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Plant genetic diversity, irrigation and nutrient cycling in traditional mountain oases of northern Oman

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Abstract

Little is known about plant biodiversity, irrigation management and nutrient fluxes as criteria to assess the sustainability of traditional irrigation agriculture in eastern Arabia. Therefore interdisciplinary studies were conducted over 4 yrs on flood-irrigated fields dominated by wheat (*Triticum* spp.), alfalfa (*Medicago sativa* L.) and date palm (*Phoenix dactylifera* L.) in two mountain oases of northern Oman. In both oases wheat landraces consisted of varietal mixtures comprising *T. aestivum* and *T. durum* of which at least two botanical varieties were new to science. During irrigation cycles of 6-9 days on an alfalfa-planted soil, volumetric water contents ranged from 30-13%. For cropland, partial oasis balances (comprising inputs of manure, mineral fertilizers, N_2-fixation and irrigation water, and outputs of harvested products) were similar for both oases, with per hectare annual surpluses of 131 kg N, 37 kg P and 84 kg K at Balad Seet and of 136 kg N, 16 kg P and 66 kg K at Maqta. Respective palm grove surpluses, in contrast were with 303 kg N, 38 kg P, and 173 kg K ha^{-1} yr^{-1} much higher at Balad Seet than with 84 kg N, 14 kg P and 91 kg K ha^{-1} yr^{-1} at Maqta. The results show that the sustainability of these irrigated landuse systems depends on a high quality of the irrigation water with low Na but high $CaCO_3$, intensive recycling of manure and an elaborate terrace structure with a well tailored water management system that allows adequate drainage.

Introduction

Fluxes of nutrients and energy, and genetic diversity in agro-ecosystems are increasingly used as a criterion to assess the effects of management practices on the environment and system's sustainability. Initial work on nutrient balances for low-input cropping systems in Africa was done by Dutch scientists (Smaling et al., 1993). Recent advances in measurement techniques of trace gases have allowed to refine the methodology for temperate agro-ecosystems and for intensively managed Asian rice (Butterbach-Bahl et al., 2001). Yet little information is available on nutrient fluxes in complex, small scale crop rotations such as practiced in intensively irrigated desert oasis systems of eastern Arabia. This study was conducted to fill this gap of knowledge. The underlying hypothesis was that a diverse germplasm, the avoidance of salinization by an elaborate irrigation system with a well defined amount of leaching, and large surpluses of N, P and K are important characteristics of these millennia-old systems.

Materials and methods

In spring 2001 and 2002, fields in remote mountain oases of northern Oman planted to traditional wheat landraces were surveyed and the collected material was subjected to morphological and microsatellite-based molecular analyses (Zhang et al., 2005). To trace the origin of Omani wheat, the data from the latter analyses were subsequently compared to those of 36 landraces from CIMMYT's world collection of wheat. In the oasis of Balad Seet, standard soil analyses to 1.5 m depth and a KBr-tracer irrigation experiment were conducted on an Irragric Anthrosol planted to alfalfa. In the oases of Balad Seet and Maqta, horizontal nutrient fluxes (inputs and outputs) were measured at the plot level for all existing cropping systems and subsequently aggregated to establish partial oasis balances. In early 2005, first vertical flux measurements (gaseous emissions of N_2O, NH_3 and CH_4 and leaching losses of N and P) were measured in a farmer's alfalfa field. Direct readings of gaseous emissions, air temperature and moisture were obtained in the field at an interval of up to 5 min by a 12V battery-powered photoacoustic infra-red multi-gas analyzer (INNOVA 1312-5) to which a custom-made Teflon®-coated PVC cuvette-receptor of 0.30 m diameter and 10 l volume was fitted. Detection limits for N_2O, NH_3 and CH_4 were 20 µg kg^{-1}, 200 µg kg^{-1} and 400 µg kg^{-1}, respectively (Hans, unpublished). 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.

Results and Discussion

Diversity of wheat

The morphological characterization revealed that the collected landraces were often mixtures of T. *aestivum* and T. *durum* comprising a total of eight known and two new botanical varieties (Al-Maskri et al., 2003). A dendrogram of three Omani bread wheat landraces and the CIMMYT landraces demonstrated that the three Omani bread wheat landraces clustered closely together but were fairly distant from all other landraces except for two from Pakistan (Zhang et al., 2005).

Properties of terrace soils and irrigation management

The C_{inorg} contents exceeded 4% at all depths. These high values reflect the lime content of up to 43% throughout the profile. Soil pH values ranged from 8.3 to 8.4. Organic carbon averaged 3.2% at 0-0.45 m and declined substantially with depth. The soil's electrical conductivity (EC) was 0.9-1.4 dS m^{-1} at 0-0.45 m, but 4-5 times higher below 0.45 m depth. Irrigation cycles lasted 6-9 days with a volumetric water content of 30-13%. The KBr-tracer experiment revealed that 52-56% of the irrigation water was stored in the upper 0.4 m of the soil and about 33% of a 60 mm irrigation was leaching beyond 0.8 m.

Horizontal fluxes and partial balances of nutrients

Input intensities far exceeded outputs for N, P and K on cropland but also on land planted to date palms (Fig. 1). At Balad Seet N_2-fixation by alfalfa, estimated by a ^{15}N study at 380-480 kg ha^{-1} yr^{-1} with an average total dry matter of 22 t ha^{-1}, greatly contributed to the cropland N-balance. In this oasis cropland nutrient inputs from manure were 1.3–5.9-fold higher than those from synthetic fertilizers, in palm groves this ratio varied from 2.3–73-fold. Nutrient gains per unit area in palm groves were higher than on cropland, by 131% for N, by 1% for P and by 106% for K. The relatively lower rates of manure and synthetic fertilizers applied to palm groves compared to cropland were for N and P compensated by the application of human faeces. Compared to palm groves nutrient removal by harvested products from cropland was 344% higher for N, 231% higher for P and 131% higher for K (Table 1).

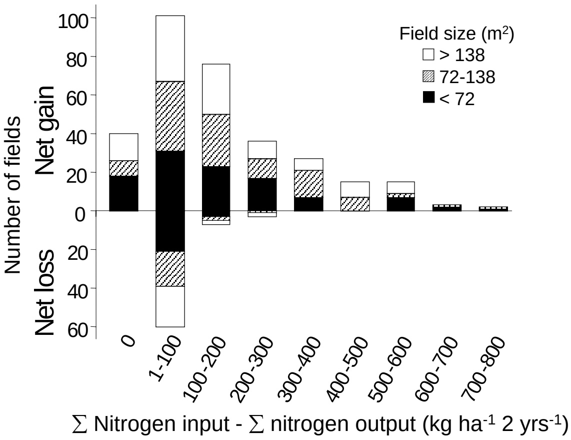

Figure 1. Bi-annual partial balances (inputs minus outputs) of nitrogen on the three different field size classes at the 'core oasis' of Balad Seet, Oman, from 2001/2002. Columns show absolute frequencies in their respective input classes and comprise all 385 fields of the oasis system.

Compared to cropland at Balad Seet, fields at Maqta received on average only 61% of the total N, 39% of the P and 64% of the K inputs. Similar differences in input intensities were noted for palm groves. In contrast to Balad Seet, irrigation and human faeces contributed only very small amounts of N, P, and K at Maqta. Average annual area-based nutrient surpluses in cropland were similar in both oases, but were much higher for palm groves at Balad Seet than at Maqta (data not shown).

Gaseous emissions

The trace gas measurements of spring 2005 with respective minimum and maximum air temperatures of 7 and 42°C yielded emission rates equivalent to 2-24 kg N_2O, 1-104 kg NH_3-N and 3-1200 kg CH_4 ha^{-1} yr^{-1}. Emissions seemed to strongly depend on soil temperature and time after irrigation (soil moisture), but only marginally on the presence of manure compost.

Conclusions

Remote Omani mountain oases are refugia for ancient wheat germplasm. High quality irrigation water, the elaborately built soil structure of the terraces, a system of water distribution designed to match crop needs during different growth stages and adequate drainage are the main factors explaining the lack of salinization in these systems.

At present both oases studied appear to be large sinks and sources for nutrients. Nutrient losses through leaching may be restricted to the winter months when potential evaporation is much lower than in summer and when sufficient water is available to allow its regular application at up to 90 mm per irrigation event.

Table 1. Annual inputs, outputs and partial balances of nitrogen (N), phosphorus (P) and potassium (K) in cropland and palms groves at Balad Seet (Oman) measured from October 2000 to October 2002 (Buerkert et al., 2005).

Land use system	Source / Process	Input and output (kg ha^{-1} yr^{-1})†		
		N	P	K
Cropland (4.6 ha)	Synthetic fertilizer	143	23.9	45
	Animal manure	180	40.2	267
	Irrigation water‡	10	5.2	17
	Symbiotic N_2-fixation	63	n.a.‡	n.a.
	Crop harvest	-265	-32.8	-245
	Partial balance	**131**	**36.5**	**84**
Palm groves (8.8 ha)	Synthetic fertilizer	59	1.8	4
	Animal manure + ashes	141	8.0	289
	Irrigation water	10	5.2	17
	Human faeces	170	37.0	50
	Date palm harvest (dates + stems + leaves)	-63	-12.7	-176
	Harvested understory fodder	-14	-1.5	-11
	Partial balance	**303**	**37.8**	**173**
Oasis	**Total partial balance**	**244**	**37.4**	**142**

† Positive values indicate gains and negative ones losses. ‡ Total annual spring flow of 228,587 m^3 was multiplied by nutrient concentrations of 0.57 mg N l^{-1}, 0.30 mg P l^{-1} and 1.0 mg K l^{-1} and adjusted to the respective irrigated surface area. Average irrigation intensity was assumed to be similar on both types of land use. * not applicable

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