# Phosphorus Fractions under Planted *Pueraria phaseoloides* Crop-fallow System: A Comparison with Natural Regrowth

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## Abstract

The potential of planted leguminous cover crop fallow in comparison to the natural regrowth fallow for sustaining P availability of low activity clay (LAC) soils in the tropics as the fallow period shortens was assessed at the International Institute of Tropical Agriculture, Ibadan, in the forest–savanna transition zone of southwestern Nigeria. Phosphorus availability and crop yields under the cover crop–fallow and a traditional system (natural fallow–NF) were compared in 1998 and 1999 in a long-term fallow management trial initiated in 1989. *Pueraria phaseoloides* was sown with a maize–cassava intercrop at the same season. In a 2-year cycle, 1 year of cropping was followed by 1-year fallow with *Pueraria* for the cover crop–fallow system or with natural regrowth (mainly *Chromolaena odorata*) for the natural fallow system. Maize–cassava intercropping without a fallow period (continuous cropping) was included as a control. No fertilizer was applied throughout the experimental period. *Pueraria* produced 3.9 t ha$^{-1}$ dry matter (DM) in 1998 and 8.3 t ha$^{-1}$ DM in 1999 after the fallow period. DM production from NF was 5.7 t ha$^{-1}$ in 1998 and 7.8 t ha$^{-1}$ in 1999. Phosphorus accumulation in *Pueraria* biomass was 4.3 kg ha$^{-1}$ in 1998 and 6.1 kg ha$^{-1}$ in 1999. Phosphorus accumulation in NF biomass was similar to that of *Pueraria* in 1998 but was significantly higher (8.9 kg ha$^{-1}$) than in *Pueraria* in 1999. In 1998, NF had significantly higher Olsen extractable P than *Pueraria* fallow. Biologically plant available P fractions (resin P, $NaHCO_3$ inorganic P ($P_i$), and easily mineralizable P fraction $NaHCO_3$ organic P ($P_o$) were higher under NF than under *Pueraria* fallow and continuous cropping. Although P availability was higher under NF than under *Pueraria* but crop yields under crop–fallow with *Pueraria* were comparable with those under NF. Continuous cropping without the use of chemical fertilizer produced over 200% less maize grain and about 40% lower cassava tuber yields compared with the crop–fallow systems.

## Introduction

Throughout the tropics, the shifting cultivation method has been widely used by small-scale farmers as a means of maintaining soil fertility. The method involves manual clearing, burning, and cropping a relatively small area of land for one or two years followed by a long period of natural fallow (10–30 years). The land is usually allowed to return to forest vegetation through a series of plant species successions to restore soil fertility (Nye and Greenland, 1960; Sanchez, 1976; Mokwunye and Hammond, 1992). During the fallow period, plant nutrients are taken up from various soil depths by the fallow vegetation. The nutrients depleted during the short cropping are replenished with those from fallow vegetation. Increasing population pressure, however, has led to shorter fallow periods (1–3 years) for the natural regrowth of native vegetation and forced land into more intensive cultivation. The combination of increased intensity of cropping and insufficient inputs of fertilizers to replace the nutrients removed with harvested products has led to mining of soil nutrients and loss of soil productivity (Smaling *et al.*, 1997).

Many small-scale farmers in many West African countries have found it increasingly difficult to acquire mineral fertilizers because of their unavailability and high cost. Additionally, continuous use of mineral fertilizers without addition of organic materials can result in soil degradation, invasion of noxious weeds, soil acidification, and subsequent decline in crop yield.

Natural bush regrowth is considered the most efficient type of fallow for nutrient recycling and biomass accumulation because it consists of many plant species with different types of root systems (Jaiyebo and Moore, 1964; Ewel, 1986). However, natural regrowth during the first year is slow (Uhl and Jordan, 1984), especially if cropping was continuous for many years. Short duration natural regrowth is not effective in restoring soil fertility and suppressing weeds (Ruthenberg, 1971; Agboola, 1980). It is hypothesized that planted fallow, especially if N-fixing legumes with high biomass production are used, may allow the soil to return more quickly to cropping. In an effort to minimize the soil degradation associated with intensified agriculture under shortened fallow periods, the use of cover crops such as *Pueraria phaseoloides* and *Mucuna pruriens* has been encouraged. Tian *et al.* (1999) have reported that cover crop–fallow with *Pueraria* could be a better alternative to traditional NF under shortened fallow periods for raising or maintaining productivity of low activity clay soils of the humid tropics.

Phosphorus is an important nutrient in relatively short supply in most natural ecosystems, and the primary limiting nutrient for crop production in highly weathered tropical soils (Linquist *et al.*, 1997). Past research work (Sanginga *et al.*, 1996; Tian *et al.*, 2000) on cover crops has focused largely on their N contribution to the soil. Research activities aiming specifically at determining the effects of leguminous cover crops on soil P availability are rare. Plant species can be manipulated in improving P use efficiency in low P soil (Rao *et al.*, 1999). There is evidence to support the hypothesis that *Pueraria* can improve P availability in soil (De Swart and van Diest, 1987). The aim of this study was to compare P fractionation and availability and crop performance under NF with planted *Pueraria* fallow.

## Materials and methods

### *The study site*

Long-term fallow management experiments were conducted at the International Institute of Tropical Agriculture (IITA) research farm at Ibadan, southwest Nigeria (7°30 N, 3°54 E, 213 m above sea level), which is located in the forest–savanna transition zone. Rainfall distribution is bimodal: the main rainy season is from April to August, and there is a minor rainy season from August to October, followed by a long dry season from November to March. The annual rainfall amounts when the data for this report were collected were 794.3 mm (1998), 1647.9 mm (1999), and 1306.2 mm (2000), with a 40-year average of 1290 mm.

Prior to the initiation of the long-term trial in 1989, the study site was under forest for

23 years. During the first quarter of that year, the forest was cleared manually and the small number of trees of economic value [e.g., oil palm trees (*Elaeis guineensis*) and the timber trees (Iroko) *Milicia excelsa* (Ex-*Chlorophora exelsa*)], found scattered at the site, were retained. Plant biomass was burned after land clearing. The unburned wood was removed from the plots.

Soils of the experimental site were Alfisols (USDA Taxonomy). Slopes constituted 5% of the site. Upper slopes (replicate 1) and middle slopes (replicates 2 and 3) were located on Egbedà and Ibadan soil series (Oxic Paleustalf (USDA Taxonomy), and the lower slope (replicate 4) was located on a Gambari soil series (Typic Plinthustalf (USDA Taxonomy). Mean surface soil (0–15cm depth) properties at the start of the study in 1990 were as follows. The soil had a pH (1:1 $H_2O$) of 6.5, 12.4 g kg$^{-1}$ organic carbon, and 7.4 mg kg$^{-1}$ (Bray No. 1) P. The concentrations of extractable cations were 4.31 Ca, 0.92 Mg, and 0.36 K in cmol (+) kg$^{-1}$. The particle size distribution (0–10 cm) was 772 sand, 110 silt, and 118 clay in g kg$^{-1}$ (Tian *et al.,* 1999).

### *Treatments and experimental design*

The experimental design was a randomized complete block with four replicates. *Pueraria phaseoloides* fallow was compared with traditional natural regrowth (NF) and continuous cropping with a single plot size of 12 m x 20 m. The three treatments were:

1. Maize–cassava–*Pueraria* intercrop followed by the second year *Pueraria* fallow (cover crop–fallow)
2. Maize–cassava–intercrop followed by the second year natural regrowth fallow (NF)
3. Maize–cassava intercrop every year (continuous cropping).

At the beginning of the crop–fallow cycle, *Pueraria* in the cover crop–fallow, and dominantly *Chromolaena odorata* in the traditional natural regrowth fallow (NF) were cleared with machetes and burnt to simulate farmers' practice in the locality. No fertilizers or herbicides were applied throughout the experimental period.

Maize seed (cv. TZPB-SR-W in 1998 and DMR-LSR-W in 1999) were sown at a population of 40,000 plants ha$^{-1}$ in rows spaced 100 cm apart and within-row spacing of 25 cm at the onset of the rainy season every year. Cassava cuttings, (cv. TMS 30572 in 1998 and TMS 92/03266 in 1999) each about 25 cm long, were planted at the same time with maize at a density of 10,000 plants ha$^{-1}$. Cassava was planted in rows that were 100 cm apart and had a within-row spacing of 100 cm. *Pueraria phaseoloides* was seeded at a rate of 5 kg ha$^{-1}$ every year. *Pueraria* seeds were drilled between intercropped maize–cassava rows during the same season as maize–cassava. The cultivated plots were weeded at 3 and 8 weeks after planting (WAP). *Pueraria* vines climbing on cassava plants were removed manually from the cassava. Maize was harvested at 16 WAP, and cassava was harvested the following year, at about 52 WAP. This land-use practice was repeated in each of the subsequent years when new fallow plots were brought into cultivation.

### *Observations*

The biomass production of *Pueraria* and *Chromolaena* after the fallow was measured before planting. Aboveground biomass was collected within two 1 x 1 m quadrats in each plot. Composite surface soil samples (0–5cm) were collected at planting in each plot. Each composite sample consisted of 20 sampling points taken randomly in a plot. The soil from each plot was bulked and a subsample was taken. Subsamples were air-dried and ground to pass through a 2- or 0.5 mm sieve for analysis.

Maize biomass was estimated at physiological maturity. Maize grain yields at harvest were expressed at 12% moisture content. Cassava biomass was estimated at harvest and tuber

TABLE 1
Dry matter production and P accumulation of fallow vegetation

| Fallow systems | 1998 | | 1999 | |
|---|---|---|---|---|
| | Dry matter ($kg\ ha^{-1}$) | P uptake ($kg\ ha^{-1}$) | Dry matter ($kg\ ha^{-1}$) | P uptake ($kg\ ha^{-1}$) |
| Continuous cropping | 2222 | 1.40 | 2249 | 1.50 |
| Natural fallow | 3860 | 4.23 | 8283 | 8.90 |
| *Pueraria* fallow | 5740 | 4.32 | 7845 | 6.14 |
| $LSD_{(0.05)}$ | 2355 | 1.02 | 3928 | 2.41 |

yield expressed as fresh tuber yield. Plant biomass was oven dried at 65°C for 72 hours to estimate dry weight.

### Soil and plant analysis

Soil pH was determined in water (1:1 soil/water ratio). Soil organic carbon was determined by the wet combustion method (Nelson and Sommers, 1975). Plant samples were wet digested with a mixture of $HClO_4$ - $HNO_3$. Phosphorus was measured colorimetrically by molybdate blue method in an auto-analyzer (IITA, 1982).

### Phosphorus fractionation

A modified version of the Hedley *et al.* (1982) procedure as described by Tiessen and Moir (1993) was used to sequentially fractionate soil P. In the sequential extraction, five inorganic ($P_i$) and three organic P ($P_o$) fractions were removed by anion exchange resin (BDH No. 55164), 0.5 M $NaHCO_3$, 0.1 M NaOH, 1M HCl and concentrated HCl in that order. The 0.5 M $NaHCO_3$ extracted labile P forms and NaOH extracted moderately labile P forms (Stewart and McKercher, 1982), while 1M HCl extracted Ca-bound P. Phosphorus not recovered in these successive extractions was the residual fraction determined by digesting the soil residue in $H_2SO_4$-$H_2O_2$. Further details of the method are described in Kolawole *et al.* (2004). Analysis of variance of data collected was performed using a Statistical Analysis Systems programme (SAS, 1985).

## Results

### Fallow biomass and P uptake

As expected, vegetation biomass under continuous cropping was lower than under the crop–fallow systems (Table 1). Biomass production under NF and *Pueraria* were comparable for both years. However, biomass production was higher in 1999 than in 1998. Phosphorus uptake was higher in NF residues than in *Pueraria* in 1999.

### Selected soil chemical properties and P fractions

In 1998, soil pH, soil organic carbon contents and Olsen extractable P were significantly lower under continuous cropping than under the crop–fallow systems (Table 2). NF had significantly higher Olsen extractable P than *Pueraria* fallow.

Biologically plant available P fractions (resin P, $NaHCO_3$ inorganic P ($P_i$), and the easily mineralizable P fraction $NaHCO_3$ organic P ($P_o$) were higher under NF than under *Pueraria* fallow and continuous cropping (Table 2). Total $P_o$ was higher with the fallow systems than with continuous cropping.

In 1999, NaOH-$P_i$ and residual P were higher under NF than under *Pueraria* fallow. NaOH-$P_o$ and total $P_o$ were higher under *Pueraria* than under continuous cropping and NF. $NaHCO_3$-$P_o$ was higher under continuous cropping than under NF. For both years, however, total extractable P was not

TABLE 2
Selected chemical properties and P fractions of surface (0–5 cm) soil of an Alfisol under continuous cropping and fallow/cropping systems.

| | 1998 | | | 1999 | | |
|---|---|---|---|---|---|---|
| | Continuous cropping | Natural fallow | *Pueraria* fallow | Continuous cropping | Natural fallow | *Pueraria* fallow |
| pH (1:1 $H_2O$) | 6.2b | 7.0a | 6.8a | nd | nd | nd |
| Org. C (g $kg^{-1}$) | 9.9b | 15.2a | 12.2ab | nd | nd | nd |
| Olsen P (mg $kg^{-1}$) | 2.5b | 8.0a | 4.6b | nd | nd | nd |
| P fractions (mg $kg^{-1}$) | | | | | | |
| Readily available | | | | | | |
| Resin-$P_i$ | 0.4b | 4.8a | 0.8b | 0.4 | 0.4 | 0.4 |
| Labile | | | | | | |
| $NaHCO_3$-$P_i$ | 2.8a | 2.4ab | 1.4b | 4.8 | 5.6 | 4.0 |
| $NaHCO_3$-$P_o$ | 3.6b | 8.8a | 6.6ab | 12.6a | 8.5b | 10.0ab |
| Moderately labile | | | | | | |
| NaOH-$P_i$ | 13.1a | 5.9b | 4.6b | 8.2ab | 10.3a | 7.4b |
| NaOH-$P_o$ | 16.0 | 19.6 | 18.9 | 13.6b | 15.6b | 24.7a |
| Long-term availability | | | | | | |
| Residual P | 25.4 | 29.4 | 22.4 | 28.6a | 31.9a | 19.4b |
| Total-$P_o$ | 24.6b | 48.8a | 55.1a | 52.4b | 47.1b | 67.2a |
| Total P | 85.5 | 99.4 | 101 | 114 | 114 | 114 |

Means followed by different letter(s) are significantly different from each other ($P$= 0.05) using Duncan's Multiple Range Test. Absence of letters indicate no significant differences.
nd = not determined

significantly different under continuous cropping and the fallow systems.

### *Maize grain, cassava tuber yields and P uptake*

For both years, continuous cropping produced significantly lower yields of maize grain and cassava tubers compared with the fallow systems (except in 1998 when cassava tuber yields was not significantly different under the three treatments); (see Table 3.). Both fallow systems produced comparable maize grain and cassava tuber yields.

## Discussion

Phosphorus availability was observed to be higher under NF than under *Pueraria*. Phosphorus absorption has been observed to be lower in crops after *Pueraria* fallow than after NF except for when residues were used as mulch (Ferreira, 1998). Using P sorption isotherms, Ferreira (1998) predicted that the standard P requirement to meet 0.2 µg P $g^{-1}$ in solution of soil sampled at 6 weeks after maize was planted reduced from 15.7 µg P $g^{-1}$ soil after NF to 13.3 µg P $g^{-1}$ soil after *Pueraria* fallow. However, in the present study, higher fractions of easily mineralizable P were not observed under *Pueraria*. It is possible that the reduction in P requirement by *Pueraria* was mainly due to the supply of P from *Pueraria* residues. Also, decomposing Pueraria residues might have produced organic anions, which block sorption sites thereby making native soil P more available. Tian *et al.* (1999) indicated that *Pueraria* was better in recycling P than natural vegetation dominated by *Chromolaena*.

TABLE 3
Maize grain, cassava fresh tuber yields and P uptakes under continuous cropping and fallow cropping systems at Ibadan

| | 1998 | | 1999 | |
|---|---|---|---|---|
| | Maize grain yield (kg $ha^{-1}$) | P uptake (kg $ha^{-1}$) | Maize grain yield (kg $ha^{-1}$) | P uptake (kg $ha^{-1}$) |
| Continuous cropping | 567 | 1.63 | 258 | 1.0 |
| Natural fallow | 2092 | 7.39 | 745 | 2.71 |
| *Pueraria* fallow | 1898 | 8.21 | 994 | 4.26 |
| LSD (0.05) | 794 | 5.93 | 480 | 2.64 |
| | Cassava tuber yield (t $ha^{-1}$) | P uptake (kg $ha^{-1}$) | Cassava tuber (t $ha^{-1}$) | P uptake (kg $ha^{-1}$) |
| Continuous cropping | 6.4 | 0.41 | 7.8 | nd |
| Natural fallow | 5.4 | 0.35 | 13.3 | nd |
| *Pueraria* fallow | 5.6 | 0.35 | 13.8 | nd |
| $LSD_{(0.05)}$ | ns | ns | 1.9 | |

ns = not significant nd = not determined

Total extractable P was comparable under continuously cropped plots and plots with a crop–fallow cycle but continuously cropped plots had lower plant available P fractions than crop-fallow cycle treatments. However, continuously cropped plots had a large part of P in the refractory (residual P) fraction. The increase in residual P may represent a withdrawal of P from active nutrient cycling as a result of a more frequent cultivation. This is an indication that fallow may enhance the transformation of P from plant unavailable fractions to available forms, supporting higher crop yields under crop-fallow cycle than continuous cropping.

The lower P uptake in maize grain, lower soil nutrient contents, and soil pH obtained in the continuously cropped plots compared with crop–fallow plots buttressed the fact that cropping intensification caused deterioration of these nutrients in the soil.

The observation that DM accumulation was comparable between NF and *Pueraria* was consistent with the result of Tian *et al.* (1999). The amount of vegetation biomass produced was higher in 1999 than in 1998 because the rainfall in 1999 was heavier than in 1998. Although plant available P fractions were higher under natural fallow system compared with planted *Pueraria* system, but crop yields under both crop-fallow systems were similar, indicating that other factors beside P availability affects post-fallow yield responses of crops.

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