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Research article

Seasonal variation of phosphorus forms in soil amended with poultry manure in two agro-ecological zones of Nigeria

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Abstract: Seasonal variation of phosphorus forms in response to poultry manure was conducted at two agro-ecological zones of Nigeria. The experimental design was a factorial experiment arranged in a Randomized Completed Block Design (RCBD) comprised of Factors A (Locations; (Rainforest and Southern Guinea Savanna), Factors B (Sampling seasons; (onset of rainy season, peak of rainy season, cessation of raining season, onset of dry season and peak of dry season) and Factors C (Poultry manure rates; (0 ton ha^{-1}, 10 ton ha^{-1} and 15 ton ha^{-1}) making 30 treatment combinations, with three replication per treatment. Initial samples were collected at 0–15 cm for soil properties determination before poultry manure application. Manure nutrient content and soil properties were determined using standard laboratory method. Poultry manure was incorporated into the soil before the onset of rainfall after preparation of the experimental layout. Samples were collected at 0–15 cm at experimental sites during sampling seasons for determination of Inorganic P and total P using standard laboratory method while organic P was calculated as difference between total and inorganic P. From this study, poultry manure rates, locations and sampling seasons have significant effects on soil phosphorus forms in which application of 15 ton ha^{-1} of poultry manure released higher TP, OP and IP with strong seasonal variations which were maximum at the peak of the rainy season during the sampling seasons at the two locations. We would conclude that soil phosphorus forms would highly depend on the rate of organic manure, environmental factors and metrological differences in the locations. However, additional studies are needed to further investigate seasonal variation of soil phosphorus forms in response to other types of organic manure and inorganic fertilizer in different soil types by quantifying their synergistic and antagonistic effects.
Keywords: Soil - Phosphorus - Seasonal variations - Manure.

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INTRODUCTION

The application of poultry manure has been considered essential for sustainable agricultural production and the mineralization of soil organic manure releases nutrients into the soil (Rahman 2013, ArslanTopal *et al.* 2014, Hu *et al.* 2018). The use of organic amendments in agricultural land is an important issue for soil management (Thangarajan *et al.* 2013). Phosphorus has been reported as an indispensable element of Earth's and as one of the limiting nutrients for plant growth (Weihrauch 2019, Du 2020, Hou 2020). Soil phosphorus exists in various chemical forms such as organic and inorganic and these phosphorus forms differ in the fate and behavior in soil (Rowe *et al.* 2016). Literature has reviewed, total and available phosphorus as important indicators to measure phosphorus levels in soil (Jonczyk *et al.* 2015). Manure application has been reported to increase soil concentrations of phosphorus forms (Yan 2018). According to Qaswar *et al.* (2020) animal manure could improve soil total phosphorus. Long-term poultry manure amendment has been reported to increase the content of readily available inorganic P (Pi) in poultry-amended soil than unfertilized soil (Poblete-Grant *et al.* (2020). Previous research work has stated that, the application of manure resulted in a higher content of total

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phosphorus (TP) and organic Phosphorus (OP) than those found in soils that received no fertilizer (control) or mineral fertilizer (Milić *et al*. 2019).

Many researchers have concluded that variations in soil micro-environments and litter types during the wet and dry seasons in different agro-ecological zones have influence on soil microbial structure and activity, which affect phosphorus forms in soil (Cotrufo *et al.* 2015, Zhan *et al.* 2021). Understanding the change in soil phosphorus forms during the rainy and dry seasons is important for the management of soil phosphorus dynamics. Although, many works on soil phosphorus forms in other parts of the country have been documented, little or no information has been acquired on phosphorus forms in soil amended with poultry manure in the Rainforest and Southern Guinea Savanna zones of Nigeria. Therefore, this study was carried out to determine the soil phosphorus forms in soil amended with poultry manure during the rainy and dry season in the Rainforest and Southern Guinea Savanna soils of Nigeria.

MATERIAL AND METHODS

Description of the study sites

The present study was undertaken during 2021 and 2022 at the Federal University of Technology (FUTA) Akure, Ondo State in the Rainforest savanna at a place approximately 7° 18' 12'' N, 5° 8' 4'' E (Fig. 1) and Kogi State University, in the Southern Guinea savanna at a place approximately 7° 30' N, 6° 42' E (Fig. 2) of Nigeria. Akure have an annual rainfall of 1300 mm to 1600 mm (occurs mainly from March to October) which peaks in July and the dry season of four months (November to February). Mean annual temperature of 32°C with the elevation ranging from 255 to 381 m above sea level and a relative humidity of 85 to 100% during the rainy season and less than 60% during the dry season (Onyekwelu *et al.* 2006, Fasinmirin & Oguntuase 2008) while Anyingba have mean annual rainfall of 1,250mm with peak pattern occurring in July to September. The Dry season lasts about 5 months (November–March). The temperature varies from 17°C to 36.2°C. The relative humidity is moderately high and varies from an average of 65 to 85% throughout the year (Amhakhian *et al.* 2012).

Experimental design

The experimental design was a factorial experiment arranged in a Randomized Completed Block Design (RCBD) comprises of factor A, B and C. Factors A is Locations (Rainforest and Southern Guinea Savanna), Factors B is Sampling seasons (onset of rainy season (ORS), peak of rainy season (PRS), cessation of rainy season (CRS), onset of dry season (ODS) and peak of dry season (PDS)) and Factors C is Poultry manure rates (0 ton ha^{-1}, 10 ton ha^{-1} and 15 ton ha^{-1}) making 30 treatment combinations, with three replication per treatment.

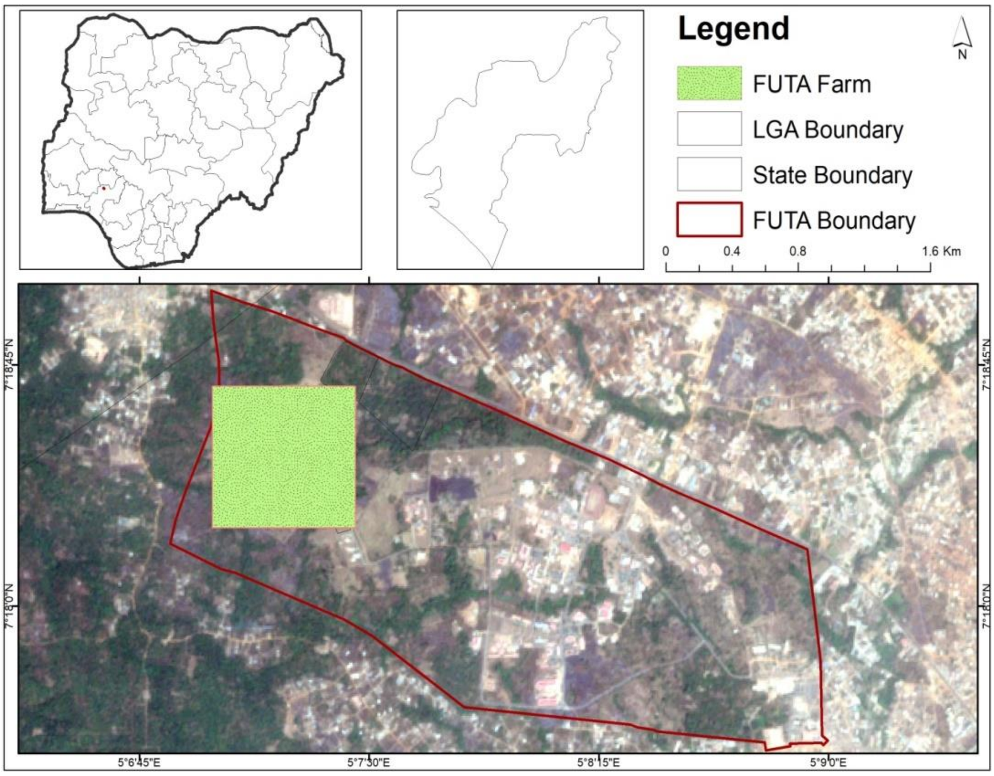

Figure 1. Map of the experimental site at Rainforest Savanna.

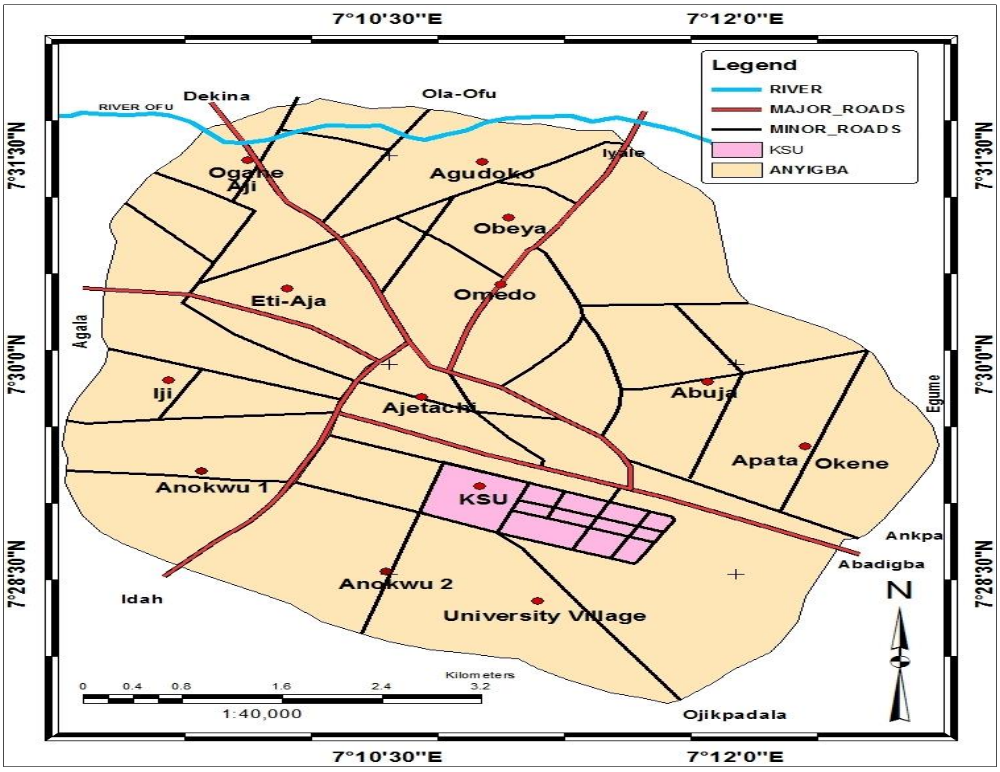

Figure 2. Map of Anyigba showing Kogi State University.

Poultry manure collection and analysis

Fresh poultry manure used as treatments for this experiment was collected from the animal sections of the Teaching and Research Farm of the Federal University of Technology Akure in the Rainforest and at the animal sections of the Research and Demonstration Farm of Kogi State University, Anyigba in the Southern Guinea savanna of Nigeria. The nutrient compositions of the poultry manure were analytically determined in the laboratory according to the procedure of Carter (1993) before application.

Soil properties determination

Initial soil properties were determined from the locations before the application of poultry manure at the beginning of the experiments. Five soil core composite samples were randomly collected at 0 to 15 cm depth from the locations, bulked together and taken to the laboratory for the determination of chemical properties using Carter (1993) method. Soil pH was measured using pH meter; Organic matter (OM) content of the soil was determined using Walkley-Black method. Soil Total Nitrogen (TN) was analyzed by Kjeldahal method. The available Phosphorus (Av. P) contents was analyzed using the Bray p-1 method, also extractable potassium (K^+) and sodium (Na^+) was measured by flame Photometer. The exchangeable basic cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) were extracted with 1M ammonium acetate at pH=7.0. The CEC of the soil was determined from ammonium acetate saturated sample.

Cultural practices and treatment application

The fields were manually cleared using cutlass and hoe. Nine experimental plots were made; that is three plots for each poultry manure rate used. Each of the plots was 2 m by 2 m with an alley way of 1 m and was raised by 30 cm to prevent the overland flow of applied amendment from plots to plots. The poultry manure was applied on the cultivated soil at the two locations in March 2021 at 0 ton ha^{-1}, 10 ton ha^{-1} and 15 ton ha^{-1} before the onset of rainfall.

Samples collections

Five soil cores composites samples were randomly collected from each plot from 0 to 15 cm depth and were bulked together during the sampling seasons for determination of phosphorus forms.

Procedure for phosphorus forms determination

Soil samples were air-dried and allowed to pass through 2 mm mesh sieve. About 100 g of the sieved samples were weighed into a well-labeled cup according to the treatments. Total p was determined using per chloric acid digested method ($HClO_4$) Murphy-Rilley procedure (1962). Organic P was determined using ignition method (Legg & Black 1955) and inorganic P was estimated by Brap p-1 (Bray & Kurtz 1945).

Collections of meteorological data

The meteorological data were collected from the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) weather observatory, FUTA and from Geography Department of KSU.

Data Analysis

All data collected were subjected to analysis of Variance (ANOVA) and significant means were separated using appropriate mean separating tools at $P \leq 0.05$ (Turkey Test) and graphs were plotted on Sigma Plot TM v. 15.0 for windows.

RESULTS AND DISCUSSION

The nutrients concentrations of the poultry manure used for the experiment were presented in table 1. Rainforest Savanna poultry manure had 25.40% of organic carbon, 3.24% of nitrogen, 3.00 mg kg^{-1} of phosphorus, 1.56 cmol kg^{-1} of potassium and 1.24 cmol kg^{-1} of calcium while the Southern Guinea Savanna poultry manure had 24.56% of organic carbon, 2.93% of nitrogen, 2.52 mg kg^{-1} of phosphorus, 1.40 cmol kg^{-1} of potassium and 1.00 cmol kg^{-1} of calcium. The carbon to nitrogen ratio (C:N) ratio were 7.84 in the Rainforest Savanna and 8.38 in the Southern Guinea Savanna and according to the previous author the lower the C:N ratio of the poultry manure the faster its decomposition rate (Morris & Boerner 1998a)**.**

Table 1. Nutrients concentration of the poultry manure used for the experiment.

Locations	Nitrogen (%)	Organic carbon (%)	Phosphorus (mg kg^{-1})	Potassium (cmol kg^{-1})	Calcium (cmol kg^{-1})	C/N
Rainforest savanna	3.24	25.40	3.00	1.56	1.24	7.84
Southern Guinea savanna	2.93	24.56	2.52	1.40	1.00	8.38

Note: C/N means carbon to nitrogen ratio.

Table 2. Initial soil properties of the study areas.

Locations	pH	N (%)	OC (%)	P (mg kg^{-1})	Na (cmol kg^{-1})	K	Mg	Ca	TEB (cmol kg^{-1})	EX. A	CEC
Rainforest savanna	6.2	0.30	2.47	1.88	0.08	2.14	2.35	4.46	9.03	0.82	10.13
Southern Guinea savanna	4.8	0.04	0.79	5.87	0.37	1.56	1.54	3.38	6.85	1.49	8.5

Initial soil properties at the locations were presented in table 2. In the presence study, however, soils in the Rainforest Savanna soil showed high nutrient content with pH of 6.2, % N of 0.30, % OC of 2.47, P of 1.88 (mg kg^{-1}), Na of 0.08 (cmol kg^{-1}), K of 2.14 (cmol kg^{-1}), Mg of 2.35 (cmol kg^{-1}), Ca of 4.46 (cmol kg^{-1}), TEB of 9.03 (cmol kg^{-1}), EX.A of 0.82 (cmol kg^{-1}) and CEC of 10.13 (cmol kg^{-1}) compared to Southern Guinea Savanna soil with pH of 4.8 % N of 0.04, % OC of 0.79, P of 5.87 (mg kg^{-1}), Na of 0.37 (cmol kg^{-1}), K of 1.56 (cmol kg^{-1}), Mg of 1.54 (cmol kg^{-1}), Ca of 3.38 (cmol kg^{-1}), TEB of 6.85 (cmol kg^{-1}), EX.A of 1.49 (cmol kg^{-1}) and CEC of 8.5 (cmol kg^{-1}). Differences in the soil properties in the two locations might be attributed to crop management, environmental interactions, differences in climatic factors and differences in the plant soil requirement (Liebig *et al.* 2004, Osobamiro & Adewuyi 2015).

Table 3. Seasonal Classification of Monthly Climate Parameters in Rainforest Savanna zone (Year 2021–2022).

Sampling seasons	Months	Soil Temperature (°C)		Rainfall (mm)	Relative Humidity (%)
		Maximum	Minimum		
Onset of Rainy	March 2021	32.5	24.8	84.5	96.12
Season (ORS)	April 2021	31.7	24.5	139.5	95.98
Peak of Rainy	May 2021	29.8	24	132.6	96.34
Seasons (PRS)	June 2021	28.7	23.1	233.7	97.29
	July 2021	27.3	23	115.6	97.73
	August 2021	27.2	23.1	251.8	96.24
Cessation of Rainy	September 2021	28.7	23.3	269.7	98.68
Seasons (CRS)	October 2021	29.6	23.9	158.9	98.29
Onset of Dry	November 2021	31	24.3	50.8	97.11
Seasons (ODS)	December 2021	33.4	22.7	5.5	94.63
Peak of Dry	January 2022	33.6	20.6	0	95.2
Seasons (PDS)	February 2022	35.6	25.3	8.6	84.57

Source: West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), Federal University of Technology, Akure, Nigeria.

Table 4. Seasonal Classification of Monthly Climate Parameters in Southern Guinea Savanna zone (Year 2021–2022).

Sampling seasons	Months	Soil Temperature (°C)		Rainfall	Relative
		Maximum	Minimum	(mm)	Humidity (%)
Onset of Rainy	March 2021	33.7	21.7	0.06	84
Season (ORS)	April 2021	33.3	21	4.5	83.2
	May 2021	32.6	20.3	5.1	83.1
Peak of Rainy	June 2021	30.5	19.4	9.4	83.3
Seasons (PRS)	July 2021	29	18.4	6.3	88
	August 2021	28.3	18	13.1	84
Cessation of Rainy	September 2021	28.9	17.8	8.7	83.6
Seasons (CRS)	October 2021	30.9	25.3	4.4	84.2
Onset of Dry	November 2021	33	26.4	0.2	83.1
Seasons (ODS)	December 2021	33.3	25.9	0	84.5
Peak of Dry	January 2022	33.3	21.6	0	86.9
Seasons (PDS)	February 2022	34.2	21.7	3.8	83.5

Source: Geography Department of Kogi State University, Anyigba Nigeria.

Seasonal rainfall in the Rainforest savanna ranged from 50.8 mm to 269.7 mm with the maximum values of 269.7 mm in August at the peak of the rainy season but declining drastically to 50.8mm in November at the onset of the dry season and peak of the dry season. The maximum temperature ranged from 27.2°C to 35.6°C with maximum values of 35.6 at the onset and peak of the dry season in November and February and declined to 27.2°C in August at the peak of rainy season while the minimum temperature ranged from 21.7°C to 25.3°C with maximum at the onset of dry season in November and the minimum value of 21.7°C at the onset of rainy season in March. The relative humidity ranged from 84.57 (%) to 98.68 (%) with the peak value in September at the cessation of the rainy season and the minimum value in February at the peak of dry season (Table 3).

For the Southern Guinea Savanna zones, seasonal rainfall ranged from 0.00 mm to 13.1 mm with the maximum in August at the peak of the rainy season but declining drastically to 0.00 mm in November at the onset of the dry season and peak of the dry season. The maximum temperature ranged from 33.7°C to 28.3°C with a peak value at the onset of the rainy season in March and declined to 28.3°C in August at the peak of the rainy season. More so, the minimum temperature ranged from 18°C to 21.7°C with the maximum at the onset of the rainy season in March and declined to 18°C in August at the peak. The relative humidity ranged from 83.1(%) to 86.9 mm with a peak value in February at the peak of the dry season and a minimum value observed in September at the cessation of the rainy season (Table 4). We expect that, climatic factors may imply soil phosphorus forms because climatic factors have been predicted to influence soil phosphorus forms (Wu *et al.* 2018).

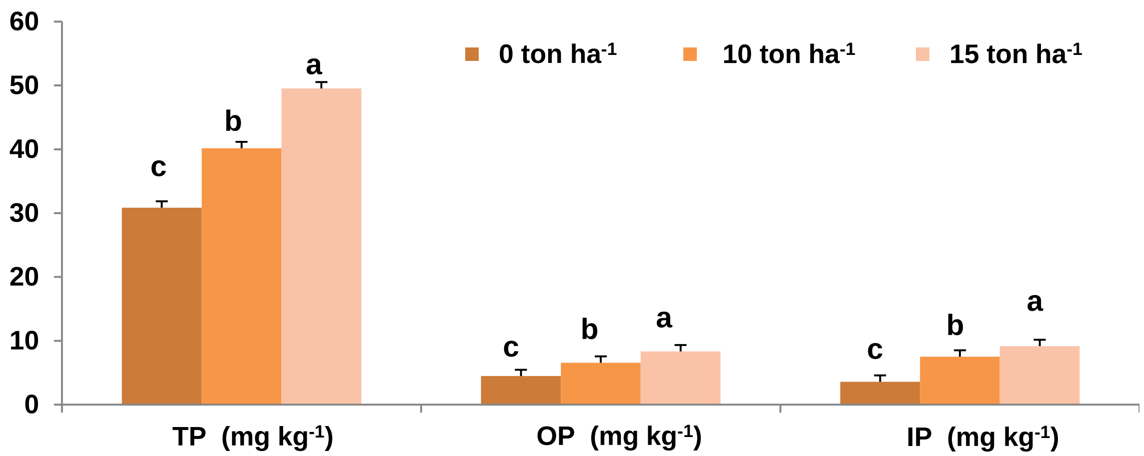

Figure 3. Effects of poultry manure on phosphorus forms. [Key: TP=total phosphorus, OP= organic phosphorus, IP= inorganic phosphorus; Vertical bars show standard errors of the means considered (n = 3). Bars with the same alphabet (s) within the poultry manure rates are not significant different (p ≤0.05)]

Effects of poultry manure rates on some selected soil phosphorus forms were presented in figure 3. It was observed that, poultry manure rates have significant effects on soil phosphorus forms (p <0.05). This result is following Yan (2018) who reported the application of manure to increase soil concentrations of phosphorus forms. Application of 15 ton ha^{-1} of poultry manure had the higher total, organic and inorganic phosphorus. This was in accordance to the findings of Jamal *et al.* (2016), who reported increased in soil-available phosphorus at a higher poultry manure application rate. Likewise, soil total phosphorus was drastically high in the manure rate compared to organic and inorganic phosphorus. This result also goes in line with Milić *et al.* (2019) who reported higher content of total phosphorus (TP) due to the application of manure in soil.

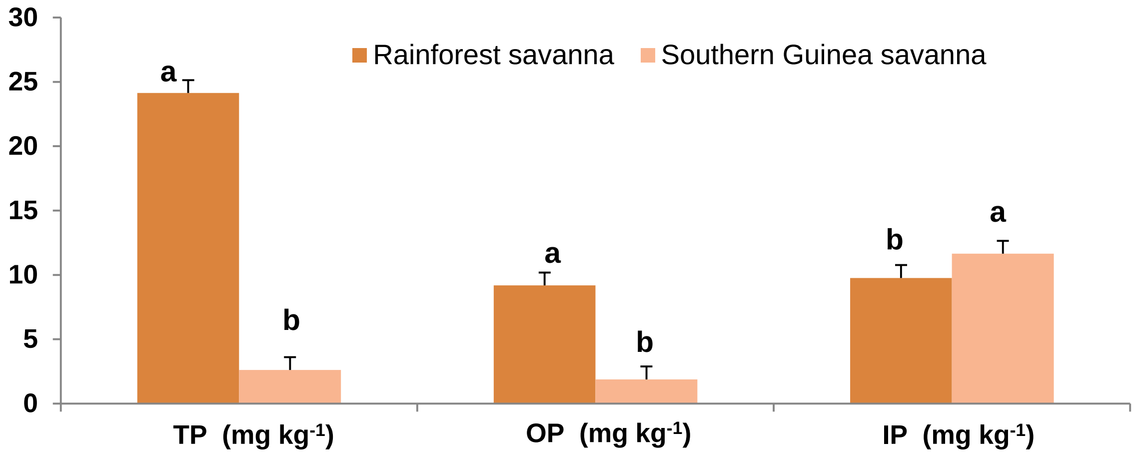

Figure 4. Effects of location on phosphorus Forms. [Key: TP=total phosphorus, OP= organic phosphorus, IP= inorganic phosphorus; Vertical bars show standard errors of the means considered (n = 3). Bars with the same alphabet (s) within the locations are not significant different (p ≤0.05)]

Effects of locations on soil phosphorus forms were presented in figure 4. Soil phosphorus forms were significantly different (*p* <0.05) among the agro-ecological regions in our study; this could be related to the different soil properties, biological and environmental factors. The highest phosphorus form concentrations were predominantly higher in Rainforest savanna soil than in Southern Guinea savanna soil. This might be attributed to higher soil organic matter contents that was observed in Rainforest Savanna soil (Table 2) that encourage microbial activities in effective nutrient degradation and mineralization (Al-Dhumri 2013)

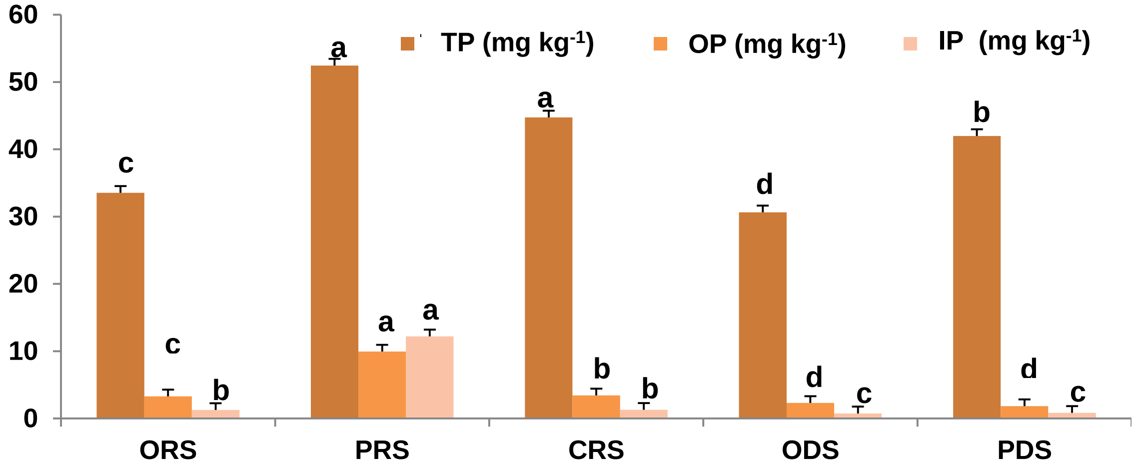

Figure 5. Effects of sampling seasons on phosphorus Forms. [Key: TP=total phosphorus, OP= organic phosphorus, IP= inorganic phosphorus; Vertical bars show standard errors of the means considered (n = 3). Bars with the same alphabet (s) within the sampling seasons are not significant different (p ≤0.05); ORS= Onset of Rainy Season, PRS= Peak of Rainy Season, CRS= Cessation of Rainy Season, ODS= Onset of Dry Season, and PDS= Peak of dry Season]

The effects of sampling seasons on soil phosphorus forms are presented in figure 5. Soil phosphorus forms varied significantly with the sampling seasons except at the peak and cessation of the rainy season where significant differences were not observed in total p and at the onset and peak of dry season where significant differences were not observed in inorganic p. The result is in accordance with studies that reported vegetation litters vary during the wet and dry seasons to have a great influence on soil phosphorus forms (Xia *et al.* 2016, Ge *et al.* 2017). The seasonal rates soil phosphorus forms were higher at the peak of the rainy season and declined at the onset of the dry season. The higher soil phosphorus during the peak of the rainy season may have resulted from higher rainfall patterns in soil during the rainy season, supplementation of above-and below-ground plant litter and fast mineralization rate by soil microorganisms. This was in agreement with the study of Li *et al.* (2017), who reported that atmospheric precipitation and vegetation influence the variation of the content of phosphorus while the decline at the onset of dry season in TP, OP and IP might be due to increase in the soil temperature during the dry season (Table 3 & 4) that caused increased soil P retention which results in the low release of phosphorus into the soil solution. This result agrees with Lin (2012).

Table 5. Interaction effects of poultry manure rate and locations on soil phosphorus forms.

Locations	Poultry manure rate (ton ha^{-1})	TP (mg kg^{-1})	OP (mg kg^{-1})	IP (mg kg^{-1})
Rainforest savanna	0	130.95c	21.69d	14.55c
	10	165.97b	30.04b	21.28b
	15	195.4a	35.64a	24.93a
Southern Guinea savanna	0	32.46e	19.58e	11.51e
	10	34.41e	21.95d	12.76d
	15	37.57d	23.84c	14.41c

Note: TP=total phosphorus, OP= organic phosphorus, IP= inorganic phosphorus.
The means with same letters in the columns separated using Turkey's Test are not significantly different at p ≤ 0.05 level test same letters.

The interaction effects of poultry manure rate and locations on soil phosphorus forms were presented in table 5. Significant differences (*P* <0.05) were observed between the poultry manure rate across the locations. The TP values ranged from 34.41 (mg kg^{-1}) to 195.4 (mg kg^{-1}), OP values ranged from 19.58 (mg kg^{-1}) to 35.64 (mg kg^{-1}) and IP values ranged from 11.51 (mg kg^{-1}) to 24.93 (mg kg^{-1}). TP, OP and IP are significantly higher in soil amended with 15 ton ha^{-1} of poultry manure compared to other poultry manure rate in the two locations while the effects of the poultry manure is more pronounced at the Rainforest Savanna soil than the Southern Guinea savanna soil. The higher performance of the poultry manure rate in the Rainforest savanna soil could be explained by the higher nitrogen content that was determined in the poultry manure used in soil and the results go in line with Kwiatkowska-Malina (2015) who reported soil organic carbon, nitrogen and their related environment to have effects on soil phosphorus in different ecological zones.

Table 6. Interaction effects of poultry manure rate and sampling seasons on soil phosphorus forms.

Sampling seasons	Poultry manure rate (ton ha^{-1})	TP (mg kg^{-1})	OP (mg kg^{-1})	IP (mg kg^{-1})
ORS	0	73.3ef	19.88fg	9.26i
	10	85.6def	25.21e	11.64fgh
	15	103.7bc	28.88cd	13.5ef
PRS	0	86.03de	29.94cd	22.18c
	10	118.7b	40.76b	35.04b
	15	155.8a	48.38a	41.68a
CRS	0	106.2bc	25.55e	12.12fgh
	10	109.1b	28.12d	14.65de
	15	115.4b	30.87c	16.12d
ODS	0	72.5ef	14.28h	10.37hi
	10	83.1def	17.96g	11.67fgh
	15	91.47d	20.69f	13.24efg
PDS	0	70.5f	13.0h	11.23ghi
	10	104.44bc	17.92g	12.1fgh
	15	115.1b	19.90fg	13.81ef

Note: The means with same letters in the columns separated using Turkey's Test are not significantly different at p ≤0.05 level test same letters.

The Interaction effects of poultry manure rates and sampling seasons were presented in table 6. Soil TP, OP and IP indicate significant differences (*p* <0.05) between the poultry manure rate and the sampling seasons. The TP values ranged from 70.5 (mg kg^{-1}) to 155.8 (mg kg^{-1}) with maximum value in the peak of the rainy season and minimum in the peak of dry season in soil amended with 15 ton ha^{-1} of poultry manure. OP and IP values ranged from 13 (mg kg^{-1}) to 48.3 (mg kg^{-1}) and 11.23 (mg kg^{-1}) to 41.68 (mg kg^{-1}) with maximum values in the peak of the rainy season in soil amended with 15 ton ha^{-1} of poultry manure and minimum value in the peak of dry season in soil amended with 0 ton ha^{-1}. The higher soil phosphorus forms during the peak of the rainy season at the soil amended with 15 ton ha^{-1} of poultry manure is due to vegetation cover, plant composition and higher rate of the manure that have effects on soil phosphorus forms. This finding agreed with the report of passed authors that explained vegetation cover, higher nitrogen content in manure and soil moisture content has varying characteristics during the dry and wet season which influences soil phosphorus (Salako 2008, Feng *et al.* 2018, Jin *et al.* 2018).

Table 7. Interaction effects of locations and sampling seasons on soil phosphorus forms.

Locations	Sampling seasons	TP (mg kg^{-1})	OP (mg kg^{-1})	IP (mg kg^{-1})
Rainforest savanna	ORS	141.07d	27.86c	10.54d
	PRS	198.7a	53.42a	50.45a
	CRS	185.29b	33.46b	15.51b
	ODS	132.88d	14.98h	11.68cd
	PDS	162.5c	15.91h	13.10c
Southern Guinea savanna	ORS	34.03e	21.45ef	12.40c
	PRS	41.64e	25.97d	15.50b
	CRS	35.15e	22.90e	13.07c
	ODS	32.19e	20.30f	11.84cd
	PDS	31.06e	18.31g	11.66cd

Note: The means with same letters in the columns separated using Turkey's Test are not significantly different at p ≤0.05 level test same letters.

Soil phosphorus forms were significantly affected by sampling season in the two locations. However, there was no significant difference in TP during the sampling seasons and at the onset and peak of dry seasons for IP at the southern Guinea savanna. The TP values ranged from 31.06 (mg kg^{-1}) to 198.7 (mg kg^{-1}), OP values ranged from14.98 (mg kg^{-1}) to 53.42 (mg kg^{-1}) and IP values ranged from 11.66 (mg kg^{-1}) to 50.45 (mg kg^{-1}) across the sampling seasons in the locations with the maximum value in the peak of rainy season at the Rainforest Savanna soil and minimum in the peak of dry season at Southern Guinea Savanna soil for TP, OP and IP respectively. The non-significant observed in TP during the sampling season and for IP at the onset and peak of dry seasons in the Southern Guinea savanna goes in line with work of Lin (2012). Who reported increase in soil temperature to caused increased soil P retention which has effects on low release of phosphorus in the soil.

Table 8. Interaction effects of locations, poultry manure rates and sampling seasons on soil phosphorus forms.

Locations	Seasons	Poultry manure rate (ton ha^{-1})	TP (mg kg^{-1})	OP (mg kg^{-1})	IP (mg kg^{-1})
RFS	ORS	0	114.80fg	20.05lmnop	7.54k
		10	137.33ef	28.23fg	11.04hijk
		15	171.1cd	34.61cd	13.06fghij
	PRS	0	133.45efg	36.04c	30.35c
		10	196.36b	55.68b	55.08b
		15	266.3a	68.53a	66.01a
	CRS	0	179.12bc	30.77ef	12.53fghij
		10	183.43bc	32.70de	15.90def
		15	193.33fg	36.09c	18.10d
	ODS	0	114.60fg	10.38s	10.51ijk
		10	134.23efg	15.61qr	11.55ghij
		15	149.82de	18.95nopq	12.99fghij
	PDS	0	112.76g	11.18s	11.94ghij
		10	178.51bc	17.30opqr	12.86fghij
		15	19.22b	19.26mnop	14.50efgh
SGS	ORS	0	31.80h	19.70mnop	10.52ijk
		10	33.96h	21.50jklmn	12.55fghij
		15	36.34h	23.15hijkl	13.96efgh
	PRS	0	38.61h	23.83hij	14.12efgh
		10	40.95h	25.84gh	15.02defg
		15	45.34h	28.23fg	17.35de
	CRS	0	33.24h	20.33klmnop	11.68ghij
		10	34.75h	23.54hijk	13.40fghij
		15	37.45h	24.84hi	14.13efgh
	ODS	0	30.41h	18.18opqr	10.23jk
		10	32.03h	20.31lmnop	11.79ghij
		15	34.12h	22.43ijklm	13.49fghij
	PDS	0	28.23h	15.86pqr	10.52ijk
		10	30.37h	18.54nopqr	11.33hij
		15	34.59h	20.53klmno	13.13fghij

Note: The means with same letters in the columns separated using Turkey's Test are not significantly different at p ≤0.05 level test same letters.

The interaction effects of poultry manure rates, locations and sampling seasons are presented in table 8. Soil phosphorus forms were significantly affected by locations, seasons and poultry manure although, significant differences were not observed at the soil amended with 15 ton ha^{-1} and 10 ton ha^{-1} of poultry manure at onset and peak of dry season in the Rainforest Savanna soil and at the southern Guinea Savanna in all the poultry manure rate during the sample season for TP. The TP values ranged from 28.23 (mg kg^{-1}) to 266.3 (mg kg^{-1}), OP values ranged from15.86 (mg kg^{-1}) to 68.53 (mg kg^{-1}) and IP values ranged from 7.54 (mg kg^{-1}) to 66.01 (mg kg^{-1}) in the soil amended with poultry manure rate across the sampling seasons in the locations with the application of 15 ton ha^{-1} of poultry released the higher value in the peak of rainy season at the Rainforest Savanna soil and application of 0 ton ha^{-1} of poultry releases the lower values in the peak of dry season for TP, OP and at the onset of rainy season for IP at Southern Guinea Savanna soil respectively. From our observations, total p recorded the highest values followed by organic p in all the poultry manure amended soil during the sampling seasons in the study locations while inorganic p recorded the lowest values. This result was in agreement with Milić *et al.* (2019) who reported, higher content of total phosphorus (TP) and organic Phosphorus (OP) than those found in soils that received no fertilizer (control). Lower values recorded for inorganic phosphorus (IP) in all the poultry manure-amended soil during the sampling seasons at the locations, might be likely to the fixation (or mineralization) of phosphorus by soil microorganisms (Azeez *et al.* 2010) and due to depletion of inorganic phosphorus in natural ecosystems (Peñuelas *et al.* 2013). Mores so, Rainforest Savanna soil released higher TP, OP and IP than Southern Guinea Savanna soil. The might be due to the slightly acidic nature of Rainforest Savanna soil (Table 2) that encourages the phosphorus availability in the soil. Our finding was supported by Penn *et al.* (2019) who reported availability of phosphorus in soil with a pH range of 6.5 to 7.0. Non-significant differences that were observed for TP in all the manure rates during the sampling seasons at Southern Guinea savanna could be to higher soil temperature observed at the location (Table 4) that have effects on TP. This finding corresponds with a similar trend that was reported by Lin (2012) on low release of soil phosphorus due to an increase in soil temperature.

CONCLUSIONS

Our study has provided an improved understanding of phosphorus dynamics in poultry manure-amended soil during the rainy and dry seasons in the Rainforest and Southern Guinea Savanna soils of Nigeria. The results from this study revealed that poultry manure, locations and sampling seasons have significant effects on total p, inorganic and organic P. Poultry manure rates significantly increase total p, inorganic and organic P in which the application of 15 ton ha^{-1} of poultry manure released the higher phosphorus forms in most of all the sampling seasons at the two locations. Soil phosphorus forms showed strong seasonal variation, in which at peak of the rainy season released higher values. This might be due to higher rainfall pattern in soil during the rainy season, supplementation of plant litter containing above- and below-ground and the acceleration of mineralization by soil microorganisms.

Our findings also verify that, locations have significant effects on soil on total p, inorganic and organic P in which Rainforest Savanna soil had more of these nutrients than Southern Guinea Savanna soil due to slightly acidic nature of the soil in Rainforest Savanna that favor the of P availability in soils. Therefore, from this result, it would be noted that, soil phosphorus forms would highly depend on rate of organic manure, environmental factors and metrological differences in the locations. Though, additional studies are needed to further investigate the seasonal effects on soil phosphorus forms in response to other types of organic manure and inorganic fertilizer in different soil types by quantifying their synergistic and antagonistic effects.

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