The Journal of Agriculture and Environment Vol:9, Jun.2008 Technical Paper

MANAGEMENT OF NATIVE SOIL NITROGEN FOR REDUCING NITROUS OXIDE EMISSIONS AND HIGHER RICE PRODUCTION

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ABSTRACT

Present production of rice is far below its reported potential yield because of being N-deficiency, the major constraint. Because of poverty, small farmers have to rely on native soil N-supply. Between wheat harvest and rice transplanting, a dry-to-wet season transition (DWT) period exist with changing soil moisture from aerobic to anaerobic and a large amount of native soil N loss is hypothesized. To study soil N dynamism and possible management options for DWT, two years field experiments were conducted in Chitwan with four land management treatments like bare fallow, mucuna, mungbean and maize. Treatments were randomly allotted in 10 m^2 *plots. During DWT, building up of 50-75 kg of nitrate-N was observed at 60-75 % field capacity (FC) soil moisture but lost after flooding through leaching and denitrification, resulting in low grain yield and N uptake of succeeding rice. Growing cover crops during DWT, reduced leaching loss by half and* N_2O *emissions by two thirds of those in the bare fallows. Atmospheric-N addition by legumes ranged from 27 to 56 kg* ha^{-1} *depending on the types of legumes and increased N uptake and grain yield by 24-42 kg N* ha^{-1} yr^{-1} *and 1.2-2.1 Mg* ha^{-1} yr^{-1}*respectively. Thus, cultivation of grain/green manure legumes appears economically and ecologically beneficial.*

Key Words: bare fallow, crop N uptake, denitrification, green manure, leaching, nitrate catch crops, nitrification

INTRODUCTION

Rice (*Oryza sativa* L.) is an important food crop of Nepal. Rice and wheat provide food for about 23 million people in Nepal (Ladha et al., 2000) and cover about 0.5 million hectares in Nepal (Hobbs and Morris, 1996). The reported maximum grain yield of rice was 8 Mg ha^{-1} in mid hills research station at Khumaltar (Pandey et al., 1999) and 5 Mg ha^{-1} in an experimental station at Bhairahawa (Regmi et al., 2002). Long-term monitoring on experimental stations and farmers' field indicates that at constant inputs, the grain yield of both crops is declining. Currently, the mean yield of rice is 2 Mg ha^{-1} (Pandey et al., 1999). However, to provide food for a rapidly growing population, Nepal needs to increase the production of rice by 1 Mg ha^{-1} and that of wheat by 0.6 Mg ha^{-1} by the end of 2020 (Hobbs and Adhikari, 1997; Gami et al., 2001). The gap between the maximum observed and national average yield as well as the declining yield trend requires an urgent research attention.

A number of factors have been associated with the current low and even declining productivity of the system. A diagnostic field survey conducted in the Terai area of Nepal identified both short-term and long-term key problems associated with low production and declining productivity in the rice-wheat system (Harrington et al., 1993). Dominating both the long and short-term problems are soil fertility issues, primarily associated with N deficiency.

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Since about 40% of Nepalese farmers live below the poverty line with less than 244 US$ per capita of annual income (CBS, 2001), the use of external inputs (i.e. mineral fertilizers) are not affordable to these marginal farmers. Because of poor road networking, the availability of mineral fertilizers is not on time. Consequently, the N nutrition of rice largely based on the supply from the native soil N pool and animal manure. Under such circumstances, the efficient use of systems' internal resources such as the recycling of crop residues and manures, minimization of nutrient losses, and the addition of N by biologically fixed N (BNF) must be explored to much larger extent than at present.

OBJECTIVES

Two years field experiments were conducted in Agronomy farm of Rampur Campus and participatory research in three field sites of Chitwan. The objectives of the study were to

(1) quantify the effect of DWT land management on
    soil N mineralization, nitrate-N leaching and N_2O emissions
    N immobilization in grown crop biomass
    atmospheric N_2 fixation by legumes
(2) evaluate the effect of DWT land management on wet season rice, involving
    soil and residue N mineralization
    grain yield and N uptake

MATERIALS AND METHODS

Two years field trials were conducted in agronomy farm of Rampur Campus and in three farmers' fields of Mangalpur Village Development Committee, Chitwan. The experimental sites were located at 27°37' N latitude and 84°25' E longitude with an elevation of 240-260 meter above sea level. The monthly rainfall gradually increased from 101 mm in April to 930 mm in July. The total annual rainfall of 2600 mm is concentrated in the period between May and October. The site was under continuous rice-wheat rotation for more than 10 years. The transplanting period is June-July and before transplanting of lowland rice there exists a DWT period. The average monthly temperatures and rainfall of the experimental site are presented below.

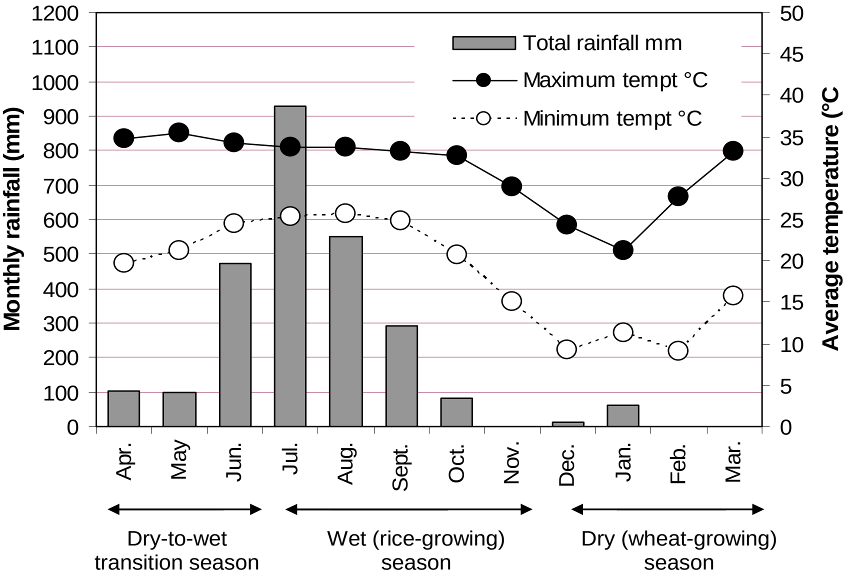


Figure 1. Monthly rainfall and mean maximum-minimum temperatures at the lowland field site in Nepal (field experiment, Rampur, Chitwan province, Nepal, 2003).

Eexperimental soils

Soils at the experimental field sites were sandy loam. The soil reaction is acidic (pH 6.1-6.8) with low organic carbon (1.1-1.5%) and low nitrogen (0.1%).

Plant material

Freshly uprooted, 21-day-old seedlings of Masuli rice were transplanted at 20x20 cm spacing with three seedlings per hill in the puddled, flooded soil during wet season. Mucuna (puriens var utilis L.), mungbean (Vigna radiata L.) and maize (Zea mays) were DWT period land-management crops. Mucuna, mung bean and maize were seeded at 40x30 cm, 40x5 cm and 40X20 cm spacing respectively.

Soil and plant analyses

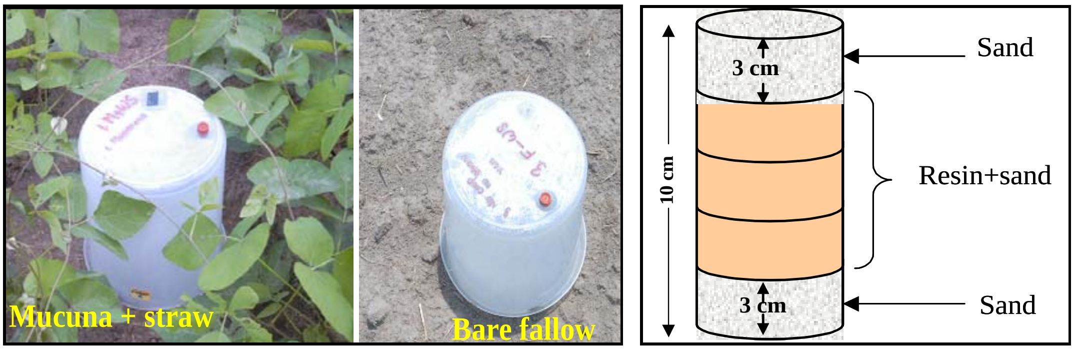
The crop dry matter was determined based on 1m^2 harvest areas at the end of DWT. The total N was determined by micro-Kjeldahl and ^{15}N was analysed using mass spectrometry (ANCA SL coupled to 20-20 stable isotope analyser IRMS, Europa scientific/ PDZ now Sercon Ltd., UK). The natural abundance of the staple isotope ^{15}N was determined in finly ground plant samples using the method described by Shearer and Kohl (1980) with

$$\text{o/oo } \delta 15 \text{ N excess} = \frac{\text{atom } \%\delta^{15}\text{ N sample} - \text{atom } \%\delta^{15}\text{ N atmosphere}}{\text{atom } \%\delta^{15}\text{ N atmosphere}}$$

The share of biological nitrogen fixation was calculated as,

$$\text{Ndfa } \% = 1- \frac{\delta^{15}\text{N excess in the sample}}{\delta^{15}\text{N excess in the reference plant } + \beta} \text{ X } 100$$

The ß-values for natural discrimination against ^{15}N were taken from Becker and Johnson (1998). Soil samples of about 40 g (dry weight) were extracted with 100 ml of 2M KCl after shaking for two hours. Ammonium and nitrate nitrogen were determined colorimetrically using an EC standard Autoanalyser III, Bran+Luebbe, Norderstedt, Germany.



(a) (b)

Figure 2. NO_3-N collection chambers in the field plots (a) and resin capsule (b) prepared to put in the soil to measure nitrate leaching, Rampur, Chitwan, Nepal, 2003.

The NO_3-N leached from the topsoil during DWT was determined in mixed ion-exchange resin cores containing three resin bags in each core and placed at 30 cm depth. Nitrous oxide emission from soils during the DWT was collected bi-weekly in closed chambers of 19 cm diameter and 24 cm height as well as after each rainfall in 20ml closed vials by double displacement method. The initial gas sample was taken just after installation of the chamber and next after 2 hours later. Gas samples were analyzed for N_2O by using gas chromatography (SRI [Torrance, CA] 8610C) with a back flush system to eliminate water vapour and on an electron capture detector (ECD) at a column temperature of 40°C, and ECD temperature of 320°C. The N_2O emission was expressed as $\mu g\ m^{-2}h^{-1}$. The soil moisture was measured bi-weekly at a depth of 10 cm during DWT by using Time Domain Refractometer (TDR: Trime FM 2 (IMCO GmbH, Ettlingen, Germany).

Treatments application

The DWT period land management treatments were bare fallow and three different transition season crops, namely mucuna, mungbean and maize. Treatments were arranged in a Complete Randomized Block Design (RCBD) in four times replicated 4mx3m sized plots.

RESULTS AND DISCUSSION

The outcomes of the experiments are presented and discussed with findings of the other workers in this section.

Soil N dynamics during the dry-to-wet transition season

The DWT period in rice-wheat fields of the Terai, Inner-Terai, river basins (tars) were long enough to grow transition season crops to manage seasonal soil N dynamics. A gradual increment in soil moisture resulted change in the available forms of N_{min} in the soil. The initial NH_4-N content in the bare soil decreased from 21.2 to 5.9 kg ha^{-1} and from 12.3 to 9.3 kg ha_{-1} at 6 weeks after wheat harvesting in the years 2001 and 2003, respectively. At soil saturation by the monsoon rains, the NH_4-N content gradually increased to 26.4 and 28.8 kg ha^{-1} after 14 weeks of wheat harvesting in the years 2001 and 2003, respectively. A reverse pattern was observed in the case of NO_3-N in both years. Nitrate peak of 51 kg ha^{-1} and 75.3 kg ha^{-1} were observed in the bare fallow soil in the years 2001 and 2003, respectively. With the onset of monsoon rain, the bare soil was saturated by water and almost all NO_3-N disappeared from the soil in both years.

The highest NO_3-N (51 kg ha^{-1} in 2001 and 75 kg ha^{-1} in 2003) built up was observed at soil moisture content of 60-75% FC under bare fallow. Other workers like Inubushi et al. (1996) observed a nitrate peak at 60% FC and Flessa et al. (1996), Bollmann and Conrad (1998) observed nitrate peak at <80% FC. Thus, in present study 60-75% FC soil moisture was most favourable for nitrifying bacteria and that result the highest NO_3-N in the soil. However, the NO_3-N peak observed in 2003 was much higher than that in 2001. In 2003, the soil drying and wetting cycles were more frequent and more severe than in 2001. As Sehy, et al. (2004) observed an enhanced activity of nitrifying bacteria in the soil under frequent soil drying and wetting, the higher nitrate peak in 2003 could be due to the presence of higher frequency of wetting and drying cycles.

Numbers of studies on the N dynamics in seasonally flooded soils of South Asia, and Southeast Asia highlighted the occurrence of the Birch effect (N mineralization peak) after the first rains and the near complete disappearance of the nitrate fraction at the beginning of the main wet season (Pande and Becker, 2003; Shrestha and Ladha, 1998). Numerous authors reported large N losses by denitrification after soil flooding (Bacon et al., 1986). In present study, the disappearance of 47-73 kg NO_3-N ha^{-1} from the field at the end of DWT may be attributed to a combination of nitrate leaching and denitrification caused by heavy rain and soil saturation.

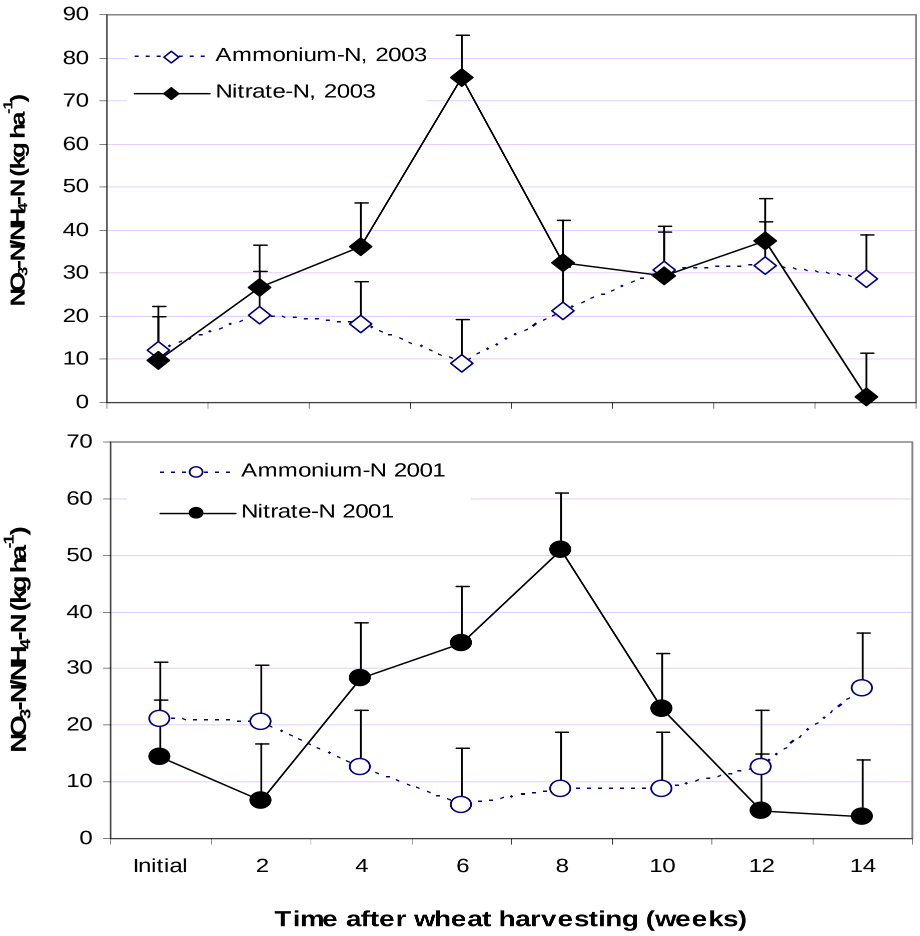


Figure 3. Soil N_{min} dynamics in the bare fallow soil during the dry-to-wet season transition period (2001 and 2003). Bars present standard errors of the mean (n=4).

The growth of the transition season crops reduced the soil NO_3-N peak from 51 kg ha^{-1} in the bare fallow to 25, 27 and 32 kg ha^{-1} in 2001 and from 75 kg ha^{-1} to 34.9, 36.6 and 29.4 kg ha^{-1} in 2003 in the land management treatments maize, mungbean and mucuna respectively. Large differences in NO_3-N leaching from the top soil were also observed among DWT treatments. The highest amount (12 kg ha^{-1}) NO_3-N leached from the topsoil from the bare fallow control and the lowest 0.57 kg ha^{-1} of NO_3-N was leached from the mucuna treatment. Other workers like Kladivko et al. (2004), also observed reduced nitrate leaching from a topsoil of Indiana by growing nitrate trap crops in the field. Shrestha and Ladha (1998), observed significantly (P=0.05) reduced NO_3-N leaching from the plots with maize, indigo, and mungbean during DWT than bare fallow control in the Philippines. Hartemink et al. (1996) observed a significantly reduced NO_3-N leaching from the topsoil in the Sesbania sesban, Zea mays and weedy fallow than bare fallow. Present study, the lowest NO_3-N leached from the plots of mucuna treatment could be linked with immobilization of soil N_{min} in the plant biomass.

Large amounts of nitrous oxide emissions observed during DWT with several cycles of soil drying and wetting. Both prolonged drying and prolonged wetting periods decreased the emission. A first peak of N_2O emission of 27 µg N m-2 h^{-1} was observed at 63 % FC soil moisture in the bare fallow treatment. This peak was related with the maximum of NO_3-N in the soil and was possibly associated with the oxidation of NH_4-N (nitrification). In an incubation study, Hütsch et al. (1999) observed a significantly higher amount of emission by changing the soil water content from 60% to 120% FC. Flessa et al. (1996) and Bollmann and Conrad (1998) determined nitrification as the main determining process for N_2O emission in soil with < 80% FC. Parton et al. (1996) observed the best condition for nitrifiers at 60% FC soil moisture with large associated N_2O emissions. By alternate draining and flooding in rice fields, Xing and Zhu (1997) observed 4 times higher N_2O emission than with continuous flooding in southern China. Kaiser and Ruser (2000) observed inverse relation between N losses in the form of N_2O and efficiency of N uptake by grown crop. The present study, the initial peak of N_2O emissions at 75% FC soil moisture could be due to nitrification.

After the onset of monsoon, the soil got saturated and the highest amount of N_2O emission of 48 µg N m^{-2} h^{-1} was observed in the bare fallow treatment with rapid reduction in the NO_3-N content in the soil. As NO_3-N is negatively charged and not sorbed onto clay particles, it is prone to losses, particularly by leaching in sandy soils but also by denitrification, particularly in saturated clay soils (Bacon et al., 1986; Davidson et al., 1986). The second highest peak of N_2O emissions observed after soil flooding could be due to denitrification in the bare fallow control. The significantly reduced N_2O emissions from the plots of maize, mucuna and mungbean DWT treatments could be linked with the efficient utilization of Nmin by the crops in plant biomass.

Nitrogen assimilation by transition season crops

Crops grown during DWT showed large differences in N accumulation. Total N accumulation by maize was 43 kg N ha^{-1} and that of the grain legume mungbean and the green manure legume mucuna were 53 and 80 kg N ha^{-1} respectively in 2001. Nitrogen-15 analysis indicated that the major portion of this N was derived from biological nitrogen fixation. The total N accumulation by mucuna, mungbean and maize were 108, 80 and 54 kg ha^{-1}, respectively in 2003 also and the highest N (116 kg ha^{-1}) accumulation was from the straw amended mucuna treatment. The N accumulation by maize was linked to the soil NO_3-N depletion, however, mungbean and mucuna derived N from both soil Nmin and from the atmosphere. The highest amount of above ground biomass was observed with mucuna and growing mucuna during DWT may be a promising option to recycle soil NO_3-N, which may otherwise be loosed, and to add substantial amounts of atmospheric N.

Soil N dynamics during rice growing (wet) period

The biomass of the crops grown during DWT was incorporated into the soil and observed large differences in soil NH_4-N among DWT pre-treatments in flooded soil. The highest amount (51.2 kg ha^{-1}) of NH_4-N occurred in the mucuna pre-treatment where 116 kg ha^{-1} biomass N was recycled. Second higher amount (49 kg ha^{-1}) of NH_4-N was observed in mungbean treatment, and the lowest soil NH_4-N (22 kg ha^{-1}) was observed in the bare fallow treatment during the initial two weeks after soil flooding and it rapidly declined afterwards. There was sharp decline in the soil NH_4-N content 4 weeks after rice transplanting in all treatments and that was possibly associated with N uptake by the growing rice crop.

Rice grain yield and N uptake

Rice grain yield responded to the N savings and/or N adding effects (BNF) of the DWT pre-treatments. The lowest rice grain yield of 1.7 Mg ha^{-1} (average of 2001 and 2003) was obtained from the DWT period bare fallow treatment. The wet season rice grain yield of 2.5, 2.9 and 3.7 Mg ha^{-1} (average of 2001 and 2003), were observed in the DWT pre-treatments maize, mungbean and mucuna respectively. The highest grain yields of 3.61 Mg ha^{-1} in 2001 and of 3.79 Mg ha^{-1} in 2003 were observed in the mucuna treatment with N uptake of 77 kg ha-1. The lowest N uptake of 32 kg ha-1 was determined in the bare fallow pre-treatment. The highest N uptake determined in the mucuna pre-treatment could be associated with combined effects of soil N savings and atmospheric N_2 fixation.

Grain yield is related to the amount of available N in the soil pool and to the N uptake capacity of the crop (Cassman et al., 1997). Becker et al. (1990), Ladha and Reddy (2003) showed increased grain yield of the subsequent rice crop by growing legumes and recycling their biomass in the field. Peoples et al. (1995) reported upto 120 kg ha-1 of the nitrogen fertilizer equivalence (NFE) for green manures and grain legume residues. Becker and Ladha, (1996) showed high synchrony among N supply of incorporated legume residue, N demand and N recovery by rice. In present study also, the highest grain yield in the mucuna pre-treatment could be linked with synchronization among residue mineralization, N demand and N uptake by rice plant. Similarly, the lowest grain yield in the bare fallow pre-treatment could be the result of heavy N loss during DWT period by both leaching and denitrification.

CONCLUSION

Massive loss of native soil nitrogen occurs in rice-wheat rotations when fields are left bare fallow during the dry-to-wet season transition period. Growing grainlegumes and green manure crops during the transition season can immobilize soil N in the plant biomass in addition to adding N from the atmosphere. Reduced amounts of available soil Nmin by growing crops during DWT result reduced N losses by both leaching and denitrification. That also reduces N_2O emission from the soil and increases grain yields of subsequent crop rice substantially. While these management strategies can effectively enhance N cycling in rice-wheat rotation system but N balance indicates that in the long term, crop yields cannot be sustained without the additional application of mineral fertilizers and/or compost. The combination of the proposed options with the application of other organic manures (compost) and chemical fertilizers can sustain the system with increased grain yield of rice.

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