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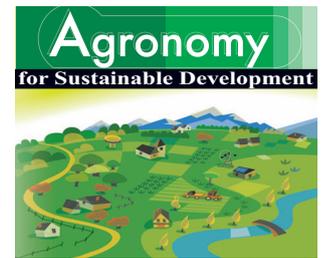
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Research article

Plant age and rock phosphate effects on the organic resource quality of herbaceous legume residues and their N and P release dynamics

B. VANLAUWE^{1*}, A. IDRISSE², J. DIELS³, N. SANGINGA¹, R. MERCKX⁴

¹ Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, PO Box 30677, Nairobi, Kenya

² Ministère des Enseignements Secondaire Supérieure de la Recherche et de la Technologie, BP 237, Niamey, Niger Republic

³ International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

⁴ Department of Land Management, Faculty of Applied Bioscience and Engineering, Kasteelpark Arenberg 20, 3001 Heverlee, Belgium

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Abstract – Many tropical agro-ecosystems rely on organic resources for nutrient provision. Various factors affect the nutrient release dynamics of organic resources, including application of external nutrients during their growth and their age or physiological stage at the time of harvest. Understanding relationships between organic resource management factors and the resulting nutrient release dynamics is important for optimizing nutrient recovery by crops and minimizing nutrient losses to the environment. Here, *Mucuna pruriens* and *Lablab purpureus* legumes were grown on a ‘slope’ and ‘plateau’ field, treated or not with rock phosphate, and sampled from 12 to 30 weeks after planting. These plant residues were then incubated in a sandy soil under laboratory conditions and mineral N and Olsen-extractable P dynamics were measured for 28 days. Our results showed that plant age had an impact on N, P and polyphenol contents. Application of rock phosphate only altered the P content of the legumes on the ‘plateau’ field, which had a lower soil-available P content. We also observed that mineral N dynamics of the organic resources varied between –62% of the added N released after 28 days, indicating net immobilization, and +23%, indicating net mineralization, with most organic resources showing an initial N immobilization phase. N release was negatively related to the lignin-to-N and (lignin+polyphenol)-to-N ratios of the organic resources. Lastly, we observed that the net release of Olsen P relative to the control soil varied between 0.4 and 4.9 mg kg⁻¹ and that net P release was positively related to the P content of the organic resources. In summary, legume age was the parameter that most strongly influenced the quality of the legume residues, and consequently its N and P release dynamics, with potentially significant consequences for N and P uptake recovery and losses and, ultimately, cropping system sustainability.

Lablab purpureus / *Mucuna pruriens* / N mineralization / Olsen P release / organic resource quality / Togo rock phosphate

1. INTRODUCTION

It is generally acknowledged by the research and development community studying declining soil fertility in Sub-Saharan Africa that both organic and mineral inputs are required to boost agricultural production (Vanlauwe et al., 2002). Organic resources are different from mineral inputs because plant-available nutrient release dynamics from organic resources vary widely, depending on their organic resource quality. Organic resource quality is usually expressed as a combination of N, lignin and/or soluble polyphenol content, with high quality organic resources showing relatively quick net N release dynamics (Palm et al., 2001). Moreover, while availability of mineral inputs is limited largely because of socio-economic rather than technical constraints, production of a sufficient amount of organic resources is a major difficulty in areas with limited land availability, long dry seasons, and/or large livestock populations. Organic matter cut-

and-carry systems involve a lot of labor, in the absence of mechanization, while in-situ production of organic resources results in competition for land with food crops. Substantial efforts have been made to evaluate the inclusion of herbaceous legumes in existing cropping systems to enhance the soil fertility status with minimal amounts of external inputs (Versteeg et al., 1998; Vanlauwe et al., 2003). From a soil fertility improvement standpoint, herbaceous legumes are usually preferred over grain legumes as most of the N fixed from the atmosphere by the former remains in the soil, while for the latter, a large fraction of fixed N is removed from the field through the harvested grains.

Organic resource quality is known to affect its decomposition and mineralization dynamics (Cadisch and Giller, 1997). A good overview of organic resource quality – N mineralization relationships was presented by Palm et al. (2001) in a paper describing the Organic Resource Database (ORD), that currently contains information on organic resource quality parameters including macronutrient, lignin and

* Corresponding author: b.vanlauwe@cgiar.org

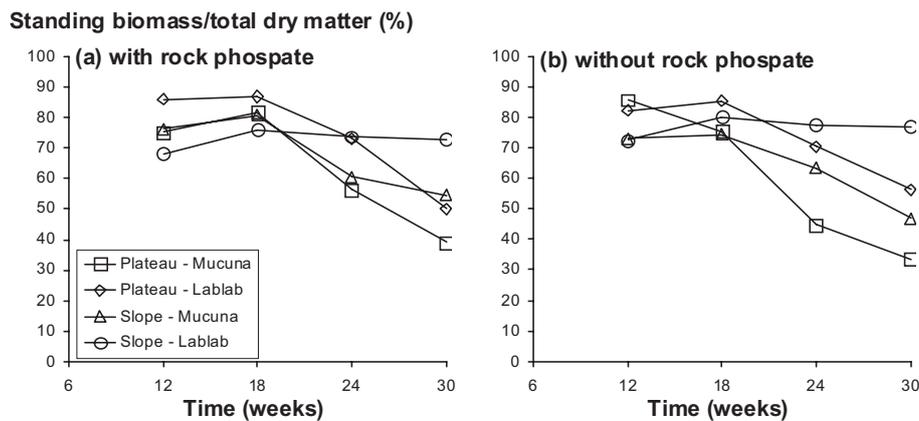


Figure 1. Ratio of standing biomass dry matter:total aboveground dry matter (standing biomass + surface litter) for the different treatments and sites, used for composing the organic resources in the incubation. 'RP' means 'rock phosphate'. Note that the ratio was determined using field assessments of dry matter production (Vanlauwe et al., 2000).

polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agro-ecosystems (<ftp://iserver.ciat.cgiar.org/webciat/ORD/>). Organic resource quality is also not constant for one species but varies with the plant components included, plant age or physiological status, and management. Vanlauwe et al. (1997) reported that quality characteristics of tree prunings varied substantially for different canopy ages. Handayanto et al. (1995) observed that application of N fertilizer significantly affected N and polyphenol concentrations of *Calliandra calothyrsus* and *Gliricidia sepium* prunings.

Organic resources are not only a source of N but fulfill a number of other functions, such as enhancement of soil moisture conditions (Vanlauwe et al., 2001), improvement of the soil-available P status (Nziguheba et al., 2000), reduction in Al concentrations in the soil solution (Pypers et al., 2005) or amelioration of the soil organic matter pool and its quality (Cadisch and Giller, 2000) with consequent impacts on soil structure and aggregation. Nziguheba et al. (2000) observed that the P content of organic resources and the soluble C-to-total-P ratio were the main organic resource parameters predicting soil P availability and maize yield.

The objectives of this work were (i) to assess the organic resource quality of aboveground *Mucuna* and *Lablab* residues as affected by plant age, application of rock phosphate and production site, (ii) to quantify available N and P release dynamics of the above legumes as affected by the same set of factors, and (iii) to explore potential relationships between short-term N and P mineralization dynamics and organic resource quality.

2. MATERIALS AND METHODS

2.1. Legume trials

Three trials aiming at quantifying rotational effects in herbaceous legume – maize rotations as affected by application of rock phosphate to the legume were established in Kasuwan Magani, a village in the Northern Guinea savanna

zone of Nigeria, along a representative toposequence. A first field, referred to as the 'plateau' field, was established on the interfluvial crest on a Ferric Acrisol with a petroferic phase, a topsoil (0–10 cm) Olsen P content of 2.5 mg kg⁻¹, and relatively high P sorption characteristics (Nwoke et al., 2004). A second field, referred to as the 'slope' field, was established on the more fertile valley slope between the crest and the valley bottom on a Haplic Lixisol with a petroferic phase and a topsoil (0–10 cm) Olsen P content of 14.1 mg kg⁻¹. The petroferic layer occurred deeper in the profile (> 80 cm) compared with the 'plateau' field. A third field, referred to as the 'valley' field, was established near the valley bottom on a Gleyic Lixisol. More details on field and site characteristics are given by Vanlauwe et al. (2000a). The trials were established in 1997 and each trial included treatments with white-seeded *Mucuna pruriens* (L.) var *utilis* (Wright) Burck and white-seeded *Lablab purpureus* L. with and without rock phosphate addition at a rate of 90 kg P ha⁻¹. The rock phosphate was collected from the Hahotoe mine in Togo and sieved through 0.15 mm before application. The rock phosphate had a P content of 17%, of which 20% was soluble in citric acid. None of the legumes was inoculated. The 'plateau' field had 3 replicates, the 'slope' field 4 replicates and the 'valley' field 4 replicates.

2.2. Organic resource collection and quality determination

At 6, 12, 18, 24, 30 and 36 weeks after planting, the legume standing biomass and surface litter was sampled with a quadrant of 0.75 by 0.75 m², placed randomly on one row, 0.5 m away from the end of the row (Vanlauwe et al., 2000a). The organic resources used in the current work were obtained by mixing standing biomass and surface litter material using the standing-biomass-to-surface-litter ratio as obtained for each plot and sampling date (Fig. 1). Note that older residues contained a larger proportion of surface litter, except for the *Lablab* residues of the 'slope' field. Only organic resources sampled between 12 and 30 weeks after planting

on the 'plateau' and 'slope' fields from the first 3 replicates were used in this work. More details on trial management and sampling are given by Vanlauwe et al. (2000a). The legume biomass samples taken on the various sampling dates were dried (65 °C), weighed, ground to pass 0.5 mm, and analyzed for total C (Amato, 1982), Kjeldhal N, total P (IITA, 1982), and lignin, using the permanganate oxidation procedure (Van Soest and Wine, 1968). The total soluble polyphenol content was quantified by Folin-Ciocalteu reagent, against a tannic acid standard after extraction of 0.1 g of plant material with 50 ml of a 50% methanol-water mixture (Anderson and Ingram, 1993).

2.3. Incubation study

The soil used for the incubation experiment was taken from the 0–10 cm layer of a Ferric Lixisol from an experimental farm in Fashola, southwestern Nigeria. The soil had an organic C content of 9.0 g kg⁻¹, a total N content of 0.72 g kg⁻¹, a mineral N content of 45 mg N kg⁻¹ dry soil, an Olsen P content of 4.3 mg kg⁻¹, a pH KCl of 6.0, an effective cation exchange capacity of 5.3 cmol_c kg⁻¹, a sand content of 840 g kg⁻¹, a silt content of 100 g kg⁻¹ and a clay content of 60 g kg⁻¹. The soil was air-dried, sieved through 2 mm, rewetted with distilled water to attain 40% of water-holding capacity, and kept at room temperature for 3 weeks prior to incubation. Fifty grams of pre-incubated soil were used for each incubation jar. The organic resources were ground through 1 mm and thoroughly mixed with the soil at a rate equivalent to 5 t ha⁻¹ dry weight basis, or 0.179 g per 50 g of soil, and placed in 60 mL bottles. Each treatment was replicated 3 times and organic resources collected from the different field-level replicates were incubated separately. Control soils did not receive any organic resources. The bottles were placed in 1.5 L glass incubation jars containing 10 mL of distilled water to keep the soils moist during the incubation period. After 7, 14 and 28 days, 3 jars per treatment were destructively sampled for mineral N and Olsen P determination. Determination of mineral N and Olsen P was also carried out at the beginning of the experiment, after the 3 weeks of pre-incubation. Ammonium N and nitrate N in the soil were determined with a scalar continuous flow analyzer after extraction of 30 g of soil with 90 mL of 2N KCl for 30 minutes and centrifugation at 150 revolutions per minute for 5 minutes (IITA, 1982). Olsen P was measured following Okalebo et al. (1993).

2.4. Mathematical and statistical analyses

Organic resource quality parameters were analyzed following a split-plot design (main plot: 'treatment', sub-plot: 'residue age') with the MIXED procedure of SAS (SAS, 1992), using 'treatment', 'field' and 'residue age' and their interactions as fixed effects and 'replicate within field' and 'replicate × treatment within field' as random effects. Mean separation was done with the PDIF option of the LSMEANS statement (SAS, 1992).

The net amount of mineral N and Olsen P released was obtained by subtracting the mineral N or Olsen P content of the unamended control treatment from the treatments that received organic resources. For each sampling date, the proportional amount of residue N or P mineralized could thus be estimated as follows, with N_{min} and P_{Olsen} referring to mineral N and Olsen P:

Residue N mineralized =

$$\frac{(N_{\text{Min}} \text{ in amended soil}) - (N_{\text{Min}} \text{ in control soil})}{\text{Residue N added to amended soil}} \times 100\% \quad (1)$$

Residue P mineralized =

$$\frac{(P_{\text{Olsen}} \text{ in amended soil}) - (P_{\text{Olsen}} \text{ in control soil})}{\text{Residue P added to amended soil}} \times 100\% \quad (2)$$

Mineral N is taken conventionally as the sum of ammonium N and nitrate N. N mineralization and Olsen P data were subjected to the MIXED procedure for each time of sampling separately, with 'general treatment' as fixed effect and 'incubation replicate' as random effect, and standard errors of the difference were calculated using the PDIF option of the LSMEANS statement. 'General treatment' combines one level of 'field', 'treatment' and 'residue age'. Simple regression analysis (SAS, 1985) was used to relate N and P mineralization dynamics with various organic resource characteristics for all organic resources combined or for the *Mucuna* and *Lablab* residues separately.

3. RESULTS AND DISCUSSION

3.1. Organic resource quality

Generally, older organic resources on both fields tended to contain less N and P, although differences between respective plant ages were not consistently significant (Fig. 2). Application of rock phosphate did not influence the N content of the *Mucuna* and *Lablab* residues on both fields but resulted in significantly higher total P contents of the *Mucuna* and *Lablab* aboveground biomass at 12 and 18 weeks after planting on the 'plateau' field. On the 'slope' field, rock phosphate did not affect residue P contents (Fig. 2). For nearly all organic resources and both fields, lignin contents did not vary significantly with residue age and rock phosphate application (Fig. 3). On the 'plateau' field, 24-week-old *Mucuna* residues had significantly higher polyphenol contents than the other residues, while residue age had relatively little effect on the polyphenol content of *Lablab* (Fig. 3). On the 'slope' field, both *Mucuna* and *Lablab* residues had higher polyphenol contents at 24 weeks. In most cases, application of rock phosphate did not influence the polyphenol content of both legumes on both sites (Fig. 3).

First, the above data clearly show that for both species, organic residue age had a major impact on its N, P and polyphenol contents, and a minor impact on its lignin content.

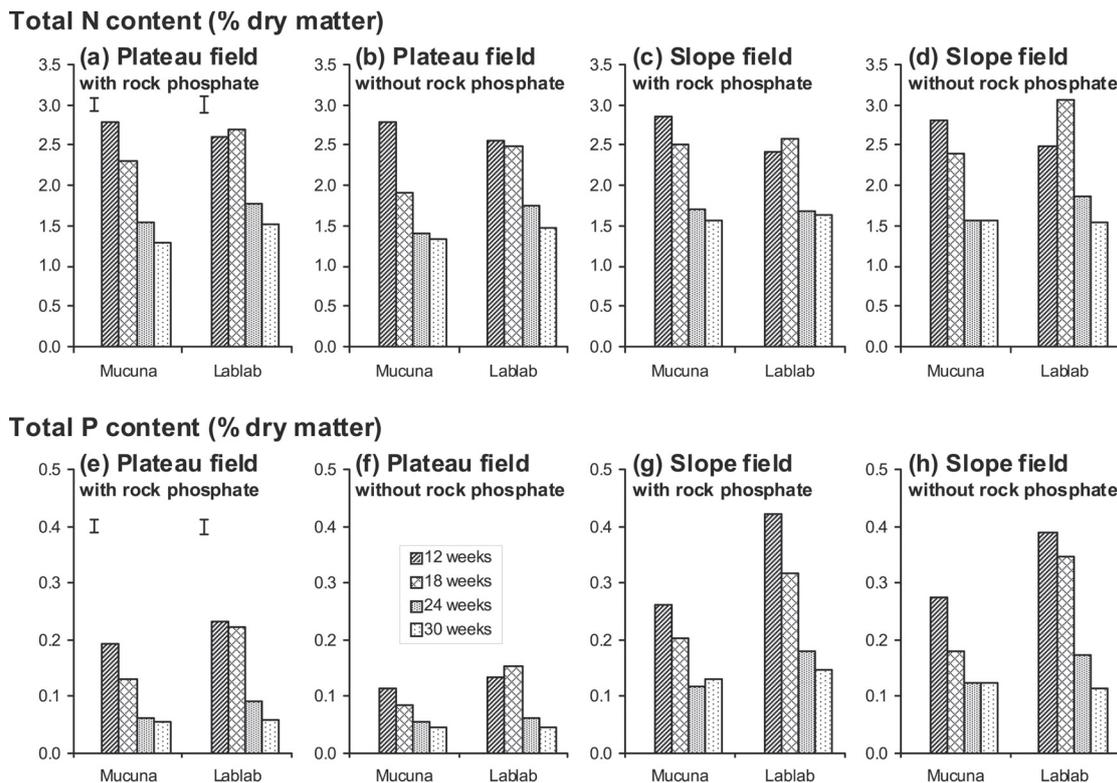


Figure 2. Total N content of the organic resources produced on the ‘plateau’ (a), (b) and ‘slope’ (c), (d) fields and total P content of these resources produced on the ‘plateau’ (e), (f) and ‘slope’ (g), (h) fields. The left error bars indicate the Standard Errors of the Difference (SED) between sampling times for one treatment, the right error bars indicate the SED between treatments at one sampling time. ‘RP’ means ‘rock phosphate’.

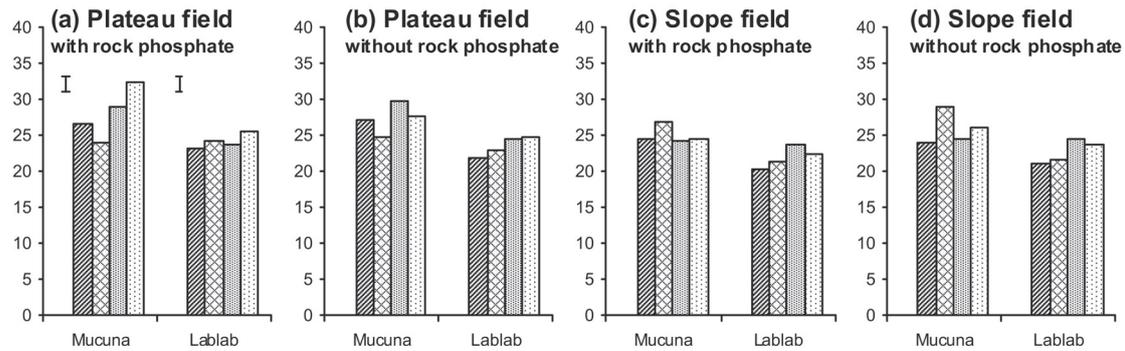
At 24 weeks, both legume N and P contents fell to about half their values at 12 weeks of age. Decline in nutrient contents of legumes with age is a well-known phenomenon and caused by advancing cell-wall formation, a decreasing leaf-to-stem ratio (Lloveras and Iglesias, 2001), an increasing proportion of senescent plant parts, and translocation of N and P from the leaves and stems to the inflorescences with increasing plant age (Ozanne, 1986). In Tanzania, Mero and Uden (1997) observed decreases in crude protein and in-vitro digestibility for various grasses and legumes between 4 and 10 weeks of age. Gunther et al. (1988) similarly observed decreasing crude protein and P contents with increasing ages of pasture fodders in Tanzania. Differences in the above parameters between 24 and 30 weeks are minimal as this period fell within the dry season (Vanlauwe et al., 2000a).

Secondly, the above data also show that total soluble polyphenol contents varied considerably between fields and organic resource ages for the same species. Tannins in plant materials are commonly associated with defenses against herbivore activity and plant materials containing over 2% tannins are usually less attractive for feeding because of their astringency (Swain, 1979). Tannins can also protect plants against fungal and bacterial attachment by encapsulating plant molecules and inhibiting essential enzymes of attaching organisms (Swain, 1979). The lower polyphenol content of younger leaves, observed in the current trials, does not agree with earlier observations by Mafongoya et al.

(1997), who reported higher soluble polyphenol contents of younger tree prunings and attributed this to the need for better protection against herbivore activity for younger prunings with a higher soluble cell content, e.g., proteins and sugars. The higher polyphenol contents of the 24-week-old *Mucuna* residues is also not caused by the higher proportion of surface litter at that time, as analysis of the Organic Resource Database (<ftp://iserver.ciat.cgiar.org/webciat/ORD/>) shows that for 5 genera (*Dolichos* spp., *Stylosanthes* spp., *Centrosema* spp., *Calliandra* spp. and *Leucaena* spp.), surface litter contains between 1.0 and 0.5 times the amount of soluble polyphenols of fresh leaves. The most likely reason for this increase is the increased formation of polyphenols as the plants are entering the dry season with likely increases in potential attacks by insects. The relative composition of polyphenols can also change as a function of changes in environmental conditions (Harborne, 1997), which may explain differences in polyphenol contents between the two sites for the same species, although it is not possible to identify specific changes in such conditions.

Lastly, application of rock phosphate only appeared to have had a major influence on the P content of both legumes on the ‘plateau’ field, although their P contents in the presence of rock phosphate (0.20–0.23%) were still far below the P contents of the legumes observed on the ‘slope’ field (0.26–0.40%), which was previously observed to contain sufficient amounts of available P to preempt any responses to

Lignin content (% dry matter)



Polyphenol content (% dry matter)

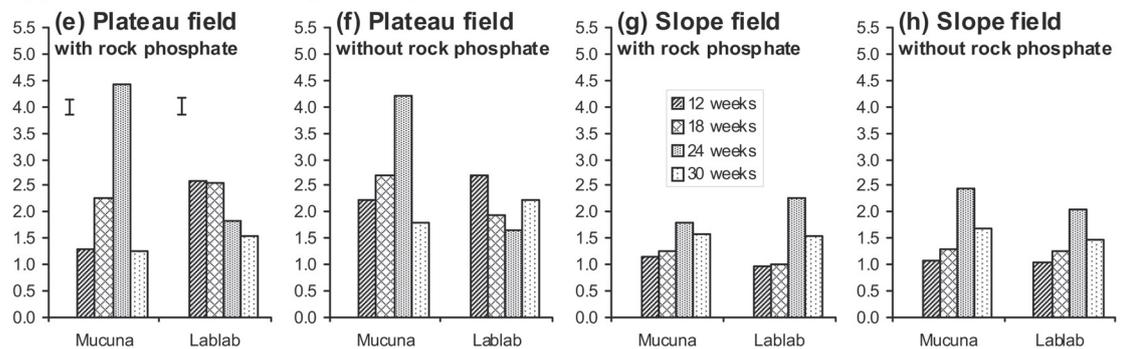


Figure 3. Lignin content of the organic resources produced on the ‘plateau’ (a), (b) and ‘slope’ (c), (d) fields and polyphenol content of these resources produced on the ‘plateau’ (e), (f) and ‘slope’ (g), (h) fields. The left error bars indicate the Standard Errors of the Difference (SED) between sampling times for one treatment, the right error bars indicate the SED between treatments at one sampling time. ‘RP’ means ‘rock phosphate’.

Proportion of N released (%)

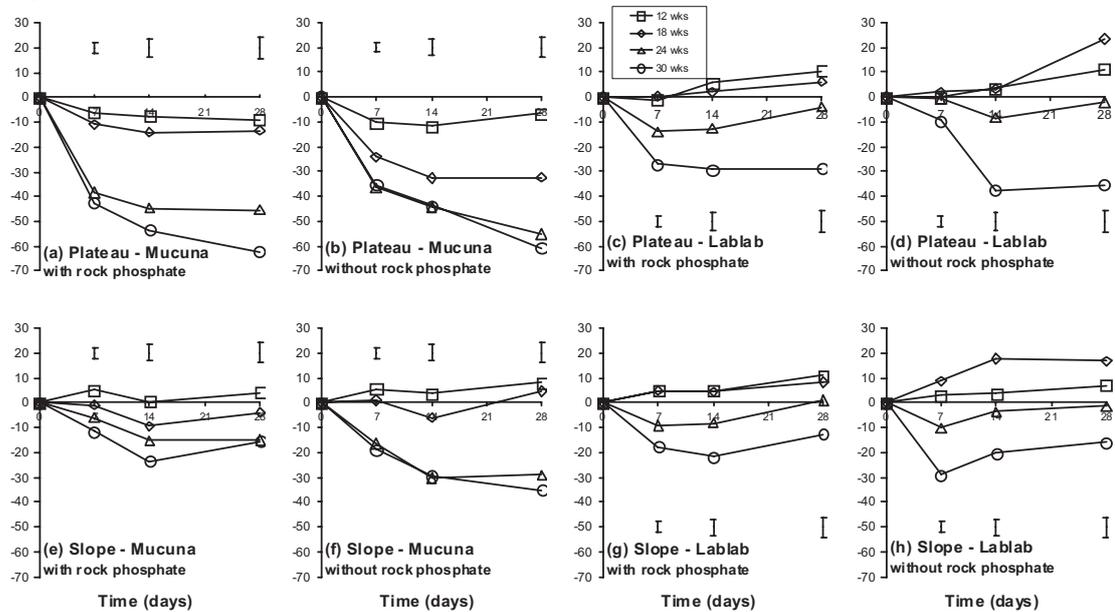


Figure 4. Proportional release of applied organic resource N during the incubation for the *Mucuna* (a), (b) and *Lablab* (c), (d) residues on the ‘plateau’ field and for the *Mucuna* (e), (f) and *Lablab* (g), (h) residues on the ‘slope’ field, as affected by residue age (‘wks’ means weeks after planting) and application of rock phosphate (‘RP’ means rock phosphate). Error bars are Standard Errors of the Difference, calculated for each sampling time.

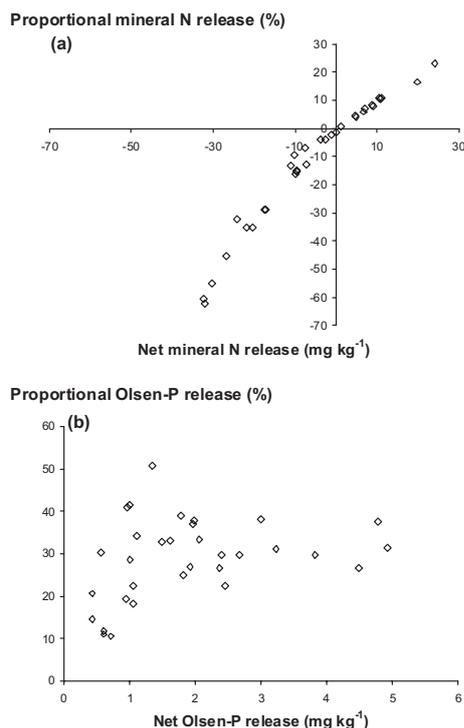


Figure 5. Relationship between proportional and net mineral N release, (a) and between proportional and net Olsen P release (b) for all organic resources used in the incubation study. The proportional release of N or P was calculated using Equations (1) and (2), while the net release of N and P was obtained by subtracting the mineral N or Olsen P content of the unamended control treatment from the treatments that received organic resources. Negative values in (a) indicate N immobilization where the mineral N contents in treated soils are less than those in the control soils.

application of rock phosphate (Vanlauwe et al., 2000a). In the latter site, P appears to have been accumulated at concentrations above those required for optimal legume growth, while at the former site, P appeared to have been the major limiting nutrient for legume biomass accumulation, especially in the absence of rock phosphate additions.

In summary, the presented organic resource quality-related observations clearly show that organic resource age had an impact on its quality, mainly in terms of N, P and polyphenol contents. Application of rock phosphate only altered the P content of the legumes on the site that had a relatively low available soil P content. Since organic resource quality has been shown to be related to its mineralization and decomposition dynamics, these management factors are likely going to affect the nutrient cycling behavior of these organic resources with potentially significant consequences for N and P crop recovery and losses, as discussed in the next section.

3.2. Mineral N dynamics and relationships with organic resource quality

Residue age significantly affected N mineralization dynamics of residues grown both with and without rock phosphate

addition (Fig. 4). Generally, younger residues led to a higher N mineralization than older residues, although the differences between each age class were not always significant. Application of rock phosphate did not affect the N mineralization dynamics of most organic resources derived from both fields. The only residues showing higher N mineralization values for all incubation periods when grown with rock phosphate addition were the 18-week *Mucuna* residues from the 'plateau' field (Fig. 4). Net N release values were highly correlated with proportional residue N release dynamics (Fig. 5a), as the amount of residue N applied varied narrowly between 102 ± 14 mg N kg⁻¹ for organic resources with net N mineralization after 28 days and between 72 ± 18 mg N kg⁻¹ for organic resources with net N immobilization after 28 days. These different N addition rates for organic resources mineralizing and immobilizing N also explain the steeper slope for immobilizing resources in Figure 5a. When considering all residues used ($n = 32$), net N release and proportional N mineralization after 28 days were significantly and linearly related to the following organic resource quality characteristics: N content, P content, lignin content, C-to-N ratio, lignin-to-N ratio, polyphenol-to-N ratio, (lignin + polyphenol)-to-N ratio, C-to-P ratio, lignin-to-P ratio, polyphenol-to-P ratio and (lignin + polyphenol)-to-P ratio (Tab. I, Fig. 6a).

The above data show that the organic resources used in this experiment belonged to classes II and IV as proposed by Palm et al. (2001) in the Decision Support System for organic N management. Class II resources have a N content above 2.5% and either > 4% soluble polyphenols or > 15% lignin and are advised to be applied in combination with N fertilizer or high quality organic resources of Class I. This addition of available N is meant to overcome potential N immobilization. Class IV resources have a N content < 2.5% and a lignin content > 15% and are advised to be applied as surface mulch as their decomposition is likely going to be slow (Palm et al., 2001). Herbaceous legume biomass is often associated with class I or high quality organic resources (> 2.5% N, < 4% soluble polyphenols, < 15% lignin), with fast N release dynamics and substantial residual effects on a following cereal, but in the current study, legume materials were shifting between classes as their age increased, with obvious impacts on their N release characteristics. While all organic resources of 30 weeks old immobilized N during this 28 day incubation, this immobilization period must have been overcome under field conditions as the responses of rock phosphate addition to enhanced legume biomass production was clearly reflected in crop and stover yields of the subsequent maize crop (Vanlauwe et al., 2000b). Nitrogen and lignin were observed to be the organic resource characteristics having the highest impact on N mineralization dynamics, as previously observed and explained by other authors (Melillo et al., 1982; Vanlauwe et al., 1996).

Furthermore, contrary to other reports presenting data on N mineralization dynamics of leguminous materials (Palm and Sanchez, 1991; Oglesby and Fownes, 1992), the apparent limited influence of soluble polyphenols on the N mineralization dynamics in the current work may be explained by the high proportion of surface litter in the organic resources used, with

Table I. R-square values of the simple linear regressions between selected N mineralization and Olsen P dynamics at 28 days and commonly used organic resource characteristics for average values of all residues ($n = 32$).

Organic resource characteristic	R-square			
	Net mineral N release	Proportional mineral N release	Net Olsen-P content release	Proportional Olsen-P release
C content (% DM [†])	0.05	0.05	0.27**	0.00
N content (% DM)	0.58***	0.61***‡	0.54***	0.05
P content (% DM)	0.52***	0.49***	0.81***	0.00
Lignin content (% DM)	0.48***	0.52***	0.19*‡	0.03
Polyphenol content (%DM)	0.15*	0.16	0.22**‡	0.00
C/N ratio	0.62***	0.68***	0.57***	0.04
Lignin/N ratio	0.75***	0.84***	0.46***	0.01
Polyphenol/N ratio	0.41***	0.45***	0.37***	0.00
(Lignin+Polyphenol)/N ratio	0.75***	0.84***	0.48***	0.01
C/P ratio	0.58***	0.65***	0.46***	0.02
Lignin/P ratio	0.64***	0.73***	0.40***	0.03
Polyphenol/P ratio	0.46***	0.52***	0.32***	0.02
(Lignin + Polyphenol)/P ratio	0.64***	0.73***	0.40***	0.03

[†] DM = dry matter.

‡ *, **, and *** indicate significance at the 5, 1 and 0.1% levels, respectively.

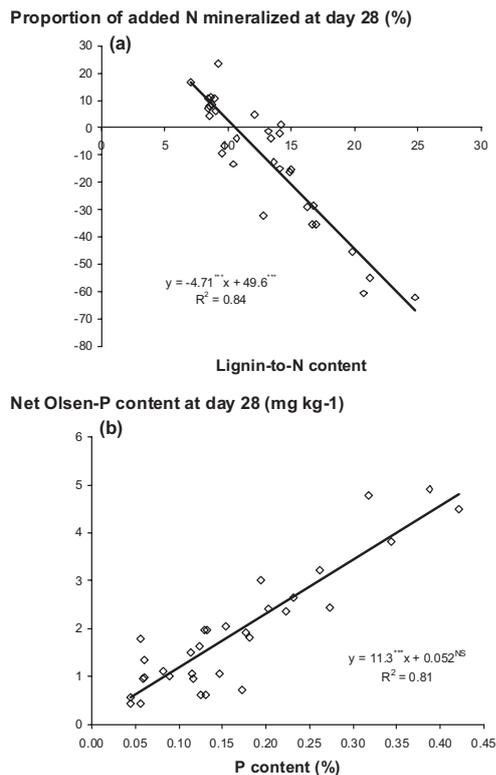


Figure 6. Relationship between the proportion of the added residue N mineralized after 28 days and the lignin-to-N content of the organic resources (a), and between the net amount of Olsen P in the soils treated with organic resources and the P content of these resources (b). All organic resources are included in the regression analysis. Negative values in (a) indicate N immobilization where the mineral N contents in treated soils are less than those in the control soils.

potential decreases in amounts of soluble polyphenols upon drying of the plant materials (Mafongoya et al., 1997).

In summary, although the N mineralization dynamics of the organic resources used followed previously reported trends, except for the lack of substantial polyphenol – N interactions, the organic resources were observed to shift between organic resource classes, as defined by Palm et al. (2001), with potential consequences for their N release dynamics and supply to a growing crop.

3.3. Olsen P dynamics and relationships with organic resource quality

When grown in the presence of rock phosphate, younger residues tended to result in higher net changes in Olsen P contents in the receiving soil compared with older residues, although differences between residue ages were not always significant (Fig. 7). When grown in the absence of RP, the age effect of *Mucuna* and *Lablab* from the ‘plateau’ field was not significant in most instances. For the residues produced on the ‘slope’ field, younger residues released consistently more Olsen P than older residues, although, as above, differences were not always significant (Figs. 7e–h). Proportional Olsen P values were not correlated with net Olsen P values and varied between 11% and 51% (Fig. 5b). Of the 32 organic resources used, 25 showed proportional Olsen P release within a narrow range, $32\% \pm 6\%$. The best ($R^2 = 0.81$) relationship between net Olsen P release and organic resource quality was obtained with the P content of the organic resources (Tab. I; Fig. 6b). Proportional amounts of P release as measured by the net increases in Olsen P of the receiving soil were not significantly related to any of the other organic resource quality parameters (Tab. I).

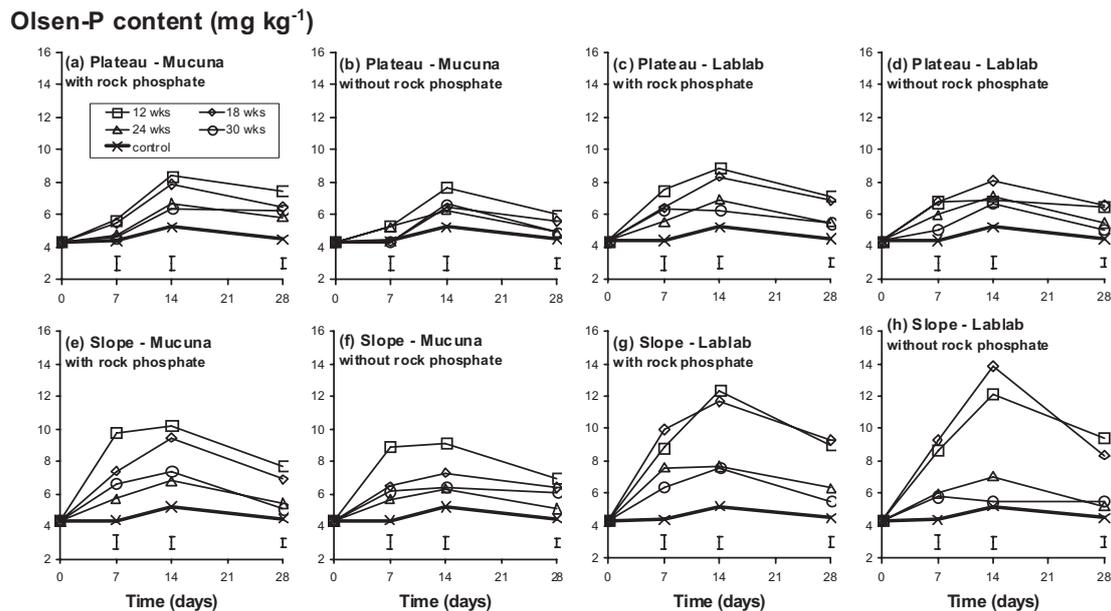


Figure 7. Olsen P content during the incubation for the treatments with *Mucuna* (a), (b) and *Lablab* (c), (d) residues, obtained from the ‘plateau’ field and for the treatments with *Mucuna* (e), (f) and *Lablab* (g), (h) residues, obtained on the ‘slope’ field, as affected by residue age (‘wks’ means weeks after planting) and application of rock phosphate (‘RP’ means rock phosphate). Olsen-P contents of the control soil are also included. Error bars are Standard Errors of the Difference, calculated for each sampling time.

The above data indicated that, contrary to N, the organic resources contained sufficient P to allow microbial degradation to proceed, resulting in net P mineralization, since Olsen P contents in all treatments were higher than or equal to Olsen P contents of the control soil at all incubation times. Palm et al. (1997) stated that organic materials with $< 0.25\%$ P will immobilize P. Pypers et al. (2005) observed increases in available P, as measured by a resin method, upon addition of P-rich residues. All residues used in their study had C-to-P ratios below 200, and increases in available P were well predicted by their P content, large concentrations of soluble P and narrow C-to-P or C-to-soluble-P ratios. Nziguheba et al. (2000) indicated a threshold for the soluble-C-to-P ratio of the residue of 30. Under this threshold, immobilization would become likely. In this study, over half of the organic resources have either a P content below 0.25% or a C-to-P ratio exceeding 200. C-to-P ratios are 181 ± 91 for 12-week-old residues, 239 ± 129 for 18-week-old residues, 461 ± 216 for 24-week-old residues and 541 ± 265 for 30-week-old residues. Increases in Olsen P contents after addition of organic resources with C-to-P ratios of 77, 227 and 704 were also observed by Umrit and Friesen (1994). The lack of P immobilization for organic resources with $< 0.25\%$ P and/or C-to-P ratios exceeding 200 could be explained by the different proportions of inorganic and organically bound P in plant materials with consequent influences on P release dynamics (Umrit and Friesen, 1994). The Olsen extractant could also have extracted part of the microbially-immobilized P.

Furthermore, organic resource quality did not appear to interfere with Olsen P release dynamics, as high correlations were observed between P content and net Olsen P release. This indicates that more P added to the organic resources re-

sulted in more net Olsen P release. The narrow range of proportional Olsen P release values for organic resources with net Olsen P release over 1 mg kg^{-1} and the consequent lack of relationships between proportional Olsen P release and organic resource characteristics further supports this. Calculations of proportional P release for treatments with less than 1 mg kg^{-1} net Olsen P release were likely not very accurate.

In summary, all organic resources used increased the soil Olsen P content, indicating net release of P from all these resources. The net increases in Olsen P were closely related to the P content of the organic resources used, indicating that other organic resource quality characteristics did not interfere with P mineralization dynamics.

4. CONCLUSION

The quality of the herbaceous legume organic resources used and their N and P mineralization dynamics depended on their age or physiological status, whereby best immediate responses to herbaceous legume addition are expected from younger materials. Application of rock phosphate only enhanced the P content of the legume residues on the site with low available soil P. Since the time of application or incorporation of the legume residues is likely going to affect the supply of N and P, for agro-ecosystem sustainability, it will be essential to match this supply with crop demand for these nutrients. Manipulating legume age, however, is often severely restricted as the legume inputs are required at the time of planting of the cereal crop. The range of options available to manipulate legume biomass and quality is likely less as the length of the dry season increases and as the rainy season changes from

bimodal to unimodal. In areas with a single cropping season per year, for example, legume residues necessarily mature and remain on the soil surface during the dry season, with often marginal amounts of organic matter remaining at planting.

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