

Full Length Research Paper

Phosphate leachate losses in sandy soil amended with different fertilizers and effects on cowpea yield

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Received 23 October 2021; Accepted 14 December, 2021

Nutrient leaching limits sustainable fertility management of tropical sandy soils. Therefore, phosphate leached from NPK 15:15:15 (NPK), sole compost (SC), phospho-compost (PC), poultry manure (PM), fresh *Gliricidia sepium* leaves (GL) and integrated (INTG) fertilizers applied at 40 kgP₂O₅ ha⁻¹ and an unamended soil (AC) in leaching columns containing 2.5 kg soil were studied. Each soil was simulated for leaching at 2, 4, 6, 8, 10 and 12 weeks after cowpea seed sowing. Fertilizer application significantly reduced total leachate volume (TLV) over AC in the order of AC > SC > NPK > INTG > PC > GL > PM. Total phosphate leached (TPL) was the highest (1505.3 mg l⁻¹) in GL followed by 436.5, 229.7, 69.0, 33.4, 30.5 and 0.0 mg l⁻¹ from NPK, INTG, AC, PM, SC and PC, respectively. The PC, PM and INTG produced significantly higher dry shoot (DSW) and root (DRW) weights, N and P uptake. Cowpea grain weight (CGW) was significantly higher (2.42 g plant⁻¹) in INTG over AC (0.99 g plant⁻¹). Significant negative correlation was between TLV and DSW, CGW, N and P uptake and between TPL and soil available P, N and P uptake. Stabilized organic (PC and SC) and integrated fertilizers (INTG) are therefore suitable for reduced phosphate leaching in sandy soil.

Key words: Chemical fertilizers, Leaching column, NPK 15:15:15, phospho-compost, phosphate leachate losses, soil nutrient leaching.

INTRODUCTION

Nutrient leaching is a major environmental (Mahmud et al., 2021; Anas et al., 2020; Rashmi et al., 2020) and economic (Garske and Ekardt, 2021; Alewell et al., 2020; Einarsson et al., 2020) challenge associated with indiscriminate chemical fertilizer usage in tropical sandy soils characterized by low capacity to hold nutrient and moisture. It is therefore a key bottleneck to achieving sustainable fertility management scheme for tropical sandy soils.

The soils of the study area (Ogbomosho, Southwestern Nigeria) are dominantly sandy with sand fraction not less than 70% (Kolawole et al., 2018; Oyeyiola, 2017). These soils are grossly deficient in total nitrogen, available phosphorus with characteristic low water and nutrient holding capacity resulting from intense organic carbon depletion (Ewetola et al., 2019; Oyeyiola, 2017; Adesina et al., 2015). Chemical fertilizers especially NPK 15:15:15 and urea are used indiscriminately by farmers in the

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study area to boost soil nutrient status every cropping season. Unguided chemical fertilizer usage leads to nutrient losses through volatilization (Jadon et al., 2018; Ding et al., 2017), sorption (Asomaning et al., 2018; Oyeyiola and Omuetti, 2010) and leaching processes (Xia et al., 2020; Islam et al., 2014). Studies on nutrient leachate losses on these sandy soils are not available despite nutrient leaching potential indicated by high torrential rainfall of about 1800 mm received annually in the study area (Ogunbode and Ifabiyi, 2019).

The low use efficiency placed at 30 to 35% for chemical fertilizer applied on sandy soils of the tropics (Li et al., 2019) has opened research areas for innovative ideas that will assure farmers in making optimal gains from every unit of chemical fertilizer applied. Achieving reduced nutrient leachate losses through careful selection of appropriate fertilizers for field application in sandy soils will not only increase economic returns (Kihara et al., 2020; Carstensen et al., 2020) to farmers but also significantly decrease the effects of nutrient leaching on water quality (Szogi et al., 2021; Xia et al., 2020; Bah et al., 2014) and global warming (Jantke et al., 2020; Schneider et al., 2019).

So much have been documented on phosphorus losses from soil solution through fixation by soil colloids (White et al., 2021; Yang et al., 2019; Asomaning et al., 2018; Lumbanraja et al., 2018; Manthambala et al., 2016; Anetor and Omuetti, 2014; Osundare, 2014; Olatunji, 2011; Oyeyiola and Omuetti, 2010) but little is known of phosphorus losses through leaching especially in Nigerian sandy soils managed dominantly by chemical fertilizers. A column leaching experiment was therefore carried out in Ogbomoso, Southwestern Nigeria between February and May, 2019 to quantify the contributions of different fertilizers to phosphate leachate losses in a sandy soil. Effects of these on soil available phosphorus, cowpea grain and biomass yields, N and P uptake were also evaluated.

MATERIALS AND METHODS

Experimental soil description

The sandy soil studied was from the Teaching and Research Farm of Ladoké Akintola University of Technology, Ogbomoso (08°10'N, 04°10'E), Nigeria. This guinea savanna agro-ecological zone is characterized by annual mean temperature of 32°C and rainfall of 1800 mm in bimodal peak patterns from April to June and September to November (Ogunbode and Ifabiyi, 2019). The soil is an Alfisols, classified locally as Gambari soil series (Smyth and Montgomery, 1962; Olatunji, 2011). It is derived from basement complex, greyish in colour and high in base saturation (Smyth and Montgomery, 1962; Oyeyiola, 2017).

Soil sampling, preparation and routine analysis

The farmland was sampled at 0 to 20 cm depth using a soil auger.

and triplicate composites were analyzed for their initial physical and chemical properties following standard procedures described by IITA (1978). Soil pH was determined on a 1:2 (soil: water) ratio after 15 min equilibration period using a glass electrode calibrated in pH buffers 4, 7 and 9. Total Nitrogen was determined by Macro-Kjeldahl method as described by Bremner (1982). The wet oxidation dichromate method was followed for organic carbon determination. Phosphorus was extracted with Mehlich-3 solution and the P in the extract was determined by Molybdate blue colour method of Murphy and Riley (1962) read on the Baush and Lomb Spectronic 20 Electrophotometer. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1 N NH₄OAc (pH 7) at a soil: extracting solution ratio of 1:10 for 15 min. The concentrations of Ca and Mg were read on the Atomic Absorption Spectrophotometer, Buck Scientific model 211 while those of K and Na were read on the Flame Photometer, Buck Scientific model 410. Particle size distribution was by the conventional hydrometer method (Bouyoucos, 1962).

Determination of phosphorus contents in the fertilizers tested

Five fertilizer types were tested and they include the commonly used compound chemical fertilizer with the trade name NPK 15:15:15. The other fertilizers were poultry manure, freshly harvested *Gliricidia sepium* leaves, sole compost, phospho-compost and integrated fertilizer. The sole compost was prepared from aerobic decomposition of sawdust and poultry manure (1:3 dry weight basis). The phospho-compost on the other hand was prepared from bone meal fortification of the sole compost at 1:5 bone meal to compost ratio. The integrated fertilizer was achieved through mixing of all the aforementioned fertilizers at 20% full dosage rate. These fertilizer materials were chosen because of their ready availability at the study area. The P contents in these fertilizer materials were determined prior to use following the Vanado-Molybdate procedure (IITA, 1978).

Experimental set up and design

The leaching column was made from polyvinyl chloride (PVC) tube of 25 cm long and 11 cm inner diameter (Plate 1). Triple fold poly mesh layer was used to cover each column at one end installed over a leachate collecting cup to prevent soil access into the leachate collected in the cup. Air dried, crushed and 2 mm sieved soil measuring 2.5 kg each was packed into each column to a depth of 20 cm representing rooting depth of most arable crops.

The experiment composed of seven treatments with three replications laid in completely randomized design. The treatments included sole application of the five fertilizer types: chemical fertilizer (NPK), poultry manure (PM), freshly harvested *G. sepium* leaves (GL), sole compost (SC) and phospho-compost (PC). The sixth fertilizer treatment was the integration of the five fertilizers (INTG) at 20% of the full application rate of each. Absolute control (AC) soil that received no fertilizer was included for comparison. All the fertilizers were applied at 40 kgP₂O₅ ha⁻¹ representing cowpea P requirement for soils in the study area (Oyeyiola, 2017). The fertilizer treatments and quantities applied per 2.5 kg soil are summarized in Table 2.

Appropriate fertilizer types and quantities were thereafter applied and mixed with each soil at 0-10 cm depth. Deionized water of 555 ml was applied into each soil to field capacity. Thereafter, leaching was simulated through application of additional 120, 140, 460, 680 520 and 420 ml of deionized water during 2, 4, 6, 8, 10 and 12 weeks after a cowpea seed (*Ifebimpe*) sowing per column, respectively. Weeding was done by hand pulling and pests were controlled using 8 ml of Lambda-cyhalothrin (karate) in 2 L of water



Plate 1. Leaching column set up made from polyvinyl chloride.

three weeks after planting and three more times, during flowering and pod formation (8, 9 and 10 weeks after sowing) stages. The cowpea was nurtured to maturity.

Data collection, laboratory analysis and data analysis

Volume and pH of the leachate collected in the basal leachate cups were measured using a measuring cylinder. The leachate were thereafter centrifuged at 2000 rpm for 15 min at every sampling time and stored in labeled glass bottles placed in the refrigerator for storage prior to phosphate content determination. Total leachate volume collected per treatment over the twelve week trial were thereafter homogenized appropriately and 100 ml sampled from each was tested for phosphate content using the Murphy-Rilley procedure (IITA, 1978) and read on the Technicon 11 autoanalyser. Total phosphate leached (TPL) was thereafter estimated as a product of the phosphate content and total leachate volume (TLV).

At harvesting, grains extracted from dried pods per plant were weighed. Uprooted plant per column were separated into shoot and root (rinsed under running water), oven dried at 65°C for 48 h and weighed to achieve dry shoot and root weights. The N and P contents in the shoots were determined following the Micro-Kjeldahl and Vanado-Molybdate procedures (IITA 1978). These were used for the estimation of N and P uptake using:

$$N \text{ uptake} = N \text{ content in the shoot} \times \text{dry shoot weight} \quad (1)$$

$$P \text{ uptake} = P \text{ content in the shoot} \times \text{dry shoot weight} \quad (2)$$

All the data collected were subjected to one-way analysis of variance using Genstat statistical package (8th edition) and significant means were separated using Duncan's multiple range test and standard errors at 5% probability level. Relationship among

the total phosphate leached and selected plant and soil parameters were established by correlation analysis.

RESULTS

Physicochemical characteristics of the soil studied, phosphorus contents and applied quantities of the fertilizers tested

The soil pH was near neutral (6.8) and very low in soil available phosphorus (6.21 mg kg⁻¹). Total nitrogen and organic carbon contents of the soil were low while exchangeable basic cations were moderate (Table 1). The chemical fertilizer was highest in P content while sole compost had least concentrations. Quantities of each fertilizer applied as shown in Table 2 were estimated based on their individual P contents.

Volume of leachate collected from soil treated with different fertilizer types

Application of different fertilizer types significantly influenced volume of water percolating through the soil at 2, 10 and 12 weeks after sowing (WAS). Higher leachate volumes were recorded at 2 and 12 WAS and least at 8 WAS across all the treatments (Table 3). Generally, leachate volume collected from soil treated with PM, GL

Table 1. Chemical and particle size distribution of the sandy soil studied.

Parameter	Value
pH (1:2 soil/water)	6.80
Total N (g kg ⁻¹)	0.15
Organic carbon (g kg ⁻¹)	4.50
Avail. P (mg kg ⁻¹)	6.21
Exchangeable bases (cmol kg⁻¹)	
Calcium	2.17
Magnesium	0.23
Potassium	0.11
Sodium	0.09
Particle size (g kg⁻¹)	
Sand	830
Silt	70
Clay	100

Table 2. Phosphorus contents and equivalent quantities of each fertilizer applied at 40 kg P₂O₅ ha⁻¹.

Fertilizers	P content (g kg ⁻¹)	Quantities applied (g)/2.5 kg soil
Poultry manure	19.4	1.13
Sole compost	15.7	1.39
Phospho-compost	22.4	0.97
Gliricidia sepium leaves	27.0	0.81
NPK 15:15:15	150.0	0.33
Integrated	ND	20% of each of the above

ND is not determined.

and PC were lower compared to other treatments at 2, 10 and 12 WAS with unamended soil producing highest leachate volume. Total leachate volume collected per treatment at the end of the trial was least in PM (369.6 ml) followed by GL (375.4 ml) and PC (385.7 ml) while AC > SC > NPK > INTG in leaching water beyond the plant root in the soil studied.

Total phosphate leached from soil treated with different fertilizer types

The different fertilizers applied at equal phosphate application rate of 40 kg P₂O₅ ha⁻¹ significantly influenced the concentrations of phosphate leached through the column (Figure 1). Fresh green manure (*G. sepium* leaves) and chemical fertilizer based treatments were more influential in leaching phosphate in the soil studied. Total phosphate leached was highest (1505.3 mg l⁻¹) in the GL treated soil followed by NPK (436.5 mg l⁻¹) and

INTG (229.7 mg l⁻¹) while no phosphate was detected from the leachate collected from PC treated soil. Integrating organic materials into chemical fertilizer (INTG) decreased total phosphate leached in the soil studied by 47.4% compared to sole NPK treatment. The phosphate leached from the unamended (AC) soil (69.0 mg l⁻¹) was significantly higher than those from PC (0.0 mg l⁻¹), SC (30.5 mg l⁻¹) and PM (33.4 mg l⁻¹).

Soil available phosphorus, nitrogen and phosphorus uptake of cowpea biomass as influenced by different fertilizer types under leaching condition

Soil available phosphorus varied significantly among the different fertilizer types applied at equal phosphorus rate of 40 kg P₂O₅ ha⁻¹ under leaching condition (Figure 2). The SC (8.68 mg kg⁻¹) and PM (7.36 mg kg⁻¹) produced significantly higher available P concentrations in the soil studied over other treatments. Least P concentration

Table 3. Volume of leachate collected from soil treated with different fertilizer types applied at equal phosphorus rate of 40 kgP₂O₅ ha⁻¹.

Fertilizer types	Volume of leachate (ml/column)						
	Weeks after sowing						
	2	4	6	8	10	12	Total volume
AC	156.7	74.0	56.3	2.0	60.0	167.0	516.0
NPK	178.0	69.0	48.3	1.3	13.3	151.0	460.9
PC	136.7	72.3	56.7	2.0	0.0	118.0	385.7
SC	140.0	98.7	49.0	0.7	36.7	171.0	496.1
PM	127.3	78.0	8.0	0.0	8.3	148.0	369.6
GL	118.3	63.7	41.7	0.0	11.7	140.0	375.4
INTG	130.0	74.0	18.3	0.0	35.0	156.7	414.0
SED	17.2	ns	ns	ns	0.48	12.6	7.12
Volume of water added after attaining field capacity	120	140	460	680	520	420	-

AC is unamended soil, PC is phospho-compost, SC is sole compost, PM is poultry manure, GL is *Gliricidia sepium* leaves, INTG is integrated fertilizer, SED is standard error of means, ns is not significant.

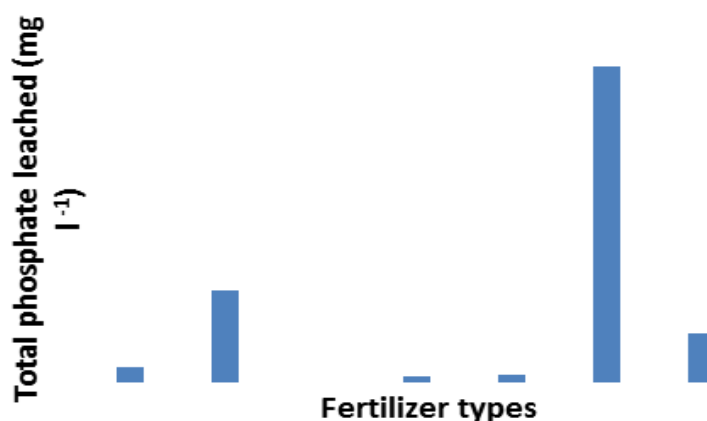


Figure 1. Total phosphate leached from soil treated with different fertilizer types. AC is unamended soil, PC is phospho-compost, SC is sole compost, PM is poultry manure, GL is *Gliricidia sepium* leaves, INTG is integrated fertilizer, and vertical bar is standard error of means.

(3.89 mg kg⁻¹) was recorded from soil treated with GL which was statistically similar to value from AC (4.01 mg kg⁻¹).

The nitrogen and phosphorus uptake by the cowpea biomass was significantly affected by different fertilizer types applied at equal phosphorus rate under leaching condition (Figure 2). All the sole organic treatments except GL were superior to the NPK in improving cowpea biomass N and P uptake. Plants from PC treated soil had highest N (48.3 g kg⁻¹) and P (4.42 g kg⁻¹) uptake while GL gave the least values of 10.3 and 0.95 g kg⁻¹, respectively. Integrating chemical fertilizer with organic materials (INTG) increased N and P uptake by 112 and

72%, respectively relative to sole NPK application.

Dry biomass and grain weights of cowpea as influenced by different fertilizer types under leaching condition

Dry shoot weight (DSW) of cowpea in sandy soil treated with different fertilizer types applied at equal phosphorus rate under leaching condition was significantly affected (Table 4). Of all the fertilizers tested, chemical fertilizer treated soil (NPK) produced the least (0.89 g plant⁻¹) DSW which was statistically similar to the value (0.58 g

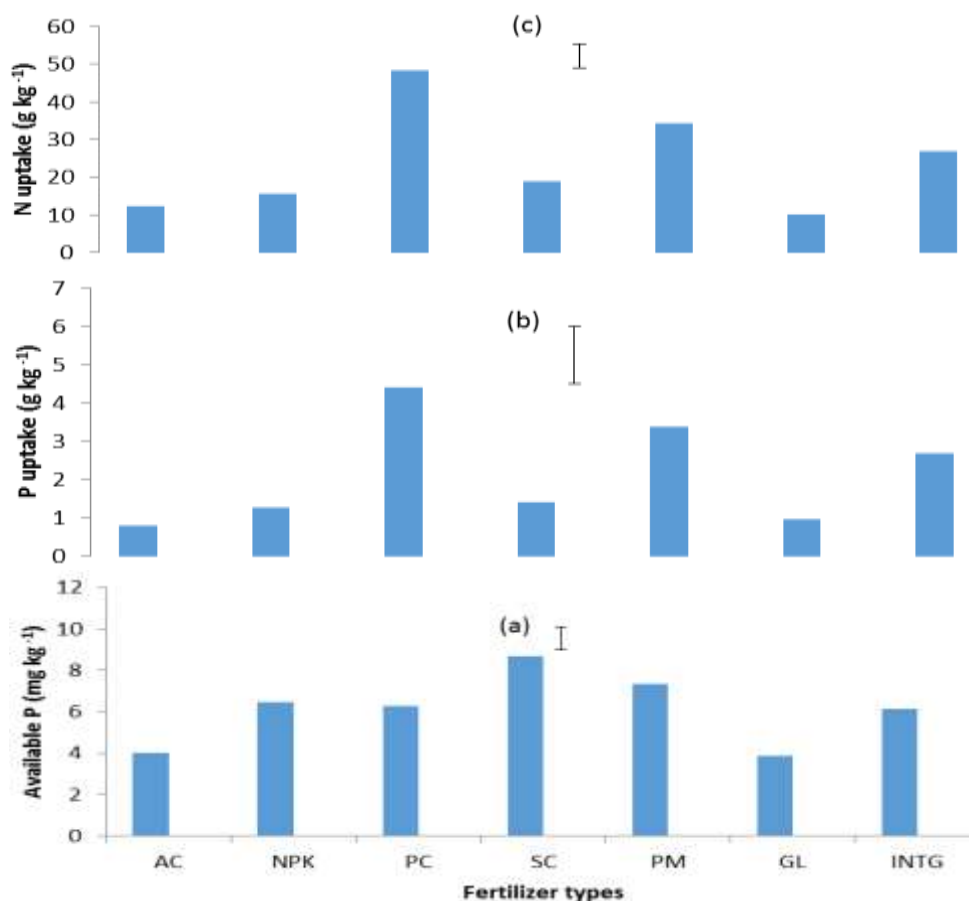


Figure 2. Soil available phosphorus (a), phosphorus (b) and nitrogen(c) uptake by cowpea biomass as influenced by different fertilizer types under leaching condition. AC is unamended soil, PC is phospho-compost, SC is sole compost, PM is poultry manure, GL is *Gliricidia sepium* leaves, INTG is integrated fertilizer, vertical bars are standard error of means.

Table 4. Dry biomass and grain weights (g plant^{-1}) of cowpea as influenced by different fertilizer types under leaching condition.

Fertilizer type	DRW	DSW	Grain weight
	g plant^{-1}		
AC	0.13 ^{a*}	0.58 ^d	0.99 ^b
NPK	0.11 ^a	0.89 ^{cd}	1.90 ^{ab}
PC	0.17 ^a	2.06 ^a	1.60 ^{ab}
SC	0.12 ^a	0.91 ^{cd}	1.73 ^{ab}
PM	0.17 ^a	1.63 ^{ab}	1.89 ^{ab}
GL	0.12 ^a	1.02 ^{bcd}	1.88 ^{ab}
INTG	0.2 ^a	1.53 ^{abc}	2.42 ^a

*Means followed by the same letter (s) in the same column are not significantly different by DMRT at $p < 0.05$. AC is unamended soil, PC is phospho-compost, SC is sole compost, PM is poultry manure, GL is *Gliricidia sepium* leaves, INTG is integrated fertilizer, DRW is Dry root weight and DSW is Dry shoot weight.

plant⁻¹) from unamended soil. All the organic based treatments: PC, PM, INTG, GL and SC were superior to

the NPK treatment producing cowpea DSW that were 132, 84, 72, 15 and 3%, respectively higher than the

Table 5. Correlation coefficient relating the total phosphate leached in a sandy soil with selected soil and plant parameters.

Parameter	DRW	DSW	LpH	Avail.P	N uptake	PO ₄ leached	P uptake	SpH	TLV	Grain weight
DRW	1									
DSW	0.52**	1								
LpH	0.24	0.28	1							
Avail.P	0.05	0.25	-0.04	1						
N uptake	0.48*	0.94***	0.34	0.37	1					
PO ₄ leached	-0.19	-0.22	-0.23	-0.58**	-0.50*	1				
P uptake	0.49*	0.96***	0.28	0.35	0.99***	-0.43*	1			
SpH	0.02	0.05	0.26	-0.41*	-0.07	0.30	-0.06	1		
TLV	-0.27	-0.63**	-0.01	0.02	-0.48*	-0.33	-0.57**	-0.03	1	
Grain weight	0.16	0.04	-0.29	0.24	-0.07	0.16	0.01	0.21	-0.39*	1

*, ** and *** significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels, respectively ($n=7$). DRW is dry root weight, DSW is dry shoot weight, LpH is leachate pH, SpH is soil pH and TLV is total leachate volume.

NPK. Cowpea dry root weight (DRW) on the other hand was not significantly influenced by the different fertilizer types under leaching condition. The INTG treatment however gave the highest ($0.20 \text{ g plant}^{-1}$) DRW followed by $\text{PM} > \text{PC} > \text{AC} > \text{GL} > \text{SC} > \text{NPK}$. Cowpea grain yield was significantly higher in the INTG (2.42 g/plant) compared to the unamended ($0.99 \text{ g plant}^{-1}$) soil although with values statistically similar to the grain yield from other treated soil in the order of $\text{NPK} > \text{PM} > \text{GL} > \text{SC} > \text{PC} > \text{AC}$.

Correlation coefficient relating the total phosphate leached in a sandy soil with selected soil and plant parameters

Total phosphate leached consistently had negative correlations with all the parameters tested (Table 5) except soil pH and grain weight with significant parallels with available P ($R = -0.58^{**}$), N uptake ($R = -0.50^{*}$) and P uptake ($R = -0.57^{**}$). Similar negative relationships existed between the total leachate volume and all the variables considered with significant correlations with DSW ($R = -0.63^{**}$), N uptake ($R = -0.48^{*}$) and P uptake ($R = -0.57^{**}$). Furthermore, soil available P had positive non-significant relationship with all the parameters except leachate pH ($R = -0.04^{\text{ns}}$), total phosphate leached ($R = -0.58^{**}$) and soil pH ($R = -0.41^{*}$).

DISCUSSION

Total leachate volume and phosphate leached varied significantly with fertilizer types. Total phosphate leached and total volume of percolating water in the soil studied is negatively correlated. This is indicating phosphate leaching contributions from other sources order than the volume of water percolating through the soil of which fertilizer type and occurrence of active organic matter

decomposition that encourages faster oxidation of native carbon are dominant factors. For example, GL which produced lower total leachate volume of 375.4ml leached highest phosphate (1505.3 mg/l) from the soil compared to SC, NPK and INTG that produced higher total leachate volumes of 496.1, 460.9 and 414.0 ml, respectively. This study shows the possibility of a fertilizer type to reduce volume of water percolating through the soil and yet encourage enhanced phosphate mobility into deeper soil layer.

Furthermore, application of *G. sepium* leaves as fresh green manure in this sandy soil imposed higher threat to phosphate leachate losses to underground water with potentials to cause multiple environmental and health hazards. It leached 245% more phosphate ions than the chemical fertilizer. Fresh farm yard manure application into soil was also found to cause annual loss of 123% kg ha^{-1} carbon (Flißbach et al., 2007; Mäder et al., 2006), a situation that predisposes soil to increased nutrient leaching (Xia et al., 2021). Manure application to soil in their fresh form in doses to satisfy plant nitrogen requirements in sandy soils encourages faster mineralization and surface accumulation of P (Xia et al., 2021; Azevedo et al., 2018) along production of negatively charged organic acids that compete with phosphate ions for adsorption on the exchangeable sites of the soil (Yang et al., 2019; Jiao et al., 2007; Guppy et al., 2005). The soil inorganic colloids (dominantly composed of exchangeable Fe and Al) in the presence of large concentrations of these organic acids, adsorb the organic acids preferentially over the phosphate ions subjecting the phosphate ions to moving into deeper soil layer (Bhattacharyya et al., 2015; Ojekanmi et al., 2011) as a result of increased net negative charge on the soil colloids.

The organic fertilizers in their stabilized (composted) or cured forms however, supported least vertical phosphate losses in the range of 0.00 (in phospho-compost) to 66.9 kg/ha (in cured poultry manure) compared to chemical

fertilizer based and raw organic fertilizer treatments (*G. sepium* leaves). The high solubility of chemical fertilizers in soil as a result of their high water soluble P contents (Azevedo et al., 2018) explains the higher (436.5 and 229.7 mg l⁻¹ equivalent to 873.0 and 459.5 kg P ha⁻¹ in sole chemical and integrated fertilizer treatments, respectively) phosphate leachate losses in the low nutrient holding capacity sandy soil studied. Similar higher phosphate leachate losses have been documented for chemical fertilizer treated sandy soils (Szogi et al., 2021; Azevedo et al., 2018; Kang et al., 2011).

Reports of redistribution of phosphorus fractions and enhanced microbial activities in the soils amended with organic materials are rated dominant mechanisms in their ability to reduced phosphate leachate losses in sandy soils (Omenda et al., 2021; Ahmed et al., 2019; Yang et al., 2008). These authors observed improved solubility of P extractable by NaOH and NaHCO₃ and reduced concentrations of water soluble P (that are highly susceptible to leaching losses) in a chemical fertilizer treated sandy soil amended with organic material. Enhanced microbial activities from soils receiving organic amendments are important in conversion of water soluble P in the soil into the organic fractions thus salvaging the phosphate ions from leaching losses (Ahmed et al., 2019; Yang et al., 2008).

Present result showed the occurrence of phosphate leaching from the soil innate reserve as depicted by the 69 mg l⁻¹ (equivalent to 138 kg P ha⁻¹) leached from the unamended soil. This further emphasis the ability of the sandy soil studied to undergo self P desorption from innate P reserves under the influx of percolating water which eventually had depleting effect on the concentrations of innate soil available Azevedo et al. (2018) discussed the possibility of phosphate leaching from innate P saturated soil bank under high percolating water even when no fresh P application was made. Efficient P management in this soil therefore requires stabilized P fertilizer sources that will serve to enhance surface microbial activities for increased biological P binding energy and redistribution the P forms.

The negative correlation between phosphate leached and total volume of leachate shows limited movement of phosphate ions along with water percolating through the soil profile. This is in consonance with the findings of Li et al. (2019). The little phosphate lost through the leaching column however was effective enough to significantly reduce uptake of N and P which had direct effect in reducing DRW, DSW and grain weight of cowpea. Integrating chemical fertilizer with organic materials (INTG) increased N and P uptake by 112 and 72%, respectively relative to sole NPK application. This enhanced nutrient uptake in INTG treatment correspondingly reduced P leaching by 43.4% compared to sole NPK. This will cumulate into reduced anthropogenic contribution of conventional cropping system to water eutrophication and global warming.

The positive correlation of phosphate leached with soil pH however, depicts increasing soil pH with increasing phosphate losses from the soil via leaching. This explains why the sandy soils from the study area are severely depleted of available phosphorus and yet have pH range of 6.8-7.6. These sandy soils are characterized by very low concentrations of Al and H ions, acidity saturation, and high concentrations of calcium and base saturations (Oyeyiola, 2017) which predispose the phosphate in these soils to be generally held by calcium ions. These phosphate initially held by the Ca ions when lost to leaching make the calcium ions susceptible to dissolution resulting in elevated soil pH, nutrient antagonism, salinity tendencies and over all poor crop performance.

The soil available P determined after harvesting was also influenced by fertilizer types. The fertilizer types that encouraged higher phosphate leaching (that is, *G. sepium* leaves, NPK and INTG) produced generally lower soil available P. This was substantiated by the significant negative correlations between available P and phosphate leached (-0.57**). In contrast, the fertilizers that supported higher soil available P, N and P uptake (PC, PM and INTG) produced significantly higher DSW and DRW. This is showing efficient use of the nutrients absorbed by the plants receiving these treatments for biomass production. Increasing P availability in the soil had been reported to enhance P uptake, shoot biomass and overall plant performance (Rollon et al., 2021; Midya et al., 2021; Lumbanraja et al., 2018; Yousaf et al., 2017). The negative significant relationship between soil available P with soil pH shows the importance of reducing the pH of the studied soil from its slightly alkaline pH range to 6.2-6.5 considered optimum for P availability to forestall P fixation with calcium in the studied soil.

Conclusion

A column leaching experiment was carried out to quantify the contributions of different fertilizer forms (consisting of inorganic fertilizer, fresh green manure, compost, cured animal manure and combination of all the aforementioned) to phosphate leachate losses in a nutrient degraded sandy soil from southwestern Nigeria. Effects of these on soil available P, cowpea grain and biomass yields, N and P uptake were also evaluated.

Results indicated that phosphate leaching in sandy soil was not only influenced by the volume of water percolating through the soil but also by other intrinsic factors such as fertilizer type, occurrence of active decomposition of organic matter and others that this study did not pinpoint. Phosphate lost through the leaching column was effective in significantly reducing uptake of N and P which had direct effect in reducing DRW, DSW and grain weight of cowpea. Composting of organic materials, co-application of raw green manure

(such as the *G. sepium* leaves tested) with stabilized organic materials and integration of chemical fertilizers with organic fertilizers are important options for mitigating phosphate leachate losses in the sandy soil studied for enhanced cowpea yield performance. Sole field application of chemical fertilizers and fresh green manure aggravate phosphate leaching in the soil studied.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interest regarding the publication of this manuscript.

ACKNOWLEDGEMENTS

The authors appreciate Mr Philip Igboba of the Soil Chemistry Laboratory at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria on the assistance received in the laboratory analysis of the soil, water and plant samples.

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