production is significant; although only 17% of global cropland is irrigated, it provides 40% of the world food production (FAO, 2000). Moreover, irrigation is globally responsible for approximately 70% of anthropogenic water consumption (FAO, 2000). Irrigation not only stimulates plant growth, but also accelerates microbial C- and N-turnover in the soil (Andren et al., 1992; Davidson, 1992). To obtain optimal irrigation benefits, additional crop management practices to optimize nutrient inputs and mode of tillage must be adapted. Any modification of crop management

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and irrigation practice will affect the carbon and nitrogen cycles of these agricultural systems.

In the Aral Sea Basin (ASB), intense agricultural irrigation has reduced the river discharge to the Aral Sea, resulting in more than 80% loss of its volume over the past decades (Micklin, 2007). This demise has led to the "Aral Sea Crisis," which denotes a complex combination of ecological consequences of regional and global dimensions. In Uzbekistan, cotton cultivation was continued after independence from the Soviet Union, and the country still ranks as the fifth largest cotton producer in the world (Bremen Cotton Exchange, 2007). The current agricultural production systems are characterized by crop rotations of cotton–wheat–rice under heavy inputs of water and fertilizers. High inputs of mineral N (150–300 $kg\,N\,ha^{-1}\,yr^{-1}$), in combination with high topsoil moisture levels after irrigation, are conducive to significant N losses to the environment either in the form of nitrate or as gaseous N (NH_3, NO, N_2O, N_2) to the atmosphere.

Although N_2O fluxes under different cropping systems have been investigated (Bouwman et al., 2002), only limited information is available for irrigated agriculture. A few studies reported a strong stimulation of N_2O fluxes by irrigation, but these studies were conducted in temperate semi-arid agricultural systems (Jambert et al., 1997a; Hao et al., 2001) or semi-arid subtropical rice/wheat rotation systems (Aulakh et al., 2001; Majumdar et al., 2002). For irrigated cotton, various studies identified denitrification as the main pathway of fertilizer losses from the soil–plant system (Chua et al., 2003), but did not report on N_2O fluxes (Hou et al., 2007). In Australia, denitrification losses of 40–60% of the applied N fertilizer were reported (Rochester et al., 1996). This is in accordance with findings by Mahmood et al. (2000) who measured denitrification losses of $65\,kg\,N\,ha^{-1}$ using the acetylene inhibition. This corresponded to 40% of the applied fertilizer during one season in the semiarid subtropical climate of Pakistan. Based on a ^{15}N balance approach, Rochester (2003) estimated that roughly $2\,kg\,N\,ha^{-1}$ ($\sim$1.1% of the N applied) was lost as N_2O during the cotton-growing season.

However, to the best of our knowledge, no investigations have been published on N_2O emissions from irrigated agricultural systems in an arid environment based on in-situ flux measurements. Given the 2.7 million ha of irrigated cotton in the five central Asian countries alone (FAOSTAT, 2007), this topic is of great importance. The aims of this study were therefore (i) to identify the site specific regulating parameters for N_2O emissions from irrigated cotton fields in an arid area of Uzbekistan; (ii) to quantify losses of N_2O emissions from variously managed (water regime/fertilizer management) cotton fields throughout the vegetation cycle; (iii) to assess the potential of management and irrigation practice for reducing the emissions of nitrous oxide (N_2O).

2. Material and methods

2.1. Study sites

A field experiment was carried out on research sites of the ZEF/UNESCO project in the Khorezm Region, Uzbekistan, between April 2005 and October 2006. The research station was located at 41°55′N latitude, 60°61′E longitude and at an altitude of 92 m a.s.l. The climate is typically arid continental with long hot dry summers and very cold temperatures in winter. Average precipitation during 1982–2000 was less than $100\,mm\,yr^{-1}$ and the mean annual temperature was 13.6 °C (Glavigdromet, 2003).

Three sites differing in soil texture were selected for the flux measurements. Two sites were part of the Amir Temur Shirkat (a collective farm established from a Soviet kolkhoz or "sovkhoz" farm after independence) situated in the vicinity of the research station. In 2005 and 2006, N_2O emissions were measured during the entire cotton growing period, which lasted from April to October, on experimental fields of the Amir Temur Garden (ATG) farm situated in the central part of the Shirkat. In addition, fluxes were measured in 2005 during May–October on a field of the Amir Temur Cum (ATC) farm in the western part of the Amir Temur Shirkat. The soils were classified as calcaric gleyic Arenosols (FAO, 1998) with silty loamy texture. The land had previously been in a rice/cotton/winter wheat crop rotation. The ATG and ATC sites were completely managed by local farmers following common practice fertilizer and irrigation strategies, which allowed for monitoring of the impact of different local farm management strategies on the emissions of N_2O.

In 2006, N_2O fluxes were recorded on an experimental site at the campus of Urgench State University (URDU), located on a calcaric gleyic Arenosol (FAO, 1998) with a sandy loam soil texture. The experiment was a split-plot design with a total of 48 subplots each 2.5×2.5 m in size, where irrigation was applied. This experiment included two types of irrigation management practices: (i) high intensity irrigation (HI) meaning after the first irrigation of the cotton in June the next irrigation took place when the soil moisture level was 75% of field capacity, and (ii) low intensity irrigation (LI): after the first irrigation of the cotton in June, the next irrigation occurred when the soil moisture decreased to 65% of field capacity. This allowed the effect of two soil moisture regimes on N_2O emissions to be investigated on one field, characterized by higher soil moisture content and more frequent irrigation applications. Soil characteristics and the experimental setup of all sites are shown in Tables 1 and 2.

2.2. Determination of N_2O fluxes

N_2O emissions were measured using the closed chamber technique (IAEA, 1992). This method uses a gas-tight chamber enclosing soil and plants over a given interval. The chamber consists of a frame inserted a few centimeters