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Effects of transition season management on soil N dynamics and system N balances in rice–wheat rotations of Nepal

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Abstract

In the low-input rice–wheat production systems of Nepal, the N nutrition of both crops is largely based on the supply from soil pools. Declining yield trends call for management interventions aiming at the avoidance of native soil N losses. A field study was conducted at two sites in the lowland and the upper mid-hills of Nepal with contrasting temperature regimes and durations of the dry-to-wet season transition period between the harvest of wheat and the transplanting of lowland rice. Technical options included the return of the straw of the preceding wheat crop, the cultivation of short-cycled crops during the transition season, and combinations of both. Dynamics of soil N_{min}, nitrate leaching, nitrous oxide emissions, and crop N uptake were studied throughout the year between 2004 and 2005 and partial N balances of the cropping systems were established. In the traditional system (bare fallow between wheat and rice) a large accumulation of soil nitrate N and its subsequent disappearance upon soil saturation occurred during the transition season. This nitrate loss was associated with nitrate leaching (6.3 and 12.8 kg ha^{-1} at the low and high altitude sites, respectively) and peaks of nitrous oxide emissions (120 and 480 mg m^{-2} h^{-1} at the low and high altitude sites, respectively). Incorporation of wheat straw at 3 Mg ha^{-1} and/or cultivation of a nitrate catch crop during the transition season significantly reduced the build up of soil nitrate and subsequent N losses at the low altitude site. At the high altitude site, cumulative grain yields increased from 2.35 Mg ha^{-1} with bare fallow during the transition season to 3.44 Mg ha^{-1} when wheat straw was incorporated. At the low altitude site, the cumulative yield significantly increased from 2.85 Mg ha^{-1} (bare fallow) to between 3.63 and 6.63 Mg ha^{-1}, depending on the transition season option applied. Irrespective of the site and the land use option applied during the transition season, systems N balances remained largely negative, ranging from −37 to −84 kg N ha^{-1}. We conclude that despite reduced N losses and increased grain yields the proposed options need to be complemented with additional N inputs to sustain long-term productivity.

Keywords: Denitrification; Mucuna; Nitrate leaching; *Oryza sativa*; *Triticum aestivum*

1. Introduction

In South Asia, rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are often grown in the same field in an annual rotation providing from an estimated 24 million ha food for about 400 million people (Prasad, 2005). In contrast to the high-input systems of India, the 0.5 million ha of rice–wheat in Nepal are primarily produced in low-input systems (Hobbs and Morris, 1996) with less than 30 kg mineral fertilizer ha^{-1} $year^{-1}$ (Pandey and Joshy, 2000) and yields rarely exceeding 2 Mg ha^{-1} in rice and 1.3 Mg ha^{-1} in wheat (Pandey et al., 1999). From long-term field experiments it has been concluded that N is the most limiting factor for the production of both rice and wheat in Nepal (Regmi et al., 2002; Gami et al., 2001) and at least partially responsible for the recently observed declining yield trends (Ladha et al., 2003). With the current low-input orientation of the production, the N nutrition of both rice and wheat is largely based on the supply from the native soil pool and, to a lesser extent, on animal manure.

In the rice–wheat system, rice is grown during the monsoon season and wheat during the cold and dry winter season. There is a transition period of variable length between the harvest of wheat and the transplanting of rice, during which the land typically lies fallow. The length of this dry-to-wet season transition (DWT) is determined by the temperature environment and the resulting growth duration of the rice and wheat,

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and can extend up to 12 weeks in the hot tropical lowland climate of the Terai and be as short as 6 weeks at the high altitude sites of the Himalayan mid-hills (Prasad, 2005). During this DWT, the soil aeration status changes from aerobic to anaerobic, typically undergoing several cycles of soil drying and re-wetting (George et al., 1993). Such changes in soil aeration status during DWT have been shown to result initially in N mineralization and the accumulation of large amounts of nitrate in the soil. Subsequent soil saturation, at the end of DWT, reportedly results in substantial losses of native soil N by leaching and denitrification (George et al., 1995a; Aulakha et al., 2000; Pathak et al., 2006). The extent of the prevailing loss mechanism depends on the amount of nitrate present in the soil solution, the quantity of easily mineralizable carbon sources, the intensity of the rain and the flow of water in the soil profile (Li, 2000; Pathak et al., 2002). Avoidance of that loss may improve N nutrition of the succeeding crops of rice and wheat and improve the largely negative N balances (George et al., 1992).

In Nepal, cereal stubble and straw are generally removed from the field. The residue removal exacerbates the decline in soil organic matter (Walia et al., 1995; Hobbs and Pasuquin, 1999, Regmi et al., 2002) and can contribute to K imbalances (Mussgnug et al., 2006). Residue removal has also been shown in other tropical cereal-based cropping systems to largely explain a declining N supplying capacity of the soil (Mary et al., 1996; Dobermann et al., 2003). A very low external input use combined with residue removal has reportedly increased the nutrient imbalances in a range of rice-based production systems (Adhikari et al., 1999; Samra et al., 2003), but most particularly that of N deficiency (Becker et al., 1994; Ladha et al., 2003; Phongpan and Mosier, 2003). A return of the wheat straw, which is normally removed or burnt, is seen to not only return substantial quantities of carbon and potassium, but may also reduce N losses by temporary immobilization of N_{min} in the soil microbial biomass (Verma and Bhagat, 1992; Bhogal et al., 1997). Another option may be to grow short-cycled crops (<90 days) during the extended DWT of the rice–wheat systems in lowland areas and recycle the crop residues and the nutrients they contain (George et al., 1995a; Ment et al., 1998). Such crops assimilate soil nitrate and may thus protect it from leaching and denitrification losses (Samra et al., 2003). Growing nitrogen-fixing crops may additionally contribute N from the atmosphere to the system (Peoples et al., 1995; George et al., 1998). A combination of straw cycling together with legume cultivation during DWT may further increase above-mentioned benefits and has been shown to increase the grain yield of both rice and wheat (Pande and Becker, 2003).

Above results highlight (1) the importance of DWT for native soil N dynamics, (2) the role of low quality crop residues in temporary N conservation, and (3) the possible effects of pre-rice nitrate catch crops on N balances. The choice of the option will depend on the length of DTW (temperature environment along the altitude gradient) and farmers' needs or alternative use options for residues. To date, little is known about the effect of such land use options on improving the currently negative N balance of the traditional rice–wheat rotation systems in Nepal. The objectives of the field study were, therefore, to evaluate the effect of straw and legume management on N dynamics and system N balances at representative rice–wheat-growing sites in Nepal.

2. Materials and methods

2.1. Characteristics of research sites

Field experiments were conducted at two typical but contrasting rice–wheat-growing sites of Nepal between March 2003 and 2004. One site was located close to the experimental station of the Nepal Agricultural Research Council (NARC) at Lumle (1740 m above the sea level, 28°18′N latitude and 83°28′E longitude) and is representative of rice–wheat cropping system at high altitudes of the Himalayan mid-hills. The climate is cool-subtropical/temperate with cold and dry winter and a monsoon influenced warm and humid summer season. The annual rainfall of 5500 mm is concentrated in the period between May and October. The temperature ranges from 20 to 28 °C in summer and 2 to 12 °C in winter with a mean annual temperature of 19.8 °C. The cultivation period for lowland rice is between June and October, the one of wheat is between November and April. The other study site was located on the experimental farm of the Institute of Agriculture and Animal Science (IAAS) of Tribhuvan University at Rampur (250 m above sea level, 27°37′ N latitude and 84°25′ E longitude) and is representative of the lowland area of the Terai. The climate is warm subtropical with mild dry winter and a monsoon-influenced hot and humid summer season. The total annual rainfall of 2600 mm is concentrated in the period between May and October. The temperature ranges from 33.7 to 36.5 °C in summer and 19.7 to 25.4 °C in winter with a mean annual temperature of 28.6 °C. The cultivation period for lowland rice is between July and November and that of wheat is between November and March. Between the harvest of wheat and transplanting of lowland rice lies a dry-to-wet season transition period (DWT) of 8 weeks in Lumle and of 12 weeks duration in Rampur, during which the land lies typically fallow in the traditional production system of the region. Both sites were under continuous low-input rice–wheat rotations for more than 10 years. Climate data (rainfall and min–max temperatures), soil moisture profiles and the typical cropping patterns at the experimental sites are presented in Fig. 1. Both soils are classified as Ultisol (typical Tropaquult) with similar textural class (sandy loam soil). The pH was more acidic at the high altitude (pH 4.4) than at low altitude sites (pH 6.8). The soils of the low altitude sites contained less organic carbon (1.1–1.5%) and N (0.1%) than of the high altitude site, where soil organic carbon exceeded 3% and N content was 0.39%. Selected physico-chemical characteristics of the experimental soils are presented in Table 1.

2.2. Plant material

The lowland rice variety Masuli was obtained from IAAS. It is a medium duration (145 days) improved semi-dwarf variety