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Long Term Effect of Tillage and Organo-Mineral Fertilizer Application on Phosphorus Dynamics on Ferric Lixisol in Burkina Faso

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Abstract

A Pot experiment was conducted on 30 years long term soils under different soils management to evaluate the effect of organic amendments and soil tillage on phosphorus evolution in Ferric Lixisol. Two (2) levels of incubation with and without *sorghum bicolor* were used with six (6) treatments: (1) Tillage with animal traction + 10 t manure / ha / year + 100 kg NPK (14-23-14-6S-1B) / ha + 50 kg urea (46 % N); (2) Tillage with animal traction + 100 kg NPK (14-23-14-6S-1B) / ha + 50 kg urea (46 % N); (3) Minimum tillage+ 10 t manure / ha / year + 100 kg NPK (14-23-14-6S-1B)/ ha + 50 kg urea (46% N); (4) Minimum tillage + 100 kg NPK (14-23-14-6S-1B) / ha + 50 kg urea (46 % N); (5) 30-years-old fallow and (6) control plot (continuous sorghum without fertilizer) from soil fertility sustainability trial. Each treatment was pretreated with carbon plus nitrogen or without nitrogen before the experiment. The results showed that tillage increased P availability by 70 to 273 % compared to fallow in general and the use of organic matter improved only P-$NaHCO_3$ by 83 %. The effect of nutrient (carbon and nitrogen) addition varied according to different fraction of P. P-$NaHCO_3$ with sorghum incubation seems to be more responsive to nutrient addition. Therefore, minimum tillage with organic and mineral fertilizers amendments has beneficial effect on available P fractions.

Keywords: long term cultivation, tillage, phosphorus availability, carbon and nitrogen

1. Introduction

Improper agricultural practices contribute to natural resources and soil degradation (Nasir Ahmad *et al*., 2020; Ayub *et al*., 2020). The degradation of natural resources, particularly of soils, remains a major problem for agro-sylvo-pastoral sustainability in the Sudano-Sahelian zones (Lal, 1997). Improper management practices negatively affect soil health (depletion of organic matter and other nutrients) as well as decline in crop productivity (Ramos *et al.,* 2011). This decline in soil fertility results also, in depletion of soils phosphorus. There are three major pathways of P loss from soil: erosion, leaching both non-intended and sometimes mutually interlinked, and the uptake by plants and removal with harvests. Phosphorus (P) is the second most important macronutrient as an essential plant nutrient. It is a key nutrient for sustainable agricultural productivity and which limits plant growth in many soils (Scervino *et al*., 2011). In fact, when soil phosphorus is removed by plants, bioavailable phosphorus becomes limiting. Therefore, a sustainable agricultural system requires replenishment of this nutrient to increase the levels of bioavailable phosphorus (Compaoré, 1996). Major global problems related to soil phosphorus in Burkina Faso (P) are the limited plant productivity caused by its low availability and high fixation in soils (Sédogo, 1995). Phosphorus deficiency in tropical Lixisol can be caused by the nature of the geological substratum, the evolution during the formation of soil, and also by the low organic matter content and the rapid soils depletion after cultivation (Sédogo *et al*., 1991; Eduah, 2019). Inorganic fertilizer is widely used in agriculture to increase soil nutrient and soil productivity. Soil tillage is among the important factors affecting soil properties and crop yield. Among the crop production factors, tillage contributes up to 20 % (Derpsch *et al*., 2010). Organic matter has a favourable effect on P dynamics of the soil; in addition to P release by mineralization, the competition of organic ligands for Fe and Al oxides surface can result in a decrease in P fixation of applied and native P. Organic carbon plays a central role in the inherent soil fertility through mineralization of soil organic matter which occurs in tropical areas as Burkina Faso with about 2 % of the carbon stock per year (Pieri, 1989).

Phosphorus mobility in soils has been commonly studied by quantifying P in different extracts to assess its lability. For soils, H_2O or resin extractable P are thought to be composed of dissolved inorganic P, whereas $NaHCO_3$ and NaOH extractable fractions may be a mixture of amorphous and crystalline Al and Fe phosphates and some physically and chemically protected organic P (Toor *et al*, 2006). Compared to nitrogen, tillage system and its relationship with phosphorus availability have received less attention. Long-term experiments are useful to assess the evolution in soil quality induced by the adoption of cropping systems, soil management practices, fertilizer application, or organic matter management. This paper aims at studying the effect of organic amendments and soil tillage on phosphorus evolution on a Ferric Lixisol.

2. Materials and Methods

Site and Trial Description

The support of this study is a long-term trial "Soil Physical Study Trial" installed since 1990 at the Institute of Environment and Agricultural Research Station of Saria (12˚16'N, 2˚9'W) in Burkina Faso. The trial site is located in a north-Sudanian climate (Fontès and Guinko, 1995) with an average daily temperature varying from 30 ℃ during the rainy season to 45 ℃ in April and May. The rainfall is confined to the period from May to October with an annual mean of 800 mm. The main species of natural vegetation are *Parkia biglobosa, Vitellaria paradoxa*, *Tamarindus indica*, *Andropogon gayanus* and *Pennisetum pedicellatum*. The soil is Ferric Lixisol (FAO, 2006). Soil in the study area is mainly poor with low organic carbon (SOC), N and available P contents (Table 1).

Table 1. Soil physical and chemical properties

Physico-chemical characteristics	CONTENT
Texture (%):	
Coarse sand	22
Fine sand	31
Coarse silt	28
Fine silt	8
Clay	11
Total Carbon (mg kg^{-1})	0.39
Total Nitrogen (g kg^{-1})	0.03
Cation (c mol kg^{-1})	
Ca^{++}	1.99
Mg^{++}	0.67
Na^{++}	0.00
K^{+}	0.09
Sum of bases (S)	2.75
Cation exchange capacity	4.96
Saturation (S/T x 100)	57.00
pH Water	6.4
Total Phosphorus (mg Kg^{-1})	67.28

The Experiment design used in the long-term trial is a Fisher block. It consists of three blocks (or repetitions) each incorporating two parameters, namely tillage and organic amendment. Each block is divided into four elementary plots where two types of soil tillage are combined with two levels of organic amendments. The treatments are defined as follow:

T1-MO: Tillage with animal traction + 10 t cow dung manure / ha / year + 100 kg NPK (14-23-14-6S-1B)/ ha + 50 kg urea (46% N);

T1: Tillage with animal traction + 100 kg NPK (14-23-14-6S-1B)/ ha + 50 kg urea (46% N);

T3-MO: Minimum tillage+ 10 t cow dung manure / ha / year + 100 kg NPK (14-23-14-6S-1B)/ ha + 50 kg urea (46% N);

T3: Minimum tillage + 100 kg NPK (14-23-14-6S-1B)/ ha + 50 kg urea (46% N).

Two other treatments were added to the experiment as reference such as:

F: 30-years-old fallow that was served as base and

C: Control plot (continuous sorghum without fertilizer) of soil fertility sustainability trial.

This experiment was conducted in pot experiment using soil from the long-term trial with the six treatments cited earlier (T1, T1-MO, T3, T3-MO, C and F). It was conducted in 4 repetitions in pots containing 100 g of soil each and before plant sowing three types of pretreatments was applied to each treatment. The pretreatments were carbon (5 g supply in form of glucose); carbon and nitrogen (0.1 g in form of ammonium sulfate) and no nutrient supply. Two levels of incubation with sorghum and without sorghum were used with the different treatments. Sorghum variety Sariasso 14 was used for the experiment. The duration of the incubation was 4-6 weeks depending on the vegetative stage of plant. Fractionation of phosphorus was done on soil samples before incubation, and one, two and six weeks after incubation from pots without sorghum crop and on the plant material. Plant was irrigated with distilled water to avoid any nutrient supply.

Soil chemical analysis: soil pH (ratio of 1: 2.5) was measured according to Afnor standards, 1981). Soil organic carbon content (mg C kg^{-1} Soil) was assessed using the Walkley and Black, 1934 method. Soil organic matter and carbon contents were determined by the equation:

$$C\ (\mathrm{mg\,kg^{-1}}) = \frac{10 - V \times T}{PE} \times 3{,}9$$

Where, T = 10 / V '(10 = volume of $K_2Cr_2O_7$ for white and V' = volume of Mohr salt used for determination of white).

T = Mohr salt for titration

V = Mohr salt volume for the determination of the sample (ml)

PE = soil test sample (g) and

$$\mathrm{MO}\ (\%) = \mathrm{C}(\mathrm{mg\,kg^{-1}}) \times 0{,}1724$$

To determine the total nitrogen (N) and potassium (K) contents, soil samples were first hot-mineralized with an H_2SO_4-Se-H_2O_2 mixture. Total nitrogen was determined using an automatic colorimeter (Skalar SANplus Segmented Flow Analyzer, Model 4000-02, Holland), while total K was determined by flame photometry. Total P levels were determined by mineralizing soil samples, according to the Kjedhal method, using a concentrated H_2SO_4 acid solution in the presence of selenium catalyst and H_2O_2. The total phosphorus contents are then determined in the mineralizers using a SKALAR automatic colorimeter (Segmented flow analyzer, model SANplus 4000-02, Skalar Holland).

Fractionation of phosphorus

Hedley *et al*. (1982) method was used for phosphorus fractionation. The Hedley fractionation recognizes plant-available forms (Resin Pi, Bicarbonate Pi, and Bicarbinate Po) and refractory forms (NaOH Pi, NaOH Po, sonic Pi, sonic Po, HCl Pi, and Residual P) of soil phosphorus. The soil samples were weighed to 4 g and are agitated for 16 hours in 20 ml of distilled water with 2 anionic membranes saturated with bicarbonate. The membranes have an area of 2 cm^2 (1 cm × 2 cm). To release the P set by the membranes, they were removed and agitated in 20 ml of 0.5 M HCl for 30 minutes. The obtained solution was sequentially agitated for 16 h in 20 ml of buffered 0.5 M $NaHCO_3$ and 0.5 M NaOH at pH 8.5. After centrifugation and filtration, inorganic P (P- $NaHCO_3$ and P-NaOH) were determined by acid digestion by autoclaving in 10 ml of H_2SO_4 and 0.5 g of $K_2S_2O_8$. The same procedure was used for the determination of P-HCl after sharing the solution in 1.0 M HCl. P-resin was extracted by Acid mineralization in 10 ml of H_2SO_4 and 0.5 g of $K_2S_2O_8$.

Statistical analysis

The results were subjected to analysis of variance using Genstat 9th edition. Significant treatment means of each soil were identified by using the least significant differences (LSD) value at 5 % level of probability for P source, time and incubation.

3. Results

Soil tillage with soil amendment significantly ($p<0001$) increased P availability compared to fallow and the control (Table 2). Higher amount of P was observed with T1 (tillage with animal traction + 100 kg NPK (14-23-14-6S-1B) / ha + 50 kg urea (46% N)) for all P sources except from P-$NaHCO_3$ (with sorghum) .The values are ranged from 20.26 mg Kg^{-1} to 35.24 mg Kg^{-1} with the incubation of sorghum and from 12.77 mg kg^{-1} to 32.4 mg $kg^{-1}$with no incubation of sorghum. The highest P amount was observed with P-NaOH fraction (35.24 mg Kg^{-1}). Phosphorus extracted with NaOH was greater in all cropping systems compared to P-HCl, P-resin and P-$NaHCO_3$ in general. It was also observed that soil incubation has a positive effect on P availability. The results showed that soil planted with sorghum has increased P availability compared to non-incubated soil. The used of organic matter significantly increasing only P-$NaHCO_3$ content by 83 % on tillage with animal traction treatment. Addition of mineral fertilizer significantly improved P different fraction in general.

P-HCl was increased by 57 to 138 % and P-NaOH increased more than 20 % when mineral fertilizer application is combined with soil tillage.

Table 2. Effect of soil tillage and amendments on phosphorus availability (mg Kg^{-1})

	Treatment	Fallow	control	T1-MO	T1	T3-MO	T3	Lsd	P<F
Sorghum	HCl	5,86c	5,25c	8,99c	21,39a	9,88cd	15,56b	3,83	P<001
	Resin	11,94b	12,54b	19,17a	20,26a	12,38b	15,19b	3,51	P<001
	NAHCO3	16,73b	17,45b	24,17a	13,23b	17,62b	15,57b	4,56	P<001
	NaOH	25,64b	27,20b	29,19b	35,24a	24,95b	30,44a	5,44	P<001
No	HCl	4,99b	3,82b	9,24b	23,04a	9,70b	17,62a	5,62	p<001
sorghum	Resin	4,99c	2,90c	8,42b	12,77a	8,45b	11,21a	2,13	P<001
	NAHCO3	10,73c	6,279d	13,95b	17,79a	10,81c	15,98ab	2,29	p<001
	NaOH	20,81b	19,90b	31,12a	32,02a	23,04b	30,17a	6,00	P<001

Soil phosphorus availability varied significantly (P<0.001) with different soil management (Table 3). Phosphorus content was high with the used of organic matter in all the treatments. Organic matter application increased P-HCl and P-NaHCO$_3$ by 33 % and 16 % over the control and the fallow practice, respectively. The result also showed low P content with the use of mineral fertilizer compared to the other treatments.

Table 3. Phosphorus content in different soil management

Treatment	Control	Fallow	OM	MF	P<F	LSD
P-HCl (mg Kg^{-1})	12,27b	12,27b	16,79a	7,75c	<0001	2,48
P-Resin (mg Kg^{-1})	15,85	15,85	16,82	14,87	NS	
P-NaOH (mg Kg^{-1})	29,25	29,25	32,13	26,36	NS	
P-NaHCO$_3$ (mg Kg^{-1})	17,72ab	17,72ab	20,50a	14,95b	0,01	3,14

Phosphorus availability responses to the type of nutrient application were different among the treatments. The supply of carbon and nitrogen or carbon alone did not significantly affect phosphorus availability for P-HCl, P-NaOH and P-NaHCO$_3$ even though the supply of nutrient increased P availability, generally (Table 4). Only P-resin was significantly (p<0.001) affected by nutrient application. Addition of carbon and nitrogen increased both the control and the fallow practice soils P-resin content by 53 % and 51 %, respectively, compared to the no nutrient application treatment. Addition of nutrient did not increase soil P-resin content with tillage.

Table 4. Effect of soil tillage and nutrient on P availability

Treatments		P-HCl	P-Resin	P-NaOH	P-$NaHCO_3$
		(mg Kg^{-1})			
Control	Carbon	6.60	14.12bc	34.24	20.26
	Carbon_Nirogen	4.96	14.21bc	23.35	17.18
	No_nutrients	4.17	9.29cd	23.99	9.28
Fallow	Carbon	5.83	7.59d	23.18	16.72
	Carbon_Nirogen	6.06	16.98ab	31.52	23.09
	No_nutrients	5.69	11.25bc	22.22	10.39
soil scraping	Carbon	15.64	18.68ab	31.87	21.76
	Carbon_Nirogen	12.94	16.55ab	32.95	21.84
	No_nutrients	16.97	23.90a	31.82	18.83
Soil ploughing	Carbon	15.25	12.10bc	25.74	15.61
	Carbon_Nirogen	10.93	12.73bc	30.33	15.80
	No_nutrients	11.98	16.52ab	27.02	14.87
P<F		NS	0,04	NS	NS
LSD (5%)			7,51		

Nutrient application did not significantly increased phosphorus availability when sorghum is not inoculated. Significant effect ($P<0.001$) was observed only with P-resin and P- $NaHCO_3$ content with sorghum. Phosphorus availability increased until two weeks after carbon and nitrogen or carbon application and decreased until the end of the experiment for both P-resin and P-$NaHCO_3$ content (Figure 1 and 2). The P-resin content did not improve when nutrient is added. The highest amount (26.5 mg Kg^{-1}) and the lowest amount (21.7 mg Kg^{-1}) of P-resin content after two weeks were observed with no nutrient treatment and carbon treatment, respectively. Carbonate P increase with the used of nitrogen and carbon or carbon and the maximum amounts were obtained two weeks after application. The used of carbon alone improved P-$NaHCO_3$ (24.1 mg Kg^{-1}) compared to the combination of nitrogen and carbon (21.1 mg Kg^{-1}) after 2 weeks.

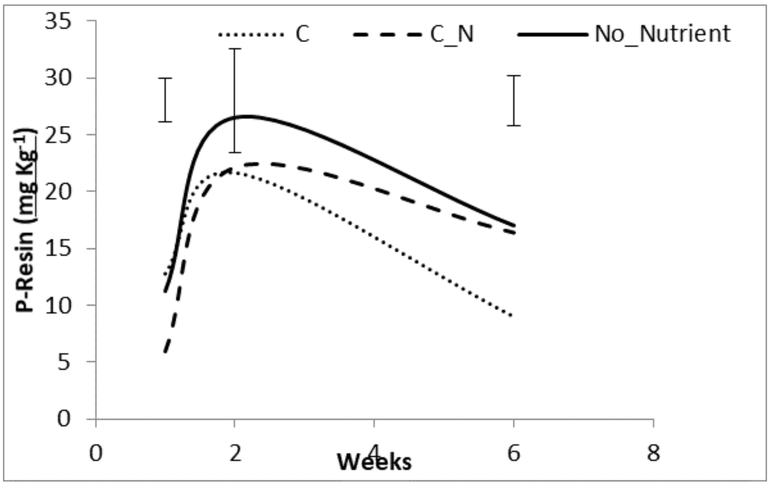

Figure1. Evolution of P-Resin after nitrogen and / or carbon application

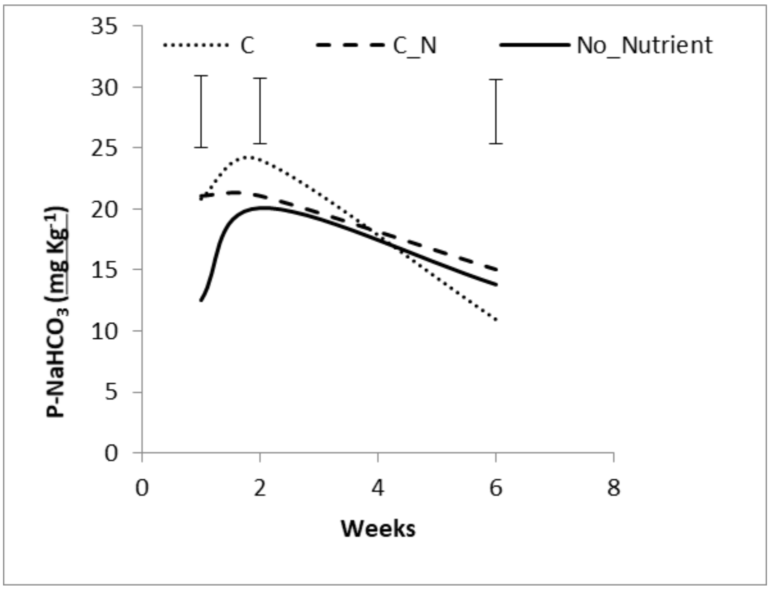

Figure 2. Evolution of P-$NaHCO_3$ after nitrogen and / or carbon application

4. Discussion

Phosphorus availability increased ($P<0.001$) with tillage and application of mineral fertilizer, in general. Soil phoughing with sorghum incubation increased P-NaOH, P-resin and P-HCl, by 37%, 70%, and 273 %, compared to fallow, respectively. Tillage has various physical, chemical and biological effects on soil depending on the appropriateness or otherwise of the methods used. Soil tillage can reduce soil drainage and improve soil structure. This condition can develop better condition for microbial activities for the mineralization of phosphorus. Management practices that improve soil aggregation may therefore have benefits for soil P availability (Andrew *et al*, 2017; Barro, 1997). The use of organic matter together with soil phoughing improved P-$NaHCO_3$ by 83 % unlike the other form of P. Phosphorus derived from NaOH, resin and HCl were greater with the use of mineral fertilizer. This can be explained by the fact that P added from manure tends to become less available to plants in long term (Sample *et al.*, 1980, Lemming *et al*., 2019). Depending of the status of P fertilizer in soil, manure and mineral fertilizer appear to contribute to different P pools (Griffin et al 2003).

The use of organic matter improved P-HCl and P-NaHCO3 by 33 % and 16 % over the control and fallow, respectively. These results are in agreement with those reported by Sharpley and Smith (1995) and Shafqat and Pierzynski (2010) who found that continuous application of organic matter significantly increased P-$NaHCO_3$ and P-HCl. The application of organic matter increases soil P solubility, decreases P fixation, and thus improves P availability to plants as reported by Khiari and Parent (2005) and Soma *et al*., (2018). Soil colloids are also essential for the P adsorption and availability (Dhillon, 2004, Pratap, 2015). Manure application increase soil fertility, especially in the Sudano-Sahelian region where nutrient depleted and weathered soils are typically managed with low input (Ouédraogo *et al*., 2001).

Soil incubation with sorghum positively influenced soil P availability. Lal and Steward (2016) reported that plants and their symbionts directly acidify soil environment by the exudation of organic acids and chelating agents, promoting and make P occluded in secondary minerals available.

Pretreatment of soil with nitrogen and carbon associated with soil management significantly affected P-resin, only. Addition of carbon and nitrogen increased both the control and fallow P-resin by 53 % and 51 %, respectively, compared to no nutrient added.

5. Conclusion

Long term effect of tillage and soil amendments had significant effect on different soil P fraction. Reduced tillage in conjunction with organic and mineral amendment improved soil phosphorus availability by 70 to 273 % compared to fallow and soil under continous cultivation. The increase occurred mainly when soil is incubated with sorghum. Addition of carbon and nitrogen improved soil P availability under soil incubated with sorghum. Reduced tillage with organic and mineral fertilizers amendments can be used to increase P availability under sorghum cropping system.

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