Vertical nutrient fluxes in a traditional mountain oasis of northern Oman

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Abstract

Little is known about matter turnover in irrigated oasis agriculture as a criterion to assess their sustainability over time. Recent data on horizontal fluxes of nitrogen (N), phosphorus (P) and potassium (K) from a typical ancient mountain oasis in northern Oman indicated annual per hectare surpluses of 131 kg N, 37 kg P and 84 kg K. The fate of these surpluses remained, however, unclear. The purpose of this study therefore was to design and test a setup that allowed to reliably determine some of the vertical fluxes (gaseous emissions of NH3 and N2O and leaching losses of N and P) across space and time. To this end a 12V battery-powered photo-acoustic multi-gas monitor (INNOVA 1312-5) was fitted to a custom-made Teflon®-coated PVC cuvette of 0.30 m diameter and 10 l volume. The cuvette contained a battery-powered ventilator and allowed not only direct readings of the afore-mentioned gases in the field but also simultaneous records of the temperature and moisture of the air contained therein at an interval < 5 min. Detection limits for NH3 and N2O were 200 µg kg-1 and 20 µg kg-1, respectively. Leaching losses below the major root zone of annual crops following irrigation events were determined with ceramic suction plates and cumulatively with custom-made resin cartridges of 0.11 m surface diameter.

First measurements in spring 2005 at respective minimum and maximum air temperatures of 7 and 42°C and surface soil (0-2 cm) temperatures from 11-24°C yielded gaseous N emission rates from a manured field planted to alfalfa (Medicago sativa L.) equivalent to 4-37 kg NH3-N and 3-18 N2O-N per hectare and year. These values were strongly dependent on soil temperature and time after irrigation (soil moisture) and to an only smaller degree on the amount of applied manure compost. Leaching losses in palm groves were 2-6% of the applied irrigation water with an estimated annual N load of 15 kg N ha-1 and 1.5 kg P ha-1, whereas on the alfalfa field they were < 2 kg N ha-1 yr-1 without measurable amounts of P. While further measurements are under way to assess the reliability of these estimates, the results obtained so far indicate that under the agro-environmental conditions of these oases there still must be other major pathways to explain the fate of N in the matter balance such as losses as N2 or the built-up of organic matter.
Introduction

In recent years matter fluxes have received increasing attention as proxies to assess the sustainability of agro-ecosystems (Wichern et al., 2004) and to determine the effects of cropping systems and management practices as drivers of matter turnover processes on emission-related global warming (Ko and Kang, 2000; Wang and Adachi, 2000; Wassmann et al., 2000; Xu et al., 2000). In this context calculating horizontal matter fluxes may be tedious but it is methodologically relatively simple compared to the determination of vertical fluxes. While leaching losses are normally determined by lysimeters, suction plates or exchange resins with reliable results over time and space, considerable debate still exists about the use of good field approaches to measure gas emissions from agricultural systems such NH3, N2O, NO, NOx, CO2 and CH4. A major drawback of most available gaschromatographic and chemoluminescence-based approaches is that they do not allow for direct readings in the field. Instead gas samples have to be stored in containers and taken to the laboratory for analysis. Closed chambers directly connected to analytical devices and providing automatic readings (Butterbach-Bahl et al., 1997) overcome this disadvantage, but are very expensive, hard to move and therefore unsuitable for most on-farm measurements. Given these constraints to large scale sampling both approaches favor homogenous environments where natural variations in emissions over small distances are assumed to be small compared to treatment-induced differences. However, this assumption may not be true for many marginal agro-ecosystems where small differences in physical, biological or chemical soil properties can cause large effects on turnover rates. To estimate vertical nutrient fluxes and to address the mentioned weaknesses of existing measurement devices for trace gas emissions we aimed at developing and testing a portable setup to directly determine fluxes of NH3 and N2O at the field level thus allowing to capture emission variations in space and time at a low cost in consumables. These measurements were complemented by a time-related determination of nutrient leaching taken with suction plates.

Materials and methods

Monitoring of gaseous emissions

A photo-acoustic infra-red multi-gas analyzer (INNOVA 1312-5, INNOVA AirTech Instruments, Ballerup, Denmark), originally developed for the detection of poison gases and the control of surgery gas flows in hospitals was the central element of the setup. To this a 14.2 cm high cuvette made of a standard PVC tube with 0.30 m diameter (10 L volume) of which the upper end was closed with a PVC lid and the inner walls coated with a Teflon film was fitted (Fig. 1; Buerkert et al., 2005). Initial trials of the setup showed that sensitivity was highest and increases in trace gas concentration linear up to 10 min after placement of the cuvette. The duration of the measurement interval (sample integration time) varied from 2–5 min. Lower detection limits for NH3 and N2O were 200 µg kg-1 and 20 µg kg-1, respectively.

In spring 2005 NH3 and N2O fluxes were measured with the described instrument on terraced Irragric Anthrosols of the Balad Seet mountain oasis (23.19° N, 57.39° E, 995 m asl) in Oman (Luedeling et al., 2005; Nagieb et al., 2004). Within this oasis a field (5 x 10 m), subdivided into flood irrigated 2 m2 sized basins (in Arabic ‘jalba’) and planted to perennial alfalfa with and without manure application was chosen. To capture variation in gas flux fluxes across space, temperature and different soil moisture levels, measurements were conducted at six locations within each ‘jalba’ for each of the measurement times during the day’s coolest (5-6 am) and hottest (1-2pm) hours of two irrigation cycles. Measurements were conducted on day 1, 5, 7 and 11 and on day 1, 5, 7 and 11 after surface flooding in two irrigation cycles, respectively. For this paper only average gas emissions data from manured plots are presented.
Figure 1. Photographs of the outside of a cuvette custom-made of a PVC tube to capture trace gas emissions in the field with the INNOVA multi-gas monitor on the left (above) and of the Teflon®-coated inner surface of the cuvette (below) showing in its centre the 12V-powered ventilator.

Leaching measurements

To estimate nutrient losses over a 12-months period on typical plots anion-cation resin-filled cartridges of 0.11 m surface diameter were buried below the major rooting depth (0.45m) of two plots planted to date palms and two plots grown to agricultural crops (0.60m depth). Suction plates of about 30 cm diameter were used to estimate irrigation-event-specific leaching losses for N and P. These plates were buried at similar depths as the resin cartridges in the same plots as the resin cartridges. For the purpose of this study leaching losses were calculated from the suction plates only and based on the amount and the concentration of N and P determined in the solution obtained at a suction pressure of 100 hPa.

Results

The gas measurements at respective minimum and maximum air temperatures of 7 and 42°C and surface soil (2 cm) temperatures from 11-24°C yielded gaseous N emission rates from the manured alfalfa field equivalent to 4-37 kg NH3-N and 3-18 N2O-N per hectare and year (Fig. 2). These widely varying data were strongly dependent on soil temperature and time after irrigation (soil moisture) and to an only smaller degree on the presence of manure compost. Leaching losses in palm groves amounted to 2-6% of the applied irrigation water with an estimated annual N load of 15 kg N ha-1 and 1.5 kg P ha-1, whereas on the alfalfa field they were < 2 kg N ha-1 yr-1 without measurable amounts of P.
Figure 2. Effects of daytime and related surface soil (0-2cm) temperature on average emission rates of ammonia (NH₃) and nitrous oxide (N₂O) from a manured field planted to alfalfa in an irrigated mountain oasis of northern Oman.

Further measurements will certainly be needed to assess the precision of the setup and determine the effects of higher summer temperatures on gaseous emission rates and of higher evapotranspiration on leaching. However, the results obtained so far indicate the potential of our approach to obtain moisture regime-dependent measurements of vertical nutrient losses from farmers’ fields taken under difficult agro-environmental conditions with a high variability in time and space. In view of the large calculated N surpluses from horizontal flux data (inputs-outputs) the vertical N-losses are surprisingly low. The N so far unaccounted for may partly be emitted as N₂ (or NO) or may be used for the continued built-up of organic matter in these soils even if this may seem unlikely given their low C/N ratio of about 12 (Wichern et al., 2004).

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References


