W. J. Horst et al. (Eds), Plant nutrition – Food security and sustainability of agro-ecosystems. 1014~1015, 2001

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Water and nutrient balance under slash-and-burn agriculture in the Eastern Amazon, Brasil - The role of a deep rooting fallow vegetation

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Key words: leaching, nutrient recycling, secondary forest, shifting cultivation, subsoil nutrient accumulation

Abstract

A 4-year-old fallow vegetation was able to noticeably deplete the soil water store down to 6 m depth. The annual uptake from 0.9 to 6 m soil depth reached 400 mm. An equivalent uptake of dissolved nutrients from this layer is likely. Thus, the fallow vegetation might pump up nutrients, which are out of reach for the shallow roots-system of the crops of a preceding cultivation phase. This feature, however, limits the scope of prolonged cropping and any agriculture that reduces the vitality of the fallow vegetation.

Introduction

In the Bragantina region of the Eastern Amazon, shifting cultivation predominates, which is mostly practiced by smallholders with properties smaller than a hundred hectare. After land preparation by slash-and-burn, maize (*Zea mays* L.), beans (*Vigna unguiculata* L.) and cassava (*Manihot esculanta* CRANTZ) are sequentially cultivated for a period of 1.5 to 2 years. In the subsequent fallow period a woody secondary vegetation can re-establish. Nowadays, however, shifting cultivation is under change. Demographic pressure on land leads to an intensified cultivation with shortened fallow periods (3-7 years) and a move to semi-permanent crops like passion fruit (*Passiflora edulis*). This development endangers the essential function of the fallow period to restore soil fertility. As a long-term consequence soil fertility deteriorates and land degrades creating a need for encroaching on primary forest areas.

Recent studies of the deeper subsoil using pits or auger revealed a deep-extending root system for primary forests in South-Pará (Nepstad *et al.*, 1991) as well as for the fallow vegetation in the Bragantina region (Sommer *et al.*, 2000). In the south of Pará, Nepstad *et al.* (1994) showed that deep roots are necessary for a sufficient water supply of the evergreen forest in the dry season. This might also be the case for the evergreen secondary vegetation in the Bragantina region. To examine this assumption, we monitored the deep soil water depletion under a fallow vegetation during the dry season in 1997.

The feature of the fallow vegetation to establish a deep root system might also be important regarding the nutrient dynamics of shifting cultivation. If the root system was important for deep-soil water uptake, an equivalent nutrient uptake might be likely. This would substantially influence the nutrient efficiency of this land-use system and diminish leaching losses. Therefore, leaching was quantified under a slash-burned site during a cultivation phase.

Materials and methods

To study the cultivation-induced leaching, a 7-year-old fallow vegetation was selected. This was slashed and burned in December 1996 and a sequence of maize, cowpea (*Vigna unguiculata*) and cassava was planted in the following 1.5 years. Concentrations of dissolved nutrients were determined in samples of soil solution taken biweekly at 0.9 m, 1.8 m and 3 m soil depth using suction-cup lysimeters (each time 6 repetitions). The nutrient concentrations were combined with water fluxes derived from a soil-water model applied on the cultivation site.

To determine deep soil water uptake, the annual dynamics of the soil water pressure head at different depth in the soil profile were recorded with tensiometers under a 4-year-old fallow vegetation starting in early April 1997. Based on this data set the soil water movement was modelled using laboratory soil-water retention curves, pedo-transfer functions and the soil water model Hydrus-1D (Van Genuchten, 1987).

Results

Due to El Niño effects the dry season of 1997 was exceptionally pronounced, with only 148 mm rainfall between 28th of August and the onset of the rainy season on 8th January 1998. In 1997 total annual precipitation was 2104mm and in 1998 2545mm. According to results of the soil water model, the transpiration of the fallow vegetation amounted to 154 mm within the dry season (Table 1). As much as 74 % of this transpiration water was extracted from the soil profile below 0.9 m depth. For the whole year, 400 mm and 427 mm of water originated from the soil layer of 0.9 to 6 m depth in 1997 and 1998, respectively. Maize, cowpea and cassava with their shallower root system did not deplete the soil water storage below 3 m depth and water from 0.9 to 3 m contributed less than 10 % to the annual water uptake.

Table 1. Soil water extraction under a 4-year old fallow vegetation from 22/8/1997 to 8/1/1998 and for the years 1997 and 1998 considering different soil layers. Percentages refer to the extraction from 0 to 6 m

Soil depth	22/8/97-8/1/98		--- 1997 ---		--- 1998 ---	
	(m)	(%)	(mm)	(%)	(mm)	(%)
0 - 0.9 m	40	26	730	65	853	67
0.9 - 3 m	41	27	199	18	223	18
3 - 6 m	73	47	202	18	204	16
Sum	154		1131		1280	

Considerable amounts of nutrients were leached below the rooting zone of these crops. At 0.9 m depth, these amounted to 77kg nitrate-N, 1.3 kg P, 25 kg K, 149 kg Ca, 34 kg Mg and 7 kg S per hectare over the two-year cropping period. However, during further percolation, nitrate, K, Ca and Mg were strongly reduced, so that losses at 3 m decreased to about 9 kg nitrate-N, 13 kg K, 45 kg Ca and 10 kg Mg per hectare over the two years (Table 2).

Table 2. Amounts of leached nutrients during the cropping period 1997-1998 considering reference soil depths of 0.9, 1.8 and 3 m

Soil depth	Nitrate-N	K	Ca	Mg
	[kg ha^{-1} 2a^{-1}]			
0.9 m	77	25	149	34
1.8 m	28	5	87	21
3 m	9	13	45	10

The decrease with depth in the amounts of dissolved nutrient was apparently related to the cation and anion exchange capacity. The effective cation exchange capacity (ECEC) of the soil at 0.9 m depth was around 1 cmol$_c$kg^{-1} and decreased to around 0.5 cmol$_c$kg^{-1} at 3 m. Anurugsa (1998) studied the anion exchange capacity (AEC) of soil of the study region at 30-50 cm depth. According to his sequential batch experiments AEC reached 0.08 cmol$_c$kg^{-1} at a soil-pH adjusted to 6.5 which increased to 0.4 cmol$_c$kg^{-1} at a pH of 3.1. Even if the ion exchange capacity of the deeper soil is rather low, the thickness of the profile allows that large amounts of exchangeable ions can be retained.

Discussion

About two-third of the annually transpired water of the fallow vegetation was taken up from the upper 0.9 m soil-layer. Still deep soil layers significantly contributed to the water supply of the vegetation. This might help to explain why most of the fallow species are able to maintain an evergreen canopy during the dry season.

The deeper soil layers, however, appeared to be out of the reach for the roots of maize, cowpea, cassava and newly introduced cash crops like passion fruit. Assuming an equivalent uptake of dissolved nutrients during water extraction, a nutrient-pumping mechanism of the deep-rooting fallow vegetation seems likely. The retention of nutrients beyond the time of cropping, therefore, provides the opportunity for the regrowing fallow vegetation to take up and to recycle these nutrients. It is likely that due to a decreasing ionic strength of the percolating soil water after fallowing of the crop land, retained ions are released and might be exported if not recycled by the fallow vegetation.

Our results on the water balance of the 4-year-old fallow vegetation show that even young secondary vegetation is able to extract deep soil water, a characteristic, so far only known for primary forest. If properly integrated into a shifting cultivation system such vegetation therefore provides a safety net against nutrient leaching. Intensified cultivation by semi-permanent or permanent crops suppresses the rootstock of the fallow vegetation and, therefore delays or even prevents its re-establishment. Hence, the nutrient efficiency of these systems is strongly reduced in the long run endangering agricultural productivity and ecosystem functioning as a whole.

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