

## CHANGES IN SOIL PHOSPHORUS IN DIFFERENT FOREST RESIDUE MANAGEMENT

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### Abstract

We analyze the short term effect of the harvest residues management on the Phosphorus (P) fractions of the soil. Four trials were installed in Northeast Argentina on Vertisols (S1), Mollisols (S2) and Entisols (S3 and S4). In S1 and S2 harvest residues and forest floor were either (1) removed (R), (2) retained (RR), 3) burnt (BR), or (4) retained at double the normal quantity (DR). In S3 and S4 harvest residues where (1) removed (WTH), 2) retained (RR) or 3) burnt (BR). Soil samples were obtained at 0-5 cm and 5-10 cm depth layers at 18 (S1), 22(S2, S3) and 10 (S4) months after burnt treatments. P fractions were determined according to Hedley *et al.* (1982) methods. Soil orders showed different total P: in Mollisols P concentration (S2: 314,3 mg kg<sup>-1</sup>) tripled those in Entisols (S3 y S4: 118,4 mg P kg<sup>-1</sup>). Differences were even higher for Organic P (P<sub>o</sub>): the highest concentration was found in Mollisols (171,4 mg P<sub>o</sub> kg<sup>-1</sup>) related to its higher organic matter, and the lowest concentration was in Entisols (44,0 mg P<sub>o</sub> kg<sup>-1</sup>). Available P was between 14 mg kg<sup>-1</sup> and 25 mg kg<sup>-1</sup>, enough to satisfy annual demands of forest plantations (*Eucalyptus* and *Pinus*). RR and DR did not show changes in the P fractions, although an increase in the P reserves (P<sub>o</sub> y P<sub>i</sub>) could be expected for the middle term, due to the decomposition of the retained/added residues. R or WTH did not affect neither inorganic nor organic P fractions. The most important change was found in BR, where the available P and other mean and highly stable inorganic P fractions increased, due to the ashes; the P<sub>o</sub> was not modified. The fire was an instant mechanism to transfer the nutrients from the biomass to the soil.

**Keywords:** Residue management, phosphorus soil, *Pinus* sp, *Eucalyptus* sp.

### Introduction

Argentina Mesopotamia, with 921,000 forested hectares, concentrates 76% of the total cultivated forest in the country (1). These forest plantations, predominantly with *Eucalyptus* and *Pinus* are located in widely varied soils (Ultisols, Mollisols, Alfisols, Entisols). Within this diversity, the distribution of stable and available forms of Phosphorus (P), as well as organic and inorganic forms, depend on their genesis and evolution stage (2,3).

In various forest soils, P is a limiting nutrient for crop growth (4). Therefore, understanding its condition and flows in each type of soil in terms of its availability for plants such as reserve plants, has significant implications on productivity and resilience on the forest ecosystem

(5), mainly in this region where total P contents were medium to low (3).

Forest operations such as soil preparation, residue management, and the use of fertilizers may affect soil fertility and increase cultivation growth (6). However, the implementation of an intensive silviculture (with harvest systems that imply significant biomass export, short rotation, and the burn of forest residues) on soils that have had previous forest cycles may produce changes in the nutrient resource of the area (7; 8, 9, 10), and specifically in the behavior of labile P and total P (11, 12). The available P may immediately increase after fire on the soil surface horizons (13, 14); however, these are short-term increases which may produce long-term losses, thus reducing forest productivity (15, 16, 11). The opposite would occur in residue conservation systems where the increase in soil organic carbon (14) would

produce significant increases in organic P fraction (17); an important P source available for plants (18).

Hedley et al. method (1982) was satisfactorily used for splitting soil-P biochemical pools into different ecosystems, and for understanding the changes induced by different management. However, in our country it was rarely applied to analyze P dynamics on soils with cultivated forests. The purpose of this work is to evaluate the effect of different methods of harvest residue management in forests in relation to organic and inorganic Phosphorus forms.

## Materials and method

### Localization and Characteristics

The study was carried out in soils of 4 locations (S) in the northeast of the Province of Entre Ríos (S1 and S2), and in the southeast of the Province of Corrientes, Argentina (S3 y S4), where they are available for forest use, and have previously experienced one or two forest cycles or rotations.

Sites S1 y S2 are located near Concordia city, with humid, warm climate, annual mean temperature of 18.5 °C, annual mean rainfall that ranges 1275 mm and 1420 mm of potential evapotranspiration. The S1 trial was performed on a Yerua Series Argiacuolic Peludert soil, and the S2 trial on a Calabacilla Series Hapludol Fluventic soil. Both soils come from 1 *E. grandis* rotation with 2 resprouting cycles.

S3 and S4, near Bella Vista, province of Corrientes, have mild climate, annual mean temperature of 20 °C, annual mean rainfall of 1330 mm and 1168 mm of annual evapotranspiration. S3 soil is Pampin Series Psamacuent soil and experienced a previous *Pinus elliotti* rotation of 24 years. S4 soil is a Bravo Series acuí Udipsament soils comes from an *E. grandis* rotation with 1 regrowth cycle.

### Treatment and design of the experiments

The following treatments in harvest residue management were applied in S1 and S2: 1) *Total residue removal* (R): after harvesting, all remaining biomass (forest floor, undergrowth, harvest residues) was removed from the plot; 2) *residue with no debarking retained* (RR): after harvesting, with no field debarking, all the biomass was retained in the plot; 3) *burnt residue* (BR): after harvesting, residues were burnt; 4) *retained at double the normal quantity* (DR): after harvesting, all the biomass was retained in the plot, and the residue obtained from R treatment was added.

In S1, between August and November 2005, treatments were applied, while in S2 treatments were applied

between November and December of the same year. Trials were performed under a fully randomized design with 4 replications in S1, and 3 replications in S2. Each experimental plot was 1,352 m<sup>2</sup>. No farm work was done on the soil, and *Eucalyptus grandis* was manually planted, using a spade.

As a result of a post-harvesting residue sampling, the amount of P stored in residues was estimated. Dry material coming from the top a tree (branches, leaves, and fruits) and the mulch were quantified. In S1, the amount of P in harvest residue of *E. grandis* was 13.5 kg.ha<sup>-1</sup> in RR, BR, and R, and 18.6 kg.ha<sup>-1</sup> in DR. In S2 the amount of P in residue was 14.4 kg.ha<sup>-1</sup> in RR, BR, and R; and 20.4 kg.ha<sup>-1</sup> in DR.

In S3 and S4 the following harvest residue management treatments were applied: 1) *Whole-tree harvesting* (WTH): whole tree was removed; only forest floor remains in site. 2) *Retained residue* (RR): All Harvest residues are spread throughout the plot. 3) *Burnt residue* (BR): Residues spread on the soil were burnt through controlled burning.

Treatments were arranged in a complete randomized block design with 5 replications in S3, and 4 replications in S4. Each experimental unit stretched over 1,680 m<sup>2</sup>. In S3, treatments were applied between September and October 2005, and in November hybrid pine was planted (*Pinus elliottii* x *Pinus caribea* var. *hondurensis*). In S4 harvest took place in 2006, burning towards the end of September 2007, and planting in October 2007. In S3, *Pinus elliottii* residues showed 25 kg P.ha<sup>-1</sup> in RR and BR. The amount of P in residues in S4 was not quantified.

### Soil sampling and laboratory determinations

Soil samples were obtained on month 10 in S4, on month 18 in S1, and on month 22 after burning in S2 and S3. Complex soil samples at 0-5cm and 5-10 cm depth layers (after 30 spades) were obtained from each plot. In these determinations, the following P fractions according to Hedley et al. (1982) method were determined: 1) highly labile P, formed by inorganic P in soil solution, and P very weakly absorbed on hydroxide and/or carbonates ( $P_{\text{highly labile}}$ ), is available for the plant and microorganisms; 2) inorganic labile P ( $P_{\text{il}}$ ) is easily available P to the plant or easily mineralizable labile organic P ( $P_{\text{ol}}$ ); 3) slightly labile inorganic P ( $P_{\text{iml}}$ ) attached to the surface of clay or FE and Al oxide and hydroxide. It is available to the plant and microorganisms in the medium term. Slightly labile organic P ( $P_{\text{oml}}$ ), associated to organic compounds such as fulvic and humic acid. 4) Relatively insoluble inorganic P related

to calcium (Ca) and P blocked in weathered soils ( $P_{iCa}$ ), unavailable to plants and microorganisms in the short and medium term, and non-reactive. 5) Highly stable and insoluble chemically inorganic and organic P ( $P_{i res}$ ), non reactive and unavailable to plants and microorganisms in the short and medium term. And 6) total P ( $P_t$ ). In S1 and S2 sites, determinations of total organic carbon (TOC) were made through dry combustion.

### Statistical analysis

The analysis of each treatment fraction of each site was made through ANOVA (analysis of variance) and when differences between treatments were detected, the average values were compared by Tukey Test at 0.05 % level of probability.

### Results and discussion

Total P levels in the soils under study are highly contrasting. Concentrations in Mollisol (S2: 314.3 mg kg<sup>-1</sup>) almost tripled those in Entisols (S3 and S4: 118.4 mg P kg<sup>-1</sup>) and differences quadrupled when organic fraction ( $P_o$ ) was analyzed. The lowest value was found in Entisols (44.0 mg  $P_o$  kg<sup>-1</sup>) and the highest in the Mollisols (171.4 mg  $P_o$  kg<sup>-1</sup>). In these soils, available P varied from 14 mg kg<sup>-1</sup> up to 25 mg kg<sup>-1</sup> and it is enough to meet the annual demands of forest crops (*Eucalyptus* and *Pinus*) according to (7) and (19).

In the short term, burnt residue (BR) was the only treatment that produced modifications in P fractions leading to an increase in  $P_i$ , and in particular, in P available to plants ( $P_{i highly\ labile} + P_{i il}$ ). Changes occurred basically in 0-5 cm depth layer.

Figure 1 shows the available P behavior as the sum of P fractions in the solution plus the easily available P ( $P_{i highly\ labile} + P_{i il}$ ), for 0-5 cm depth layer of each treatment and type of soil. As it can be observed, no changes between treatments occurred in the sampled sites at 22 months (S2 and S3), and this may be related to different processes that took place along this period of time: 1) available P due to burning could be absorbed by plants (weeds and crops), 2) P redistribution towards different fractions and re-absorption to mineral fraction could have taken place, and/or 3) transformation in  $P_o$  through microbial immobilization processes.

Unlike intense burnings, mild-moderate burnings have a temporary effect given the fact that the changes produced are not deep. The feasibility to detect changes in P fractions decreases along time (13). The significant increase in S1 and S4 may be associated to the shorter time elapsed from the burning to the sampling, where a part of P in soil solution can be found.

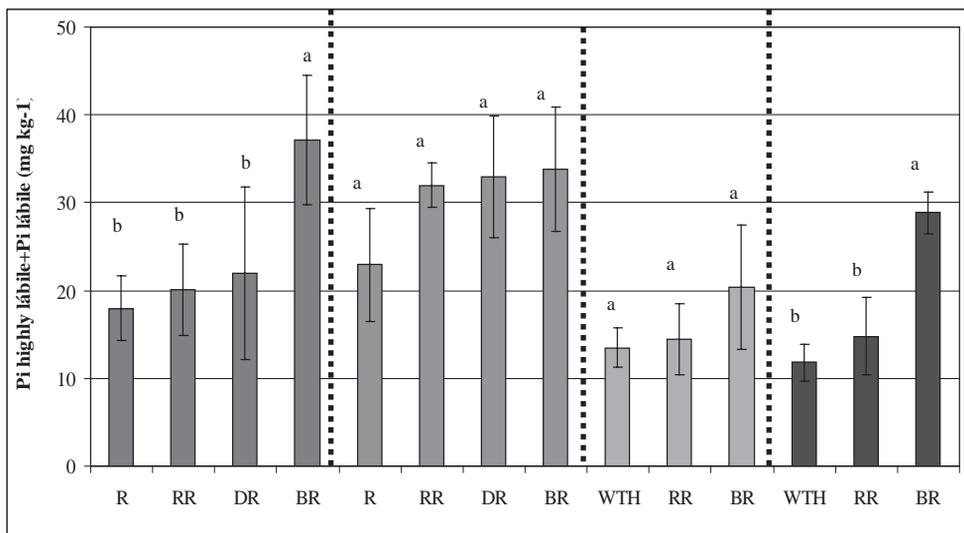


Figure 1. Available Phosphorus in 0-5 cm depth layers, under different residue management systems applied to different soils. R: removed residue; RR: retained residue; BR: burnt residue; DR: retained at double of normal quantity; WTH: whole-tree harvest. Lowercase letters indicate statistically significant differences between treatments in each soil order ( $P < 0,05$ ). Vertical bars represent the standard deviation of the sample.

In the Vertisol (S1), in addition to available P, other more stable inorganic fractions such as  $P_{iml}$  and  $P_{iCa}$  showed a significant increase, 1.4 and 1.6 times bigger than RR. In the Entisols with *Pinus* residues (S3), the burning effect also showed an increase in the non-reactive fraction ( $P_{iCa}$ ) being 1.3 higher than WTH. The increase in different  $P_i$  fractions in BR indicates a redistribution of the P that reached the soil in the form of ash, a behavior observed by (20) and (21) when assessing the fate of phosphorus fertilizers in Mollisols, Vertisols, and

Inceptisols. In Entisols with *Eucalyptus* (S4) the effects were observed in both depths, and it may be associated with the translocation of ashes in sand macropores, as stated by (18).

$P_t$  reserves only increased significantly in BR in the Entisols with *Pinus* (S3) where the biggest amount of residues was quantified, with 25 kg P<sub>ha</sub><sup>-1</sup> (Figure 2). In the Mollisols (S2), no changes were detected in inorganic fractions and in  $P_t$  as a consequence of residue burning.

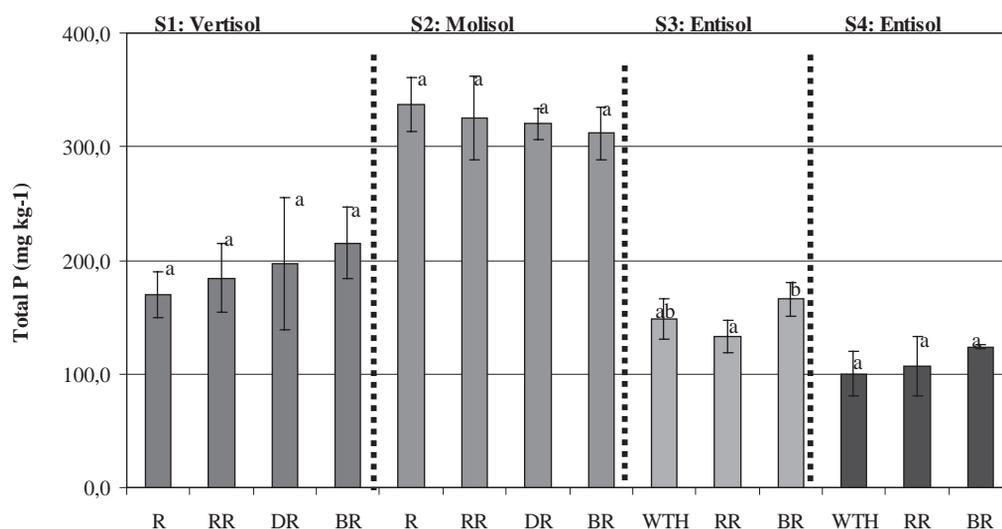


Figure 2. Total phosphorus in 0-5 cm depth layer of different residue handling Systems, according to types of soil. R: removed residue; RR: retained residue; BR: burnt residue; DR: retained at double of normal quantity; WTH: whole-tree harvest. Lowercase letters indicate statistically significant differences between treatments in each soil order (P<0,05). Vertical bars represent the standard deviation of the sample.

As indicated, between 170°C and 300°C,  $P_o$  of the soil starts its thermal mineralization with small changes in MO (22,23) reaching its maximum combustion after 500°C where P is released, and full combustion of MO with phosphate volatilization is achieved (24, 25, 26,27). Absence of changes in P organic fractions (Figure 3) allows us to infer that burning was slight and residues acted as a “shock absorber” of the temperature transferred to the soil during burning. As a consequence, the increase in available P is due to ashes that reached the mineral soil after residue combustion, and probably because of microorganism death caused by increase in temperature. (16, 24 28, 12 and 19).

Retained or removed residue did not produce significant changes in  $P_o$  fractions, which is consistent with the absence of changes in total organic carbon (TOC) levels shown in Table 1 for S1 and S2. The short time elapsed from the start of the trial in addition to other factors such as low forest residue quality (high C/N relation, presence of tannin, resin, etc) are factors that controlled the residue decomposition process in RR and DAR. It is expected that  $P_o$  reserves in the soil increase in the medium term, given the fact that until the date of the sampling, most of the woody residue remained on the soil unweathered.

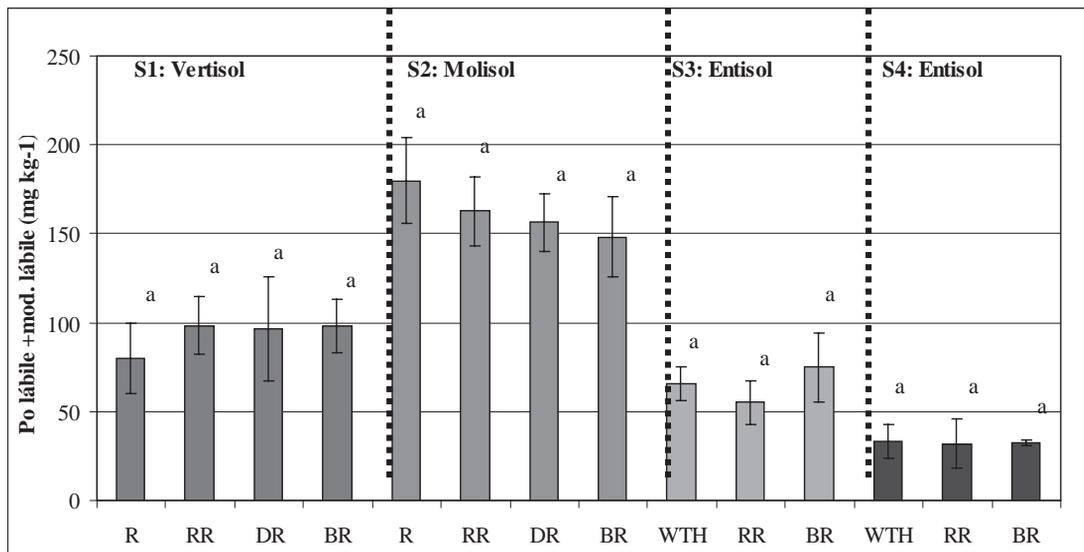


Figure 3. Total organic phosphorus ( $P_{\text{ol}} + P_{\text{oml}}$ ) at 0-5 cm depth layers of different forest residue management systems applied in different soils. R: removed residue; RR: retained residue; BR: burnt residue; DR: retained at double of normal quantity; WTH: whole-tree harvest. Lowercase letters indicate statistically significant differences between treatments in each soil order ( $P < 0,05$ ). Vertical bars represent the standard deviation of the sample.

In treatments without residues, TOC is protected against microorganisms due to the absence of disturbances such as farm work. In addition, C humidification provided by the roots of previous crop and weeds might balance the losses occurred in the organic fraction. This balance may be insufficient to detect changes.

Table 1. Total organic carbon (TOC) per site, treatment, and sampling depth layer

	S1		S2	
	0-5 cm	5-10 cm	0-5 cm	5-10 cm
DR	2,76 (0,96)a	1,77(0,28)a	2,95(0,25)a	1,49(0,0)a
RR	2,12(0,78)a	1,57(0,56)a	2,81(0,53)a	1,57 (0,07)a
R	2,04(0,48)a	1,55(0,16)a	2,79(0,31)a	1,56(0,09)a
BR	2,24(0,65)a	1,36(0,22)a	2,23(0,72)a	1,41(0,06)a

For each depth layer, similar initials indicate absence of significant differences between treatments at a 0.05 significance level. Values between brackets indicate standard deviation of the sample. S1: Peludert. S2 Hapludol. R. Total residue removal. RR. Retained residues. BR. Burnt residue - control. DR. Double residue addition.

## Conclusions

In the short term, burning produced changes in P fractions. In the Vertisols and in the Entisols (sampled at 10 and 18 months from burning), the available P and

other inorganic fractions with more stability increased without modifying the organic fractions of the soil. In this sense, burning turned out to be a nutrient transference tool from the vegetal biomass to the soil. No changes were detected in the available fraction in the Mollisols, and the Entisols, sampled at 22 months from burning.

Retained and removed residues did not produce changes in P fractions in none of the soils under study, and require additional evaluations.

Although no negative impacts on the P of the soil in the short term due to burning and residue removal have

been detected, it is worth mentioning that these practices are not recommended due to the potential direct and indirect negative effect on the soil quality and functioning in general in the medium-long term. The consequences will be greater and with immediate effect if these treatments are applied in the Entisols. The replacement of P exported in the harvest is a strategic practice to be applied together with the retention of harvest residues and field debarking.

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