Deutscher Tropentag 2000 in Hohenheim
Session: Technologies for Crop Production

Native soil N dynamics and use efficiency by lowland rice as a function of slope management

Jean Pierre Irénée Bognonkpe* and Mathias Becker

Universität Bonn, Agrikulturchemisches Institut, Karlrobert Kreiten Str. 13, 53115 Bonn;
Email: j.bognonkpe@caramail.com. Fax: (49) 228 732489

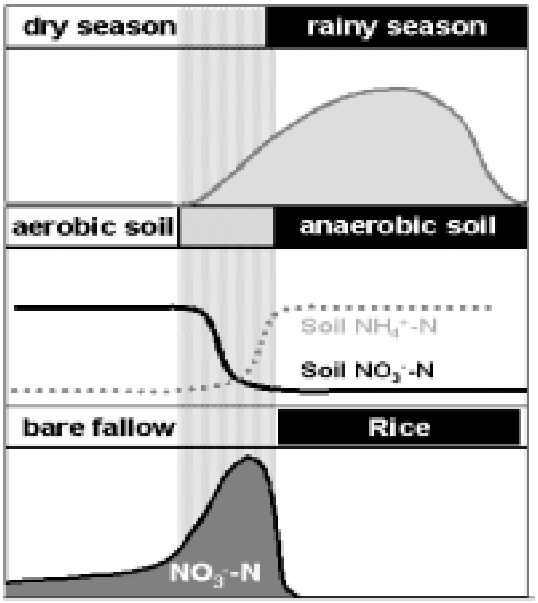
Abstract

Intensification of low-input small-holder rice farming systems in inland valleys of West Africa calls for a more efficient use of the systems' internal resources such as soil moisture and native soil nitrogen. Amounts of mineral and thus plant-available soil N, particularly nitrate, are tightly coupled to soil moisture and water movements, and are therefore likely to vary in space and time. When high amounts of nitrate in the soil are not mached with plant N uptake, the potential for N losses is increasing. Efficient use of native soil N through the development of improved crop management practices requires a quantitative understanding of N and water dynamics and thereunderlying processes. This paper presents results from three years of field experiments conducted on a model toposequence on the research farm of the West Africa Rice Development Association (WARDA) near Bouake in Côte d'Ivoire. The seasonality of native soil N dynamics was quantified and management options both on the slope and in the lowland were evaluated. Particularly during the dry-to-wet season transition period, large amounts of N are mineralized. With the onset of the rains, nitrate N is translocated from the slopes into the lowlands where it is lost via denitrification. A vegetative cover can absorb this N and temporarily protect it from loss with substantial resulting gains in lowland rice grain yield.

Keywords: Cajanus cajan, Denitrification, Oryza sativa L., West Africa.

Introduction

Most food crops in the humid zone of West Africa are produced in the undulating landscape of the inland valleys (Windmeijer and Andriesse, 1993). On the predominantly sandy Alfi- and Ultisols of the region, traditional rainfed lowland rice dominates the valley bottoms, while valley slopes are increasingly being cleared from natural forest or bush-savanna vegetation for producing upland crops. Nitrogen is the most limiting nutrient element, particularly in savanna environments (Becker and Johnson, 2000). In light of the near complete absence of mineral fertilizer use, native soil N represents the main source of N for plant nutrition (Engels *et al.*, 1995). Native soil N and particularly nitrate are likely to follow the flow of water along the toposequence and thus be prone to intense transformation and loss mechanisms (Figure 1). Understanding and managing the dynamics of native soil N at watershed scale is seen to be a prerequisite for the development of sustainable cropping systems in the inland valleys of West Africa. The objective of the present work was to quantify season dynamics of native soil N along a model toposequence and to evaluate management options for improved use efficiency of native soil N by lowland rice.



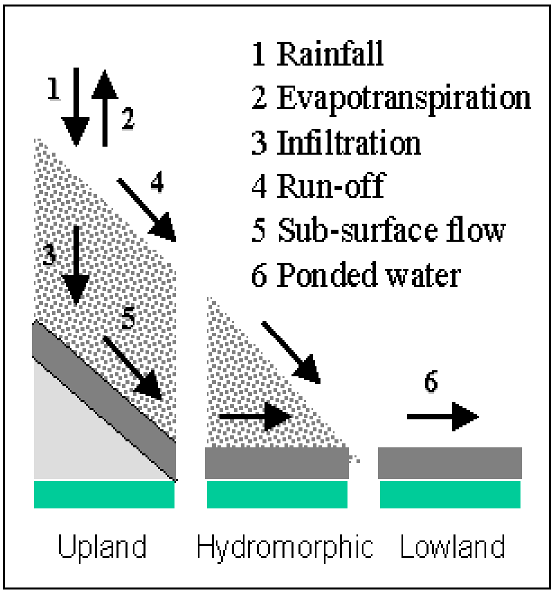


Figure 1. Conceptual relationships between rainfall, soil aeration status and soil N dynamics in a rainfed lowland (left) and of water dynamics along a toposequence (right).

Material and Methods

A three-year field experiment was conducted on a hydrologically isolated 75-m-wide and 60-m-long toposequence (devided into three 25-m-wide strips / replications) in an inland valley of the derived savann zone between 1997 and 1999. It was located on the experimental farm of the West Africa Rice Development Association (WARDA) near Bouaké in Côte d'Ivoire. In the first year, N min dynamics (ammonium and nitrate; 0-60 cm) and *in-situ* N_2O fluxes were determined between the first rain (March) and the beginning of the rice cropping season (July) every other day. In 1998 and 1999, the three 25-m-wide observations strips were further subdivided in three to study the influence of vegetation on native soil N management and its effect on the yield of lowland rice. We compared three main plot variants of slope use, representing extreme cases of subsurface interflow management to the adjacent lowland: (1) tilled bare soil (maximal N leaching and subsurface flow contribution), (2) *Cajanus cajan* (N retention in the upland through deep-rooting vegetation) and (3) banana plants in the hydromorphic valley fringe (interception of subsurface flow). Two subplot treatments were laid out in the bunded rainfed lowland below the slope management treatments to study the potential of a vegetative cover during the dry-to-wet season transition season for temporarily immobilizing soil nitrate (bare fallow vs. flood-tolerant *Aeschynomene afraspera* in 1998 and *Brachiaria* spp. in 1999). N accumulation in the biomass of the pre-rice lowland vegetation and of rice at harvest was complemented by weekly determination of soil N_{min} (0-20 cm).

Results and Discussion

Data from 1997 indicate a flush of mineral soil N occurs during the first half of the dry-to-wet season transition period, with higher amounts of nitrate found in lowland than in upland ecologies (92 vs 78 kg N ha^{-1}). Little nitrate was found in lowland soils after the onset of the main rainy season (Figure 2). In the absence of a vegetative cover, most of this nitrate N that disappeared from the N min fraction is assumed lost (about 75 kg N ha^{-1}).

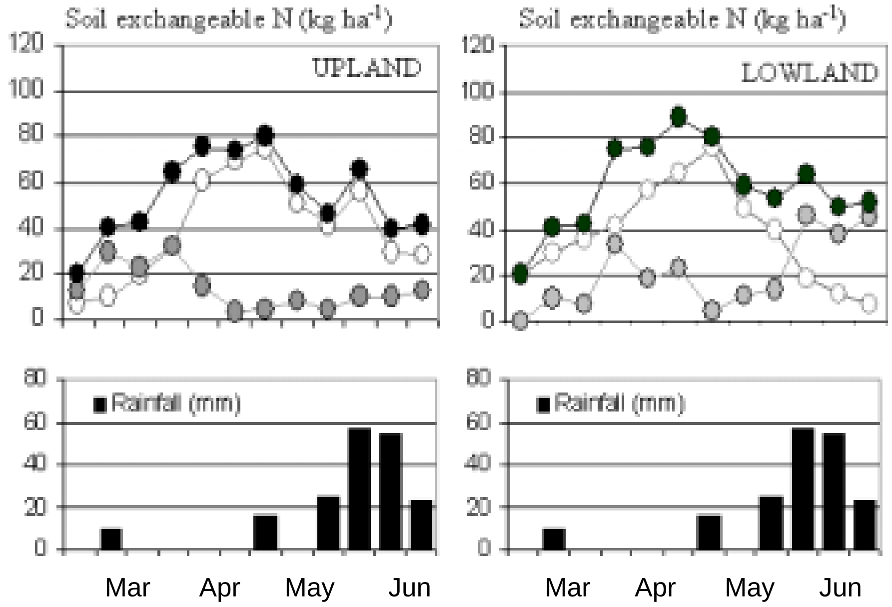


Figure 2. Rainfall pattern and native soil N min dynamics (0-20 cm) in bare upland and lowland soil during the dry-to-wet season transition period (Côte d‘Ivoire, 1997).

A steep decline of available soil nitrate was related to an increase in volumetric soil moisture. In situ N_2O fluxes peaked at the end of the transition season, indicating that native soil N that was lost from lowland soils via denitrification (Figure 2).

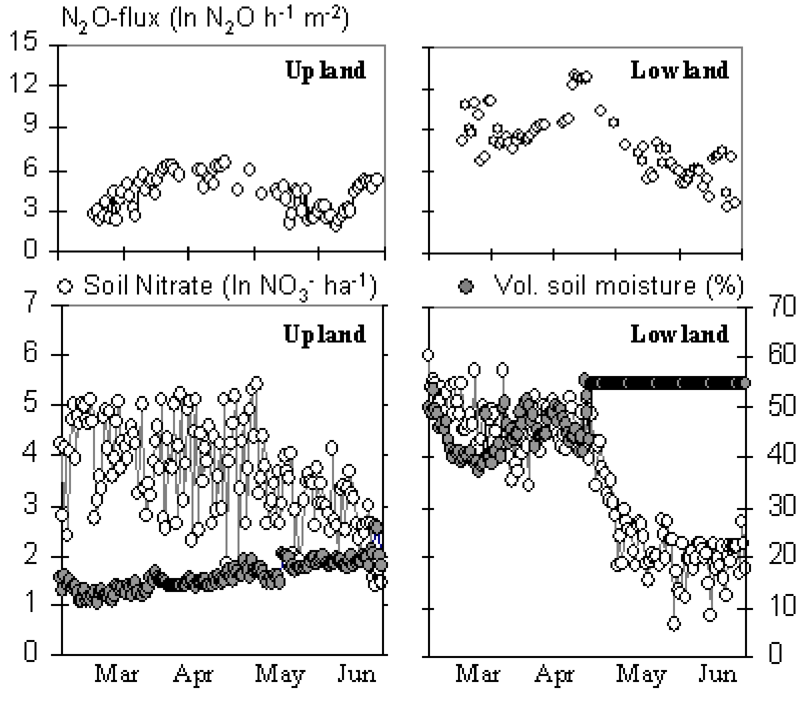


Figure 3. Dynamics of soil nitrate (0-20 cm), volumetric soil moisture (TDR) and nitrous oxide emissions from bare upland and lowland soil during the dry-to-wet season transition period (Côte d‘Ivoire, 1997).

Results from two years of differential slope management showed a peak of N_{min} occurring in lowland soils at about 2 weeks after the onset of the rainy season. Most of this N_{min} occurred as nitrate and probably originated from upland slopes. Nitrate-N input into the lowland was up to 47 kg ha^{-1} higher when adjacent slope was left bare of vegetation as compared to interception of subsurface flow in the presence of banana plants (Table 1). A deep-rooting slope vegetation (*C. cajan*) reduced N input into the lowland to 37 kg ha^{-1} (about 20% less than the bare fallow treatment). This suggests that slope management does affect N translocation along an inland valley toposequence.

Table 1. Effect of slope management on N contribution to lowland soil during the cropping season (April-October, Côte d‘Ivoire, mean values for 1998/99)

Slope management (vegetative cover)	Cumulative N min in the lowland	N min contribution of the slope
	- - - - - - - - - - - - - (kg N ha-1)	- - - - - - - - - - - -
Banana [a]	65	0
Cajanus *cajan* [b]	103	39
Bare soil [c]	112	47
LSD (0.05)	*26*	**

[a] Three densly spaced rows of banana plants in the hydromorphic valley fringe for full interception of subsurface flow water and nitrate

[b] Upland and hydromorphic valley fringe covered by an 8-month-old pigeonpea fallow to limit nitrate-N exports from the slope

[c] Soil maintained bare during the cropping season (repeated Glyphosate sprays) to maximize water and nitrate flows into the lowland

The presence of a vegetative soil cover in the lowland during the dry-to-wet season transition period acted as a “sink” for nitrate, thus possibly saving up to 25 kg ha^{-1} of native soil N from gasseous losses. Following such a “nitrate-catching” vegetation, lowland rice grain yields were 0.9 - 1.1 t ha^{-1} higher than in bare-fallow lowland plots ($p<0.04$). These yield gains were more in situations with high N input from the slope (Table 2). It may be concluded that lowland fertility and crop yields in inland valleys benefit from nutrient imports from the slope.

Table 2. Effect of lowland vegegative cover during the dry-to-wet transition season (nitrate catch crops) on lowland rice yields under three types of slope management (Bouake, Côte d'Ivoire, mean values for 1998/99).

Lowland management in the transition season (nitrate catch crops)	Slope management (N contribution to lowland)		
	Bare soil (47 kg N ha^{-1})	*Cajanus cajan* (39 kg N ha^{-1})	Banana (0 kg N ha^{-1})
	- - - - - - - - Rice grain yield (t ha^{-1}) - - - - - - -		
Bare fallow	4.52 b	4.40 b	3.16 c
Planted fallow („nitrate catch crop“)	5.55 a	5.27 a	3.23 c

Management of both the slope and the lowland vegetation during the dry-to-wet season transition season can impact significantly on lowland productivity. However, the potential contribution of a fertility that is “stolen” from adjacent uplands is likely to diminish with time and has to be seen critically in light of a rapidly increasing pressure on uplands for subsistence food crop production. Studies are currently under way to model seasonal soil N dynamics at watershed level and to develop land use planning tools for improved native soil N management in the inland valleys of West Africa.

References

Becker M and Johnson DE (2000) Cropping intensity effects on upland rice yield and sustainability in West Africa. Nutrient Cycling in Agroecosystems (in press)

Engels K, Becker M and van de Giesen N (1995) Managing native soil nitrogen on the continuum toposequence. Annual Report 1995. West Africa Rice Development Association, Bouake, Côte d'Ivoire. pp 51-52

Windmeijer P and Andriesse W (1993) Inland valleys in West Africa: An agro-ecological characterization of rice-growing environments. International Institute for Land Reclamation and Improvement (ILRI) Publication No. 52, ILRI, Wageningen, The Netherlands. 231 pp