Single-tree effects on soil P pools in a multi-strata agroforestry system

J. Lehmann[1]*, D. Günther[2], S.da Mota[3],
K. Kaiser[1], U. Treter[2] , W. Zech[1]

Introduction

The spatial and/or temporal combination of perennial crops having contrasting above- and belowground growth may provide more efficient nutrient cycling than simple monoculture plantations. However, virtually no information is available about nutrient dynamics in such multi-strata agroforestry systems (Schroth et al., 1998). This may be due in part to the complicated spatial and temporal arrangements that these cropping systems possess. In many multi-strata situations, measurements of single-tree effects may be the only feasible approach for assessing nutrient dynamics. Using single-tree effects, it is possible to recieve information about how a specific tree affects nutrient dynamics in general, which then enables us to design an agroforestry system according to formulated objectives.

Soil P dynamics can be determined with a variety of analytical methods. The sequential extraction after Hedley et al. (1982) and Thiessen et al. (1984) offers the possibility of examining various inorganic and organic P pools differing in their origin and plant availability (Cross and Schlesinger, 1995). This analytical tool has been only rarely used for tropical soils (Cross and Schlesinger, 1995), but may yield valuable information about the pathways of P in tropical soils (e.g. Beck and Sanchez, 1995; Selles et al., 1997). The incorporation of added fertilizer can be followed and the tree-specific effects on P availability tested. This is especially important in strongly weathered tropical soils which possess a high P-fixing ability due to their high oxide contents. Cross and Schlesinger (1995) showed that hydroxide inorganic P and total organic P fractions constituted a large portion of P in weathered tropical soils in contrast to less developed soils, where acid inorganic P dominates.

In this study, we present the effects of different fruit and timber tree species in a multi-strata agroforestry system in comparison to secondary vegetation and primary forest sites on inorganic and organic P pools of a Ferralsol in the Amazon basin. The S pools were also assessed, but could not be presented here due to the length of this contribution.

Materials and Methods

The study was conducted at the Embrapa experimental station near Manaus, Brazil. The average precipitation is 2503 mm yr^{-1} (1971-1993) with a maximum between December and May. The natural vegetation is a tropical rainforest. The soils are classified as xanthic Ferralsols (FAO, 1995) and are clayey, strongly aggregated, with medium organic carbon and nitrogen contents, medium to low pH of 4.0-4.5, low cation exchange capacity of 4.9 $mmol_c$ kg^{-1} and low base saturation of 33 %. In June to August 1997, soil samples from 0-5 cm depth were taken at 50 cm distances from two trees per plot and combined. The trees were arranged in a completely randomized design with three replicates. The sites were soils under *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuacu), whose fruit is used for juice and ice cream; *Bactris gasipaes* Kunth. (peach palm), managed for palmito production; *Bertholletia excelsa* Humb.&Bonpl. producing Brazil nut; *Bixa orellana* L., an important local dye (urucum), and *Pueraria phaseoloides* (Roxb.) Benth., a

[1] *Institute of Soil Science and Soil Geography, University of Bayreuth, Germany*
[2] *Institute of Physical Geography, University of Erlangen, Germany*
[3] *Embrapa-CPAA, Manaus, Brazil*
* *corresponding author, present address: Embrapa, Manaus, Brazil; Email: johannes.lehmann@internext.com.br*

leguminous cover crop (pueraria), in a multi-strata agroforestry system. Additionally, sites were chosen with spontaneous gramineous vegetation, in secondary regrowth of *Vismia* spp. and in the primary forest under *Eschweilera* spp. und *Oenocarpus bacaba*. The trees in the agroforestry system were fertilized in May 1997 according to local recommendations (Table 1). The pueraria received only lime, the secondary and primary forest sites and the grass did not recieve any fertilizer.

P was sequentially extracted according to a modified Hedley procedure (Table 2). Inorganic P was analysed using the molybate ascorbic acid method (Murphy and Riley, 1962). Total P was analysed with a ICP-OES.

Table 1 Fertilizer applications to useful trees in a multi-strata agroforestry system before soil sampling in May 1997, with N and S as ammonium sulfate (21.2% N; 24.2% S) and P as triple super phosphate (22% P).

Species	**No. of**	**N**		**P**		**S**	
	[plants ha^{-1}]	**[g plant^{-}**	**[kg ha^{-1}]**	**[g plant^{-1}]**	**[kg ha^{-1}]**	**[g plant^{-}**	**[kg ha^{-1}]**
Cupuacu	93.3	95.4	8.9	77	7.2	108.9	10.2
Peach	312.5	42.4	13.3	11	3.4	48.4	15.1
Urucum	156.3	84.8	13.3	39.6	6.2	96.8	15.1
Brazil nut	93.3	42.4	4.0	22	2.1	48.4	4.5
Total	**655.4**		**39.5**		**18.9**		**44.9**

Table 2 Sequential extraction method and properties of soil phosphorus pools.

Pool	**Extraction procedure**[1,]	**Pool properties**[3]
Bicarbonate-P_i	0.5M $NaHCO_3$[2], 16h	immediately plant available P; bound to
Bicarbonate-P_o	0.5M $NaHCO_3$[2], 16h	mineral surfaces
Hydroxide-P_i	0.1M NaOH[2], 16h	successively available P; bound to oxides
Hydroxide-P_o	0.1M NaOH[2], 16h	long-term availability; more strongly bound to oxides and in humic compounds
Dil.-acid-P	1M HCl[2], 16h	successively available P; Ca-bound
Acid-P	concentrated HCl, 10min, 80°C	long-term available P; Ca-bound and occluded P
Residual-P	5M HNO_3 and concentrated $HClO_4$, 200°C until dry	highly resistant P

[1] modified after Hedley et al. (1982) and Tiessen et al. (1984)
[2] soil:solution ratio of 1:5
[3] modified after Cross and Schlesinger (1995)

Results and Discussion

Properties of P pools without fertilization

Immediately available P was rather low in these highly weathered soils under natural vegetation (Fig.1). The largest portion of total P was found in the hydroxide-P fractions, especially P_o. This coincides well with the observations of Cross and Schlesinger (1995) that highly weathered soils have more P in successively available organic P fractions. The amounts of residual-P, however, were surprisingly low. The general P reserves in these soils seem to be very low, emphasizing the need for a sound nutrient managment practice.

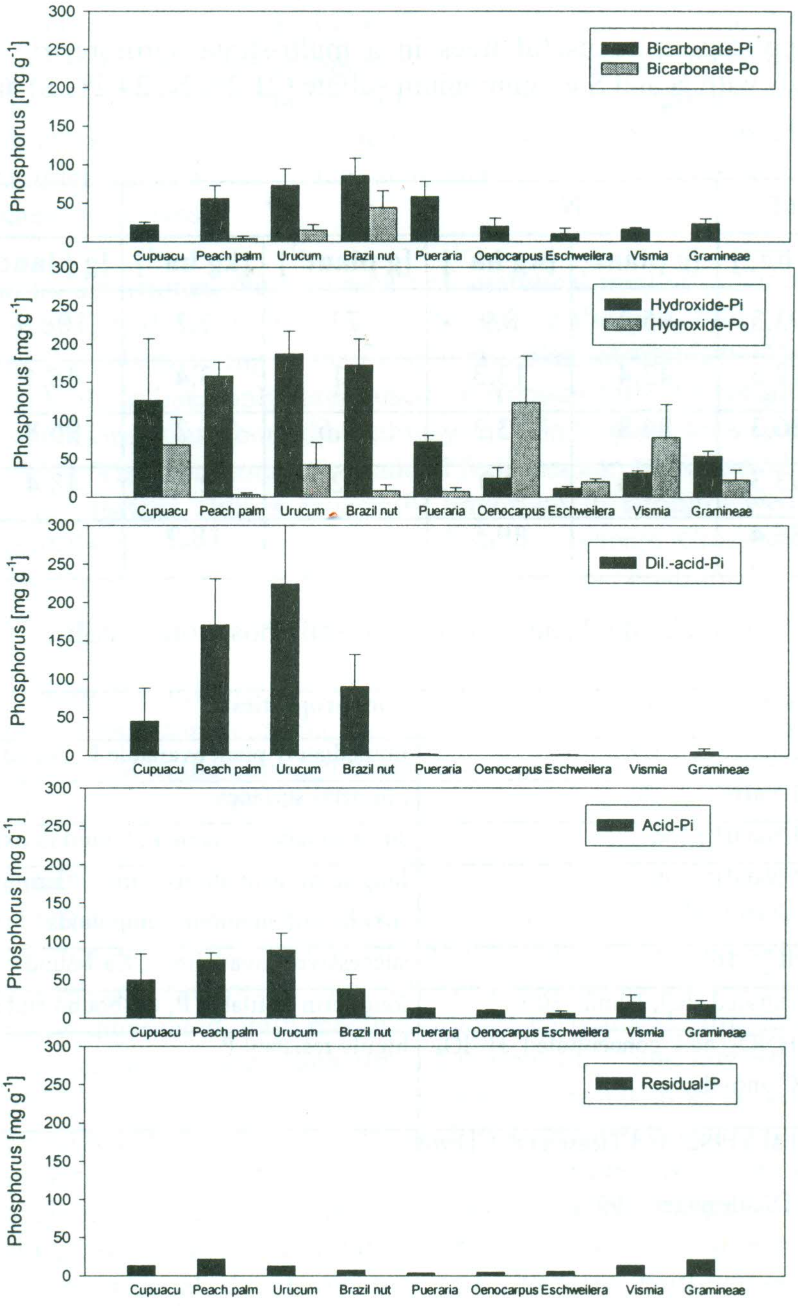

Figure 1. P pools of soils under single trees in a multi-strata agroforestry system, fallow and primary forest on the terra firme near Manaus, Brazil; means and standard errors (n=3).

Fertilizer effects on soil nutrient pools

Soils beneath undisturbed forest trees and secondary forest had lower available P (bicarbonate-P_i and -P_o, hydroxide-P_i) than the soils under the useful trees in the agroforestry system due to P fertilization (Fig.1). Also successively and intermediately available P contents (diluted-acid-P, acid-P) were higher in the fertilized soils than in the natural ecosystems. However, long-term available and highly resistant P (hydroxide-P_o, residual P) did not differ, showing that initial P properties were the same between the studied sites.

Single-tree effects on P and S pools in multi-strata agroforestry systems

The soils under different tree species in the multi-strata agroforestry system showed markedly different soil P contents, which did not reflect the amount of fertilizer applications (Table 1). Soils under cupuacu had low available P contents (bicarbonate-P_i and -P_o) similar to soils under the forest trees despite the fact that cupuacu recieved even 7, 4 and 2 times more fertilizer P than peach palm, Brazil nut and urucum, respectively, while having the lowest aboveground biomass production (M. Wolf, unpublished data). Successively available inorganic P (hydroxide-P_i), however, was similar under all agroforestry trees, but still higher than in the natural and secondary forest. This was different for hydroxide-P_o, which was higher under *Oenocarpus* and vismia than at all other sites apart from urucum and cupuacu. P fertilization did not increase this P pool. The incorporation of added fertilizer P into bicarbonate-P_i and -P_o and diluted-acid-P was most efficient under peach palm, followed by Brazil nut and urucum. Cupuacu showed a very low ability to preserve added P in available P forms.

Conclusions

The modified Hedley procedure proved to be extremely useful for the studied soil type to demonstrate the highly contrasting P dynamics of the experimental sites. The different tree species exhibited a pronounced and relevant effect on P properties in the multi-strata agroforestry system. These strongly contrasting effects have to be considered when designing multi-strata agroforestry systems and may help to improve the efficiency of nutrient cycling.

References

Beck MA and Sanchez PA (1995) Soil phosphorus movement and budget after 13 years of fertilized cultivation in the Amazon basin. Plant and Soil 184: 23-31

Cross AF and Schlesinger WH (1995) A literature review and evaluation of the Hedley fractionation: Applications to the biochemical cycle of soil phosphorus in natural ecosystems. Geoderma 64: 197-214

FAO (1995) Soil map of the world, revised legend. FAO, Rome, Italy.

Hedley MJ, Stewart JWB and Chauhan BS (1982) Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Science Society of America Journal 46: 970-976

Murphy J and Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27: 31-36

Schroth G, Barros E, Rodrigues MRL and Lehmann J (1998) A review of plant-soil interactions in multi-strata agroforestry systems with perennial crops. In: Proceedings of the International Workshop on Multi-Strata Agroforestry Systems, CATIE, Turrialba, this issue.

Selles F, Kochhann RA, Denardin JE, Zentner RP and Faganello A (1997) Distribution of phosphorus fractions in a Brazilian Oxisol under different tillage methods. Soil and Tillage Research 44: 23-34

Tiessen H, Stewart JWB and Cole CV (1984). Pathways of phosphorus transformations in soils of differing pedogenesis. Soil Science Society of America Journal 48: 853-858