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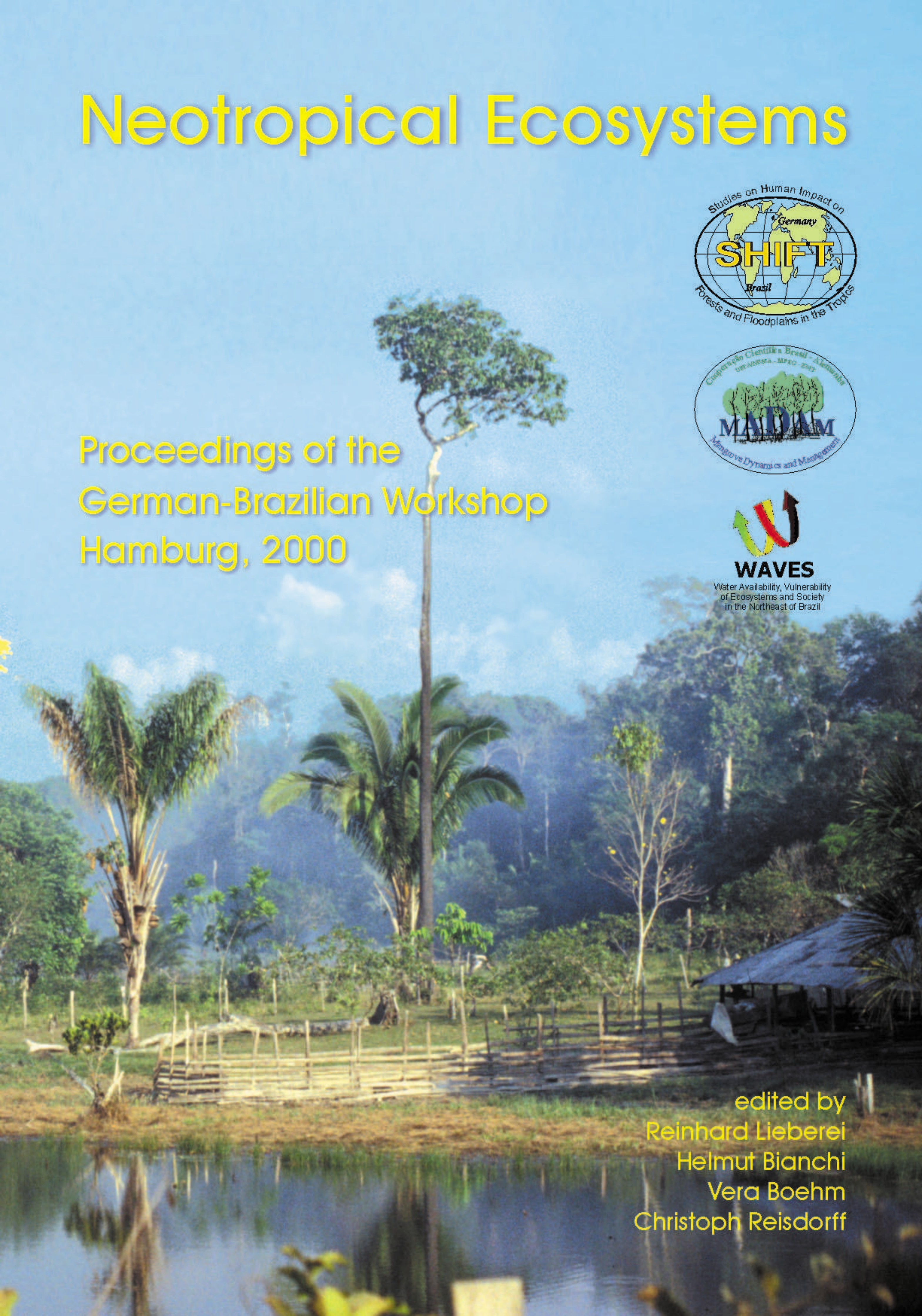

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Water Availability, Vulnerability of Ecosystems and Society in the Northeast of Brazil

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Phosphorus Availability in a Mulch System in Eastern Amazonia

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Abstract

The present study aims at studying the effect of land preparation and fertilizer application on the concentration of different phosphorus forms in the soil. The field experiments were conducted on smallholder fallow land in the northeast of Pará state, Brazil. The treatments were two types of land preparation: slash-and-burn and slash-and-mulch, both with and without NPK fertilization. A mulch layer was created by slashing and chopping the fallow vegetation and spreading the chips homogeneously over the field. Extraction of soil P was performed with (i) maize plants in a bio-assay, (ii) Mehlich extractor, and (iii) a sequential fractionation (inorganic: Resin-Pi, $NaHCO_3$-Pi and NaOH-Pi; organic: $NaHCO_3$-Po and NaOH-Po). Concentrations of P were influenced by the land preparation method in the following manner: In the plant-available P-pool (Mehlich) of the not fertilized treatments high rates of P (12.7 mg kg^{-1}) were found in the burned treatment shortly after burning as a consequence of the immediate P release out of the biomass. After 30 months, the available P had decreased to 4.7 mg kg^{-1}. In the mulched treatment, relatively low levels of available P (6 mg kg^{-1}) were found shortly after land preparation due to the slow liberation of nutrients of the not burned mulch layer, which also decreased to 4.7 mg kg^{-1}. In the fertilized plots, plant-available P did not vary much in time and between land preparation treatments. From all P fractions, resin-Pi reflects best the treatment differences in the not fertilized treatments. Fertilization in general caused considerable increase of all inorganic P fractions especially in the two more labile ones (resin-Pi and $NaHCO_3$-Pi). The bio-assay results show that in the not fertilized mulched treatment 30% more P was extracted from the soil by the maize test plants than from the soil of the burned treatment. With fertilizer application this difference increased to 43%.

Keywords

Land preparation, Slash-and-burn, Inorganic P, Organic P, P Fractionation

1 Introduction

The traditional land-use system of small farmers in the Eastern Amazon region is a fallow system including slash-and-burn practices. Intensification of land use without adjusting the traditional agricultural practices leads to a decrease of the system's productivity. A key factor of this degradation process is the nutrient losses by volatilization during slash burning (Hölscher et al., 1997). A mulch approach including land preparation without burning is considered an alternative to slash-and-burn. Moreover, periodical mulching helps to improve the physical, chemical and biological properties of the soil by the management of soil organic matter (Denich and Lücke 1998).

A large proportion of the total nutrient stock in the humid tropics are in organic form and exist primarily in the biomass of living plants, litter, and soil organic matter (SOM). Since the main soil constraints in the humid tropics are chemical rather than physical, it is evident that the management of SOM or organic inputs are crucial for sustaining soil productivity in the tropics. In general, at least 75% of the P in surface soils is found in SOM, which emphasizes the importance of SOM in the supply of this element. Phosphorus dynamics are critical to the productivity of Ultisols and Oxisols. These soils are highly P fixing and depleted of all primary P-containing minerals, and the decomposition of organic matter is an important mechanism in P dynamics (Hands et al., 1995).

Phosphorus dynamics in the soil are complex. Organic and inorganic P pools are to be found and the exchange between these pools is affected by physical, chemical and biological factors as well as by land preparation methods (Beck and Sanchez 1994).

The characterization of the inorganic (Pi) and organic P pools (Po) is fundamental to understand P cycling in the plant-soil system. Beck and Sanchez (1994) found that organic P was the primary source of plant-available P in a not fertilized Ultisol in Peru. The sequential P extraction method developed by Hedley et al. (1982) forms the basis for estimating the labile and stable forms of Pi and Po, using a series of increasingly aggressive extractants. This empirical sequential-extraction method is currently the only moderately successful approach for evaluating available Pi as well as Po, although the nature of the extractable Po pools is even less well-defined than that of the Pi pools (TIESSEN et al., 1994b).

It is necessary to understand particularly the short-term P dynamics associated with primary production and crop residue decomposition in agricultural soils, to develop management strategies that maintain or improve their properties and long-term productivity by maximizing organic P inputs and minimizing fertilizer P inputs.

The effects of residue placement on P release (BECK and SANCHEZ 1994; HAUFFMAN et al., 1996), P fertilization (HAUFFMAN et al., 1996; ZHANG and MACKENZIE 1996), P leaching (MACKENSEN et al., 1996), and P mineralization (SHARPLEY and SMITH 1989) have been studied and it could be shown that P release increased when crop residues were allowed to decompose on the soil surface rather than being incorporated. In the Amazon region there is no information available about changes in the P dynamics according to land preparation methods.

The present study aims at studying the effect of land preparation and fertilizer application on the concentration of different P forms in the soil.

2 Material and Methods

The field experiments were conducted on smallholder farmland in the municipality of Igarapé Açu, NE of Pará, on an Ultisol (0-10 cm depth: pH 5.2, Ntotal 0.07%, Nmin 53 mg kg^{-1}, P 3 mg kg^{-1}, K 15 mg kg^{-1}, Ca 0.8 cmol kg^{-1}, Mg 0.4 cmol kg^{-1}, Al 0.2 cmol kg^{-1}, Ctotal 1.07%, C/N 15.3). The municipality is located east of Belém (Bragantina region) between 0° 55' and 1° 20' S and 47° 50' W. Average annual rainfall in the region is approximately 2,500 mm, mean temperatures range between 22.5°C and 26.8 °C (Source: DNAEE).

The 4-year-old fallow vegetation (capoeira) at the study site had a total above-ground biomass of 24 t ha^{-1}, containing 9 kg of P. The treatments were two types of land preparation: slash-and-burn and slash-and-mulch, both with and without NPK fertilization. A mulch layer on the soil surface was created by slashing and chopping the fallow vegetation and spreading the chips homogeneously over the field. The fertilizers applied were: 50, 25 and 25 kg ha^{-1} for rice and 10, 22 and 42 kg ha^{-1} N, P and K, respectively, for cowpea in the form of urea, triple superphosphate and potassium chloride. The cropping system was rice followed by cowpea and cassava.

Plant-available P in the soil was determined by extracting the soil samples with a Mehlich extractor (HCl + H_2SO_4).

Furthermore, plant-available P was extracted in a bio-assay using maize as an extractor plant. The bio-assay was set up in a greenhouse and comprised the soils of 5 treatments: fallow vegetation (capoeira), burned and mulched areas both fertilized and not fertilized (all with 4 replications). Soil samples were collected from the layer at 0 – 10 cm depths. After processing, 500 g of soil/treatment were placed in pots and one maize seedling per pot was planted. Phosphorus in the plant was determined by digestion with nitric-perchloric acid and P concentration was determined colorimetrically (IITA, 1981).

Soil P was fractionated by a sequential extraction, according to HEDLEY et al. (1982), with modifications by Tiessen and MOIR (1993), and WICK (1997). The concentration of P in the extractants was determined colorimetrically. The fractions were resin-Pi (inorganic P), $NaHCO_3$-Pi and NaOH-Pi (inorganic P), as well as $NaHCO_3$-Po and NaOH-Po (organic P).

3 Results

3.1 Extractable phosphorus

The concentration of available P (Mehlich extract) in the upper 10 cm of the soil increased by the factor 4 after burning (Tab. 1). These results agree with the observations of various authors (ELLIS and GRALEY 1983; SIMMS 1987; ROMANYÀ et al., 1994) who also found increases in the

Treatments	Oct 94*	Jan 95**	Aug 95**	Aug 97**
	[mg kg^{-1}]			
Capoeira	3.0	3.3	2.3	2.0
Burning	-	12.7	3.0	4.7
Mulching	-	6.0	3.0	4.7
Burning + NPK	-	12.7	16.3	13.3
Mulching + NPK	-	6.0	13.0	13.7

*** n =10; **n = 6**

Tab. 1: Dynamics of available P (P-Mehlich) as a function of land preparation and fertilizer treatments in 0 -10 cm depths.

available P in the upper soil layers after burning fallow vegetation.

The increased amount of available P after burning (16.5 kg P ha^{-1}) exceeded the amounts of P found in the ashes (2.8 kg P ha^{-1}, data not shown). The surplus may come from: a) mineralization of P from soil organic matter and from the biomass of the vegetation decomposed in the short time span between slashing and burning/chopping of the vegetation (MACKENSEN et al., 1996); b) liming effect of the ash (JUO and MANU 1996) that raised the pH, reduced P fixation in the soil, and favored the activity of micro-organisms in the mineralization of organic matter, and c) the decomposition of the fine roots of the slashed vegetation, which are a rapidly available nutrient source (LESSA et al., 1996).

Without burning, the amount of available P increased by the factor 2 (Tab. 1). Nine months after land preparation (August 1995) a decrease of available P was found in the treatments without fertilizer, mainly due to the nutrient uptake by rice and cowpea. Similar results were obtained by RAISON et al. (1993), and JUO and MANU (1996). In the fertilized plots, a significant increase of available P was observed due to the application of 25 and 22 kg P ha^{-1} of triple superphosphate to rice and cowpea, respectively. The available P content varied from 13.0 to 16.3 mg kg^{-1} in these plots. Differences between the land preparation methods were not observed in the second cropping period.

Despite the fact that the differences are not significant at the end of the first cropping period, it is worth mentioning that during the second cropping period (August 1997) the available P in the soil (Mehlich extract) differed between

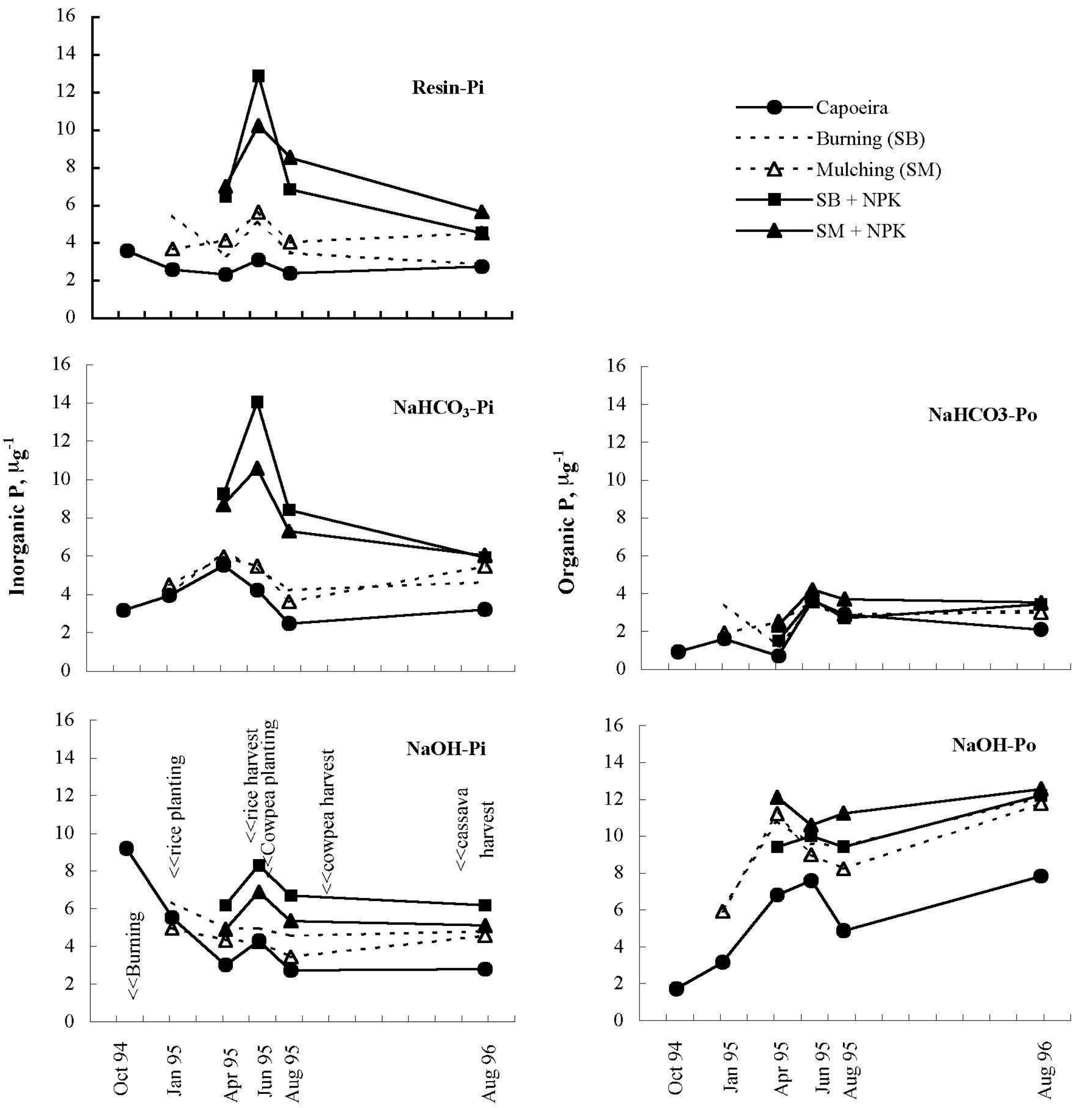

Fig. 1: Dynamics of Pi and Po fractions as a function of different land preparation and fertilizer levels in 0 -10 cm depths.

the land preparation methods. With fertilizer, there was a reduction of 20% of the available P in the burned, whereas in the mulched plots the available P was unaffected. Without fertilizer, available P increased in all land preparation treatments.

3.2 Inorganic and organic phosphorus pool (Pi and Po fractions)

The fraction of the readily available inorganic P, extracted with resin (resin-Pi), always showed a significant difference between treatments at all times (Fig. 1).

At the beginning of the rice cultivation (January 1995), the burned treatments showed higher resin-Pi contents (5.4 and 5.8 mg kg^{-1}) than the not burned treatments. The trends of resin-Pi increase with time as a function of land preparation are similar to that observed with the Mehlich extraction (Tab. 1). The increase in the resin-Pi fraction in June 1995 is probably associated with the decomposition of fine roots and straw of the rice harvested in May (Fig. 1).

After the fast increase due to burning, the resin-Pi fraction decreased rapidly during the rice cropping season. This short-lived fertilization effect of burning has also been reported by SEUBERT et al. (1977), SANCHEZ et al. (1983), and BECK and SANCHEZ (1994). The resin-Pi pool is the most easily available P source for plant growth (BOWMAN et al. 1978) and reflects short-term changes in plant availability (HEDLEY et al., 1982a).

The resin-Pi fraction was higher with fertilizer than without, fertilization having the greatest impact in June 1995 (Fig. 1). This effect was due to fertilizer application to cowpea beginning of June. After June, a reduction was observed in the resin-Pi fraction, which was caused by P uptake by cowpea and cassava.

The tendency in the $NaHCO_3$-Pi fraction was similar to that observed in the resin-Pi fraction (Fig. 1) in all treatments, with the exception of January 1995, where the effect of burning was not observed. SCHMIDT et al. (1996) observed a decline in the amount of inorganic P in the resin and $NaHCO_3$ fraction over a period of 17 years of continuous cultivation in two soil types caused by the removal of crops. The NaOH-Pi fraction was slightly increased by P fertilization (Fig. 1). Increases in levels of the inorganic NaOH-Pi fraction indicate the built up of a sink for future plant uptake. The dynamics of the inorganic P levels of resin-Pi and $NaHCO_3$-Pi fractions coincide with the dynamics of the inorganic P levels of the NaOH-Pi fraction, showing a relationship within the three inorganic fractions. A significant positive correlation was obtained between resin-Pi and $NaHCO_3$-Pi fractions in the burned (r = 0.81, p * 0.001) and in the mulched plots (r = 0.77, p * 0.001), confirming that the decrease of the amount of inorganic P in the resin fraction due to removal of the crops is accompanied by a decrease in the inorganic P fraction extractable by $NaHCO_3$ (SCHMIDT et al., 1996). Significant correlations were also found between the resin-Pi fraction and the NaOH-Pi fraction in the burned (r = 0.69, p * 0.001) and in the mulched plots (r = 0.46, p * 0.01). WICK (1997) and SCHMIDT et al. (1996) found a high correlation between all three inorganic fractions (resin-Pi, $NaHCO_3$-Pi and NaOH-Pi). HEDLEY et al. (1982) indicated that inorganic P not utilized by the plant is reabsorbed by the soil components, forming weakly to strongly adsorbed fractions (resin-Pi < $NaHCO_3$-Pi < NaOH-Pi).

With respect to the $NaHCO_3$-Po pool, neither the land preparation method nor the fertilizer treatment had any impact (Fig. 1). During the short observation period of the present study, $NaHCO_3$-Po pools were not depleted. However, TIESSEN et al. (1983), report that, in soils at Blaine Lake, after an initial increase in organic P levels due to the incorporation of the prairie vegetation, all organic P fractions were depleted and simultaneously inorganic P fractions were increased.

As opposed to burning, a slight but not significant increase of $NaHCO_3$-Po with time was observed in the mulched treatments. This increase was probably due to the decomposition process of the organic matter. ZHANG and MACKENZIE (1996) report that the return of high amounts of plant residues to the soil increases soil organic P.

The NaOH-Po pool was significantly influenced during the cropping period when comparing different land preparation methods (Fig. 1). NaOH-Po was the fraction that showed the highest short-term increase as compared to other fractions. Furthermore, an increase in NaOH-Po was concomitant with a decrease in NaOH-Pi and resin-Pi in burned areas.

Several authors are considering the NaOH-Po as an indicator of the P status and fertility of the soil. This pool is thought to represent the overall changes in soil organic matter and organic P levels by functioning as an active reservoir (source and sink) of P when the soil is stressed by cultivation and net P export (STEWART and TIESSEN 1987; TIESSEN et al., 1992; TIESSEN et al., 1994; BECK and SANCHEZ 1994).

Treatments	1995							1996		Average
	Feb	Mar	Apr	May	Jun	Aug	Oct	Feb	Aug	
	[mg P kg soil^{-1}]									
Capoeira	0.42	0.60	0.62	0.40	0.20	0.16	0.47	0.34	0.45	0.41
Burning	0.66	1.51	0.43	0.76	0.52	0.22	0.51	0.46	0.42	0.61
Mulching	1.00	1.52	0.72	0.78	0.80	0.38	0.56	1.34	0.90	0.89
Burning + NPK	1.00	2.36	1.23	0.74	2.46	0.52	1.12	0.47	0.43	1.15
Mulching + NPK	1.84	2.93	0.98	1.40	2.80	0.54	1.14	1.48	1.25	1.60

Tab. 2: Dynamics of bio-assayed phosphorus as a function of three different land preparation methods and two fertilizer treatments, using maize as test plant

3.3 Soil P availability: a bioassay of soil phosphorus

Phosphorus extracted from the soil in a bio-assay by the test plant maize showed differences between soils from different land preparation methods and sampling periods (Tab. 2). Averaging both fertilizer treatments, bio-assayed P in the mulched soil was significantly higher than in the soil from burned.

The gradual decomposition of mulch and plant residues (rice, cowpea and cassava) influences the P uptake by the test plants from soil of unburned plots. Le Mare et al. (1987), however, found no differences in available P on a dark-red Latosol in Brazil between green-manured and control treatments.

4 Conclusion

It can be concluded that in the short period of time under study, burning raised the availability of P to plants only at the beginning of the cropping phase and that the greatest increases in P levels were observed after addition of fertilizer to the soil. Without burning, P availability was dependent on mulch decomposition.

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