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SHORT COMMUNICATION

**Heidi Kreibich · Johannes Lehmann ·
Gabriela Scheufele · Jürgen Kern**

Nitrogen availability and leaching during the terrestrial phase in a várzea forest of the Central Amazon floodplain

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Abstract Availability and leaching of dissolved inorganic N (DIN = NH_4^+ + NO_3^-) in soil were measured in a periodically flooded forest of the Central Amazon floodplain (várzea) during one terrestrial phase. Special emphasis was on the effects of a legume and a non-legume tree species. NH_4^+-N accounted for more than 85% of DIN even at the end of the terrestrial phase although it decreased throughout the experimental period. While extractable NO_3^--N was always low in the soil (less than 15% of DIN), the amount of leached NO_3^--N was in the same range as NH_4^+-N. Under the legume trees mean DIN contents of the topsoil were higher than under the non-legume trees. DIN leaching from the topsoil (0–20 cm) was significantly higher under the legume trees than at the other sites, also indicating a higher N availability. Therefore, despite considerable leaching legume trees may be an important source of N supporting a high biomass production of the várzea forest.

Keywords Inundation forest · Leaching · Inorganic nitrogen · Tree species effect · Legume trees

H. Kreibich (✉) · J. Kern
Institute of Agricultural Engineering (ATB),
14469 Potsdam, Germany
e-mail: kreib@gfz-potsdam.de
Tel.: +49-331-2881550
Fax: +49-331-2881570

J. Lehmann
College of Agriculture and Life Sciences,
Department of Crop and Soil Sciences,
Cornell University,
Ithaca, NY 14853, USA

G. Scheufele
University of Trier,
54286 Trier, Germany

Present address:
H. Kreibich, Section 5.4 Engineering Hydrology,
GeoForschungsZentrum Potsdam,
Telegrafenberg, 14473 Potsdam, Germany

Introduction

The monomodal flood pulse of the Amazon and its flood amplitude of about 10 m leads to an annual water and nutrient input to its floodplain (várzea). Therefore, soils are highly fertile supporting small-scale agriculture and shifting cultivation for centuries (Coomes and Burt 1997). Over the past few decades land pressure has increased in such a way that detrimental consequences for the forest cover are clearly visible today. Knowledge about nutrient turnover, influence of tree species on soil processes, and nutrient leaching from soil are fundamental for the development of sustainable and suitable management concepts for existing forests. Despite the generally high nutrient supply in várzea soils, a low nutrient availability may occur at decreasing water level when there is no input from the river water (Melack and Fisher 1990; Kern and Darwich 1997). Enclosure experiments and field studies indicate that primarily N can be a limiting factor for biomass production because the river water is rich in major solutes, but not in N compounds (Setaro and Melack 1984; Furch and Junk 1993). The main part of dissolved inorganic N (DIN = NH_4^+ + NO_3^-) in várzea soils is NH_4^+, in contrast to upland soils, where DIN is predominated by the very mobile NO_3^- (Neill et al. 1999). However, besides NO_3^-, NH_4^+ may also be affected by the transfer to deeper soil layers (Furch 1997). Particularly during receding water or during rainfall, leaching may play an important role in the displacement of N. In contrast to major cations, leaching of NH_4^+ and NO_3^- from the forest soil on high-elevation boundaries to adjacent lake bodies is largely unknown. Since species composition of forests have an impact on soil characteristics (Augusto et al. 2002) the high percentage of species belonging to the Leguminosae (27%) is supposed to counteract N limitation by their potential for N_2-fixation. Therefore, this study is focused on the effects of a frequently found legume tree species and a non-legume tree species on soil N availability and fluxes in a várzea forest during a 4-month period of non-flooding which is defined as the terrestrial phase.

Materials and methods

The experiment was performed in the várzea forest next to Lake Camaleão on Marchantaria Island, Central Amazonia (3°15′S and 59°58′W) from 23 September 1998 to 2 February 1999. The study area has been described in detail by Junk (1997). On average the island is exposed for 4 to 7 months per year, which is the terrestrial phase. In 1998, the lowest sampling points were dry mid September and the highest points were flooded again in mid February 1999. The rainy season started in January, during the low water period. The alluvial várzea soil is derived from the suspended load which is carried by the Solimões River from the Andes. The forest soils are silty and rich in organic matter, have a relatively low bulk density and a low pH, especially in the topsoil [mean values during the terrestrial phase were 11.4% and 14.1% clay, 78.5% and 80.4% silt, 1.0 g cm^{-3} and 1.2 g cm^{-3} bulk density, 4.2 and 4.1 pH in KCl, 32.5 g kg^{-1} and 13.0 g kg^{-1} C_{total}, 2.5 g kg^{-1} and 1.3 g kg^{-1} N_{total}, 0.7 g kg^{-1} and 0.6 g kg^{-1} P_{total} in soil depth 0–5 cm and 5–20 cm, respectively (Kreibich and Kern 2003)]. Four plots (each 20×20 m) were randomly assigned for soil analyses of DIN content and for quantifying transport processes according to a single-tree approach (Zinke 1962). Within each plot we selected one nodulating N_2-fixing legume tree of *Albizia multiflora* (Knuth) Barneby & Grimes (Mimosaceae), one non-N_2-fixing non-legume tree of *Tabebuia barbata* E. Mey. (Bignoniaceae) and a non-vegetated site for comparison, to study vegetation effects on contents and fluxes of N in the soil. Nodulation and N_2-fixation were investigated in the study area by Kreibich (2002) who found that in the case of *A. multiflora* 31–48% of N derived from the atmosphere (% Ndfa).

To determine N leaching from soil, resin cores (pre-washed Amberlite MB 20 mixed with acid-washed sand) with a diameter of 45 mm and a length of 100 mm were used. The resin core method has been tested by Zou et al. (1992) in alluvial soils where no significant differences in DIN fluxes could be measured by comparison with buried-bag incubations. In our study 12 resin cores were installed on 23 September at the beginning of the terrestrial phase when the water table was between 2 and 3 m below the soil surface. Mounting was undertaken laterally from the side of a soil pit 20 cm beneath the soil surface. After 132 days at the end of the terrestrial phase, when the water table was between 1.3 and 2.3 m below the soil surface, the cores were collected and cut into four layers (0–40, 40–60, 60–80, 80–100 mm). The total fresh weight of each fraction was determined and an aliquot of about 10 g was extracted with 100 ml 1 M KCl. The top resin layer had the highest N concentrations, the two middle ones the lowest N concentrations, verifying that the capacity of the resin was sufficient to prevent break-through and no nutrients were lost by leaching. Due to capillary rise, DIN concentrations were slightly elevated in the bottom layer by comparison with the middle layers. Therefore, only the top two resin layers were taken for flux calculations as described by Lehmann et al. (2001). Soil was sampled at the same locations and on the same days as resin core installation and excavation. Soil depths of 0–5 cm and 5–20 cm were sampled at the beginning and the end of the terrestrial phase. At the beginning of the terrestrial phase soil was sampled additionally at 20–50 cm and 50–100 cm. An aliquot of a mixture of three replicate samples per plot and per treatment was extracted as described. NO_3^- and NH_4^+ contents were determined photometrically with an automatic flow analyser (RFA-300, Alpkem Corp., Clackamas, Ore. and Skalar, The Netherlands). Water content was measured gravimetrically and converted to water-filled pore space using soil-solid density data obtained by a pycnometer.

Analyses of variance (ANOVA) were carried out using a randomised complete block design. Due to inhomogeneity of variances, logarithmic transformation of the data was performed prior to analysis. In case of significant effects, means were compared using the least significant difference test (LSD) at p <0.05. The Wilcoxon test was applied to compare NH_4^+ and NO_3^-, which are dependent variables (STATISTICA 4.0).

Results and discussion

At the beginning of the terrestrial phase, water-filled pore space was significantly higher than at the end. It ranged between 49–87% and 68–100% in the soil layers at 0–5 cm and 5–20 cm depths, respectively (data not shown). Since the water-filled pore space is one of the main factors regulating nitrification, oxidation of NH_4^+ was probably favoured by increased O_2 supply during the terrestrial phase (Bollmann and Conrad 1998). However, NO_3^--N contents were at least one order of magnitude lower than NH_4^+-N contents at both times and at all sites (Fig. 1). NO_3^--N contents showed no significant difference between the beginning and the end of the terrestrial phase in contrast to NH_4^+-N concentrations which were higher at the beginning of the terrestrial phase (Fig. 1). Due to rapid nitrification, NO_3^--N displacement by leaching during the terrestrial phase was large and by far exceeded the amount present in the soil at the two sampling times (Table 1). It is remarkable that NH_4^+ was affected by leaching in the same order of magnitude as NO_3^- with average values

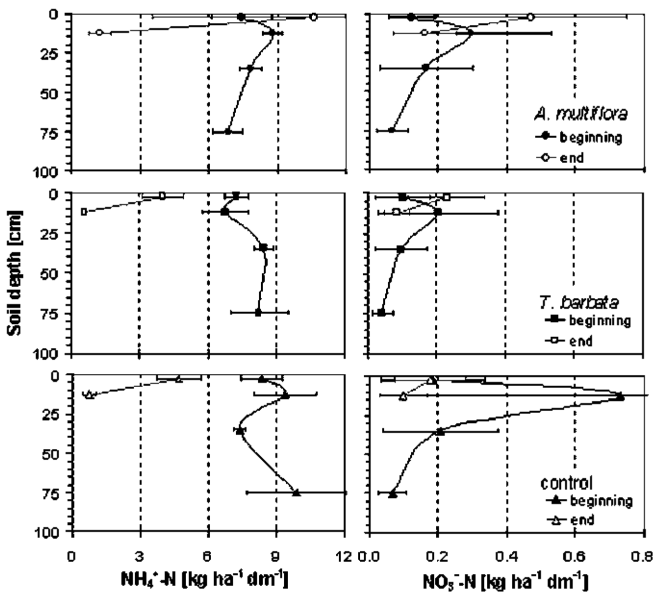

Fig. 1 Extractable NH_4^+-N and NO_3^--N concentrations in the soil profile in the floodplain forest under two vegetation influences at the beginning and at the end of the terrestrial phase (means and standard errors; n=4)

Table 1 Leaching of inorganic N at 20 cm depth under two native tree species in the várzea forest of the Central Amazon from 23 September 1998 to 2 February 1999 during a period of 132 days (means and standard errors; n=4). Values in one column followed by the same letter are not significantly different at p<0.05. DIN Dissolved inorganic N

Sites	Amounts leached (kg N ha^{-1})		
	NH_4^+-N	NO_3^--N	DIN
Albizia multiflora	2.4_a±1.2	1.3_a±0.6	3.8_a±1.3
Tabebuia barbata	0.8_b±0.1	0.4_a±0.2	1.2_b±0.2
Control	0.9_b±0.2	0.5_a±0.3	1.4_b±0.5

twice as high as leached NO_3^--N (Table 1). Besides leaching, nitrification has to be considered to be responsible for the decrease of NH_4^+ within the 0–20 cm layer. Nitrification is accompanied by acidification, which usually is indicated by low pH values between 4 and 5 in the topsoil. Due to its high mobility the produced NO_3^- can easily be leached from the topsoil. Furthermore, NO_3^- may disappear from the soil due to plant uptake, consumption by heterotrophic bacteria and by denitrification due to the high water-filled pore space. N loss via denitrification in the surface soil layer (0–5 cm) was 1.6 kg N ha^{-1} during the terrestrial phase (Kreibich 2002).

In the rhizosphere of the legume tree *A. multiflora*, on average 3.8 kg N ha^{-1} were transferred to deeper soil layers by leaching during the observation period of 132 days. This is not much compared to temperate forests where mean annual leaching ranged between 12 and 81 kg N ha^{-1} (Persson et al. 2000). However, compared with the leaching at the *T. barbata* and non-vegetated sites, the amount leached from the *A. multiflora* stands was significantly higher (Table 1). Obviously N_2-fixation led to increased DIN leaching as reported by Parrota (1992) and Garcia-Montiel and Binkley (1998). Additionally, higher N contents of *A. multiflora* leaves (3.9 g N kg^{-1}) in comparison with *T. barbata* leaves (2.3 g N kg^{-1}) may have led to a greater net N mineralisation from the N-rich biomass as reported by Constantinides and Fownes (1994) and Cantarutti et al. (2002). But neither the soil-extractable contents of NH_4^+ nor those of NO_3^- showed significant differences between the sites (Fig. 1). Only the soil of control sites tended to show higher extractable DIN. At these locations without vegetation we can assume lower N uptake and denitrification than at the other sites (Schade et al. 2001). Nevertheless the mean NO_3^--N contents under *A. multiflora* were also higher than under *T. barbata,* and at least in the upper soil layers this was also the case for NH_4^+-N (Fig. 1). This is consistent with previous findings in plantations on Hawaii (Garcia-Montiel and Binkley 1998), although there the soil internal DIN pool at a depth of 0–20 cm was 2 to 6 times higher under *Albizia falcataria* than under *Eucalyptus saligna*. As expected, in the várzea forest the effects of tree species on N dynamics were not as pronounced as shown for mono-species agricultural systems (Lehmann et al. 1999). In our mixed forest stand with 44 different woody plants, roots of various species may interact in the rhizosphere, so that soil below non-legumes might be influenced by legumes as well, and vice versa.

This study clearly showed a surplus of N below the legume tree *A. multiflora*. Since both availability and leaching of N were enhanced, we can attribute a higher soil fertility to sites influenced by *A. multiflora* which may yield benefits to other plants in the várzea.

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