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Kinetics of Phosphorus Release in Coastal Plain Sand Soils Amended with Animal Manure in Akwa Ibom State, Nigeria

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Abstract: This study was carried out to assess Phosphorus (P) release on coastal plain sand soils amended with Poultry, Goat and Pig manures which was grown with soybean, using three Kinetic models, Soil physicochemical properties were also determine, the data on P released were fitted to models . The results show that applications of animal manure did not change the texture of the soils which was loamy sand. Soils amended with animal manures increased soil pH when compared to unamended soils. The values ranged from 4.40 to 5.60 (Pig manure) > 4.40 to 5.20 (Goat manure) > 4.40 to 5.00 (Poultry manure). The mean pH was 4.82 higher than the control being 4.40. Electrical conductivity was higher than the control by 2%, Organic matter content was higher in the amended soils with a mean of 4.20% compared to unamended soil with a value of 3.76%. Total Nitrogen was higher than control by 2%, available P ranged from 6.20mgkg-^{1} in control to a mean of 6.76mgkg-^{1}. The Cation Exchange Capacity of the soil were slightly higher than the control. The order of abundance ranged from Calcium (2.16 cmolkg-^{1}) > Potassium (1.00 cmolkg-^{1}) > Magnesium (0.28 cmolkg-^{1}) > Sodium (0.09 cmolkg-^{1}), Exchange acidity value decreases with the rates of application of manure. The mean values ranged from 1.48 cmolkg-^{1} (Control) to 1.43 cmolkg-^{1} (amended soil). Effective cation exchange capacity and percentage base saturation also increases. The results also revealed that soils amended with animal manure released more P than unamended soils. The trend was: Pig manure ranged from 13 to 29.6 (mgkg-^{1}) > Goat manure ranged from 13.5 to 26.9 (mgkg-^{1}) > Poultry manure ranged from 13.5 to 24.3 (mgkg-^{1}) in Elovich model. Pig manure ranged from 2.61 to 3.39 (mgkg-^{1}) > Poultry manure ranged from 2.60 to 3.30 (mgkg-^{1}) > Goat manure ranged from 2.61 to 3.19 (mgkg-^{1}) in Power function model. Pig manure ranged from 0.06 to 0.08 (mgkg-^{1}) > Poultry manure ranged from 0.05 to 0.08 (mgkg-^{1}) > Goat manure ranged from 0.03 to 0.08 (mgkg-^{1}) in Parabolic diffusion. The concentration of P release increased with increasing time of extraction, the hours of 120 recorded the highest concentration. It also indicated that concentration of P released significantly correlated with Soil pH, OM, P, K, Ca, Mg, BS, Silt and Clay. Elovich model successfully described the P released in the soils with the highest R^2 values of 0.999 and is therefore recommended to be used for the soils.

Keywords: *coastal plain sand, phosphorus, kinetic models, animal manure and soil properties*

1. Introduction

Phosphorus (P) is an essential macronutrient element in soils that improved the growth and yield of crops (Umoh *et al.,* 2015; Umoh *et al.,* 2016). Phosphorus (P) availability is very low in the soil as compared to other nutrients due to high fixation. About 80-90% P in soil are

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unavailable, leading to a widespread Phosphorus deficiency causing low yield of crops (Yu *et al.,* 2013; Umoh *et al.,* 2014).The rate of phosphorus (P) released and availability in soils can significantly influence by certain factors such as soil types, pH, type and amount of clay, amount of P applied and the content of organic matter in soils (Uchida, 2000). High level of P released was observed in coastal plain sand soils due to the sandy nature of the parent material (Umoh *et al.,* 2019)

Quality Improvement (QI) for optimum nutrition of crop, the replenishment of P-depleted soil solution affected by the release of P from clay mineral, organic matter, iron and Al hydroxides, application of P fertilizer varies with crop and soil types. The large amount and inadequate management of fertilization in cultivation land are mainly responsible for P accumulation on the surface soils and phosphorus inputs to the soil for agricultural purposes are primarily from the applications of chemical fertilizer and organic manure which gives an optimum growth of plants and cannot be replaced by another element if deficient (Ham *et al.,* 2018).

A combined use of organic amendments has been reported to enhanced P availability in soils, provide nutrients, improved soil physiochemical conditions improved the efficiency of added P fertilizers and increased yield of crops (Umoh *et al.,* 2022). Poultry litter, farm yard manure, compost, urban and industrial wastes are reported cheap and efficacious use of fertilizers to enhance agricultural productivity and soil quality (Ekwere *et al.,* 2003; Ekwere *et al.,* 2022). When these organic amendments are added to soil, soil health and fertility status is significantly improved, leading to high crop productivity.

The kinetics of P released in soils can be estimated using different models to describe P availability in soils. Parabolic diffusion and power function equation were found to be appropriate for describing P released and Phosphate released kinetics were closely related to the ratio of desorption to dissolution of phosphate (Uzoho and Oti 2005). The kinetics investigations of P released from soil is valuable in evaluating the accessibility of soil P. The ability of different kinetic models to explain P released has been reported in many studies (Agbenin and Tissen 1995). Both diffusion and dissolution reactions are probably involved in the slower second phase of P-release. Much research had used different extract to study the kinetics of P-released in soils.

Limited information is available on the impacts of low molecular weight organic acids (as extractant) on the kinetics of P-released from soil (Tisdale *et al.,* 1985). Low molecular weight organic acids enhance P-released from labile P and crystalline P compounds (Harrold and Tabatabai 2006). The initial fast P-release has mainly been attributed to the rapid dissolution of poorly crystalline or amorphous phosphate in soil, which is ultimately converted into fixed phosphate forms (Evans and Jurinak 1976). The dissolution of crystalline phosphate minerals of the apalite group in soil might be controlled by a slower released reaction (Tisdale *et al.,* 1985).

Emperical models were suggested by different researchers (Ahmadi, 2018), that zero order, first order, Elovich, power function and parabolic diffusion models were used to describe the relationship between P released with time in soils. Assessing the kinetic release of phosphorus (P) from animal manure sources applied on coastal plain soils is limited. Therefore, the aim of this study was to determine the concentration of P release on soils amended with different animal manure sources.

2. **Materials and method**

2.1 Physicochemical analysis:

The following soil parameters were determined as described by Udo *et al.,* (2009). Particle size distribution was determined by the Bouyoucos hydrometer method using sodium hexametaphosphate as dispersing agent. The soil pH was measured in water at the soil to water ratio of 1:2.5 using a glass electrode pH meter. Electrical Conductivity was measured in the extract from 1:2.5 soils: water suspension using a conductivity bridge. Soil organic carbon was determined by wet oxidation method and the values were multiply with factors of 1.72 to obtained organic matter. Total nitrogen was determined by micro Kjeldahi method. Available P in the soil was determined by murphy and Rilay method after extraction by Bray P-1 extractant. The exchangeable cation in the soil was extracted using NH_4 OAC, K and Na in the extracts was measured using flame photometry while Mg and Ca were determined by atomic absorption spectrophotometry. Effective Cation Exchangeable Capacity (ECEC) was obtained by the summation of the exchangeable cation and exchangeable acidity. Base Saturation (%) was calculated by the sum of exchange cation x 100/ECEC.

2.2 Kinetics of P released in soils

Ten grams (10g) of Soil amended with four different levels of animal manures was weighed into each of the tubes and 20ml portion of the treatment solution containing 80mg/l prepared from (KH_2PO_4) was added to soil sample amended with 0, 2, 4 and 6 tonha-^{1} of Goat, Pig, and Poultry manure sources and experiment was replicated 3 times. The Solution were thoroughly mixed, covered properly and allowed to incubate for 1, 48, 72, 96, 120 hours respectively. The Sample were shaken with mechanical shaker for 30 minutes, and covered for the duration of incubation hours. At the end of incubation, the available P in the Supernatant Solution was determined by the method of Murphy and Riley (1962). The data obtained were subjected to the three (3) mathematical models to describe P release kinetics.

2.3 Statistical Analysis

The available P extracted at different time period was subjected to the 3 kinetics models as shown below:

Kinetic models	**Linearized Equation**
Elovich	Pt = a +bInt ……………………..……… 1
Parabolic diffusion	Po = a+b $t^{0.5}$…………………………….. 2
Power function	Pt = a+b Int……………….…………….. 3

Where Pt/Po s cumulative P release at equilibrium

a is amount of P released at time calculated from the slope of the linear requirement

b – is the intercept

(Hosseinpur and Pashamokhtari 2008)

3. Results And Discussion

3.1 Physicochemical properties of Soils amended with animal manures

The Physicochemical properties of soils amended with animal manures are presented in Table 1. The results showed that the application of manures did not change the texture of the amended soils which is loamy sand, but there was a slight decrease in sand content and a slight increased in silt content across the three amended soils. Poultry manure had the highest sand content while soil amended with pig manure had the lowest. The observation agrees with report of Adaikwu *et al.,* (2012) that good soil management practices slightly raised the clay and silt content. Soils amended with animal manures increased soil pH when compared to unamended soils. The values ranged from 4.40 to 5.60 (Pig manure) > 4.40 to 5.20 (Goat manure) > 4.40 to 5.00 (Poultry manure). The mean pH was 4.82 higher than the control being 4.40. The increase in pH could be due to the application of manures. Umoh *et al.,*(2023) reported that soil amended with animal manure raised the soil pH from 4.5 to 5.4. Electrical conductivity was higher than the control by 2%, Organic matter content was higher in the amended soils with a mean of 4.20% compared to unamended soil with a value of 3.76%. Total Nitrogen was higher than control by 2%, available P ranged from 6.20mgkg^{-1} in control to a mean of 6.76mgkg^{-1}. This observation agrees with the findings of Umoh *et al.,(*2023) who reported that soils incorporated with animal manure improved soil organic matter and total nitrogen. The Cation Exchange Capacity of the soil were slightly higher than the control. The order of abundance

Table 1: Some physicochemical properties of soils amended with animal manure

Treatment	**Rates (t ha^{-1})**	**Sand**	**Silt**	**Clay**	**Texture**	**pH (H2O)**	**EC**	**OM**	**TN**	**P**	**K**	**Ca**	**Mg**	**Na**	**EA**	**ECEC**	**BS**
		← % →					dSm^{-1}	← % →		mgkg^{-1}	← Cmolkg^{-1} →						%
Poultry manure	0	88.20	3.80	8.00	Ls	4.40	0.08	3.76	0.09	6.20	0.68	1.82	0.20	0.08	1.48	4.26	65.26
	2	88.00	4.00	8.00	ls	4.60	0.09	4.02	0.10	6.40	0.84	1.96	0.27	0.09	1.40	4.56	69.30
	4	87.90	4.10	8.00	ls	4.80	0.10	4.12	0.10	6.80	1.22	2.10	0.34	0.09	1.42	5.17	72.53
	6	87.60	4.20	8.20	ls	5.20	0.12	4.80	0.12	7.60	1.26	4.14	0.40	0.10	1.42	7.32	80.60
Goat manure	0	88.20	3.80	8.00	ls	4.40	0.08	3.76	0.09	6.20	0.68	1.82	0.20	0.08	1.48	4.26	65.26
	2	87.00	4.00	9.00	ls	4.50	0.08	3.80	0.10	6.40	0.84	1.84	0.22	0.08	1.44	4.42	67.42
	4	87.70	4.10	8.20	ls	4.70	0.08	3.98	0.10	6.50	1.10	1.88	0.28	0.08	1.42	4.76	70.17
	6	87.40	4.20	8.40	ls	5.00	0.10	4.20	0.11	6.80	1.16	1.94	0.30	0.09	1.42	4.91	71.08
Pig manure	0	88.20	3.80	8.00	ls	4.40	0.08	3.76	0.09	6.20	0.68	1.82	0.20	0.08	1.48	4.26	65.26
	2	87.00	4.50	8.50	ls	5.00	0.10	4.65	0.12	6.80	0.98	2.00	0.24	0.10	1.43	4.75	69.89
	4	86.40	5.00	8.60	ls	5.20	0.14	4.76	0.12	7.30	1.24	2.23	0.35	0.12	1.40	5.34	73.78
	6	85.20	5.20	9.60	ls	5.60	0.16	4.82	0.12	7.90	1.32	2.40	0.38	0.14	1.40	5.64	75.18
General Mean		87.40	4.23	8.38	ls	4.82	0.10	4.20	0.11	6.76	1.00	2.16	0.28	0.09	1.43	4.97	70.48
SE (±)		0.26	0.13	0.14		0.11	0.01	0.13	0.00	0.16	0.07	0.19	0.02	0.01	0.01	0.25	1.33
LSD$_{(0.05)}$		0.57	0.29	0.32		0.25	0.02	0.28	0.01	0.36	0.16	0.41	0.05	0.01	0.02	0.55	2.92

EC = electrical conductivity, OM = organic matter, TN = total nitrogen, EA = electrical acidity, ECEC = effective cation exchange capacity, BS = base saturation, ls = loamy sand, LSD = least significant difference.

were ranged from Calcium (2.16 cmolkg^{-1}) > Potassium (1.00 cmolkg^{-1}) > Magnesium (0.28 cmolkg^{-1}) > Sodium (0.09 cmolkg^{-1}), Exchange acidity value decreases with the rates of application of manure. The mean values ranged from 1.48 cmolkg^{-1} (Control) to 1.43 cmolkg^{-1} (amended soil). Effective cation exchange capacity and percentage base saturation also increases. The increased observed could be due to the addition of manures as animal manure contain essential plant nutrient (Umoh *et al.,* 2023). This is in agreement with the findings of Udom *et al.,* 2019 who reported positive effect of organic manure on soil properties.

3.2 Phosphorus (P) extracted at different times from Soil amended with animal manures

The P extracted at different times from soils amended with Poultry manure (PoM), Goat manure (GM) and Pig manure (PM) is presented in Figure 1. The amount of P released at different time interval increased with increasing rates of manure added, the control (unamended soil) released the lowest concentration while amended soils released the highest P concentration. The increased concentration in amended soil could be due to the fast rate of decomposition and mineralization with animal manure which in the process released nutrient element (P). Umoh *et al.,* (2022) and Umoh *et al.,* (2023) reported that animal manures contained essential nutrients such as P, K, N, Ca and Mg. The results also show a fast release of P in soils amended with PoM and PM compared to GM respective of the rates applied. The lowest concentration of P released in GM, shows an indicative of higher reserved of P in soils while the higher concentration released from Pig and Poultry indicates more availability of P in that soil. Ahmadi (2018) stated that dissolution of phosphate in soils can easy the released of available phosphorus.

3.3 Kinetic Model Parameters for P released in Soils amended with animal manure

The phosphorus (P) released in amended soils by Kinetic models is presented in Table 2. The concentration of P released in amended soils based on different models varied. The concentration of P released increased with increasing rates of manures added. The concentration in Elovich model was significantly higher than the Parabolic diffusion. Among the manure sources the values were statistically similar. The trend were: Pig manure ranged from 13 to 29.6 (mgkg^{-1}) > Goat manure ranged from 13.5 to 26.9 (mgkg^{-1}) > Poultry manure ranged from 13.5 to 24.3 (mgkg^{-1}) in Elovich model. Pig manure ranged from 2.61 to 3.39 (mgkg^{-1}) > Poultry manure ranged from 2.60 to 3.30 (mgkg^{-1}) > Goat manure ranged from 2.61 to 3.19 (mgkg^{-1}) in Power function model. Pig manure ranged from 0.06 to 0.08 (mgkg^{-1}) > Poultry manure ranged from 0.05 to 0.08 (mgkg^{-1}) > Goat manure ranged from 0.03 to 0.08 (mgkg^{-1}) in Parabolic diffusion. The results also indicated that the concentration of P released in the three models increased with increasing amount of animal manure added, 0 t ha^{-1} had the lowest and 80 t ha^{-1} had the highest concentration, when comparing the best fitted models, Elovich model successfully described the P released in the soils with the highest R^2 values of 0.999. This result agrees with the findings of Umoh *et al.,* (2022); Umoh *et al.,* (2024) who observed Elovich models to be best fitted equation for K released in soils of these Zone.

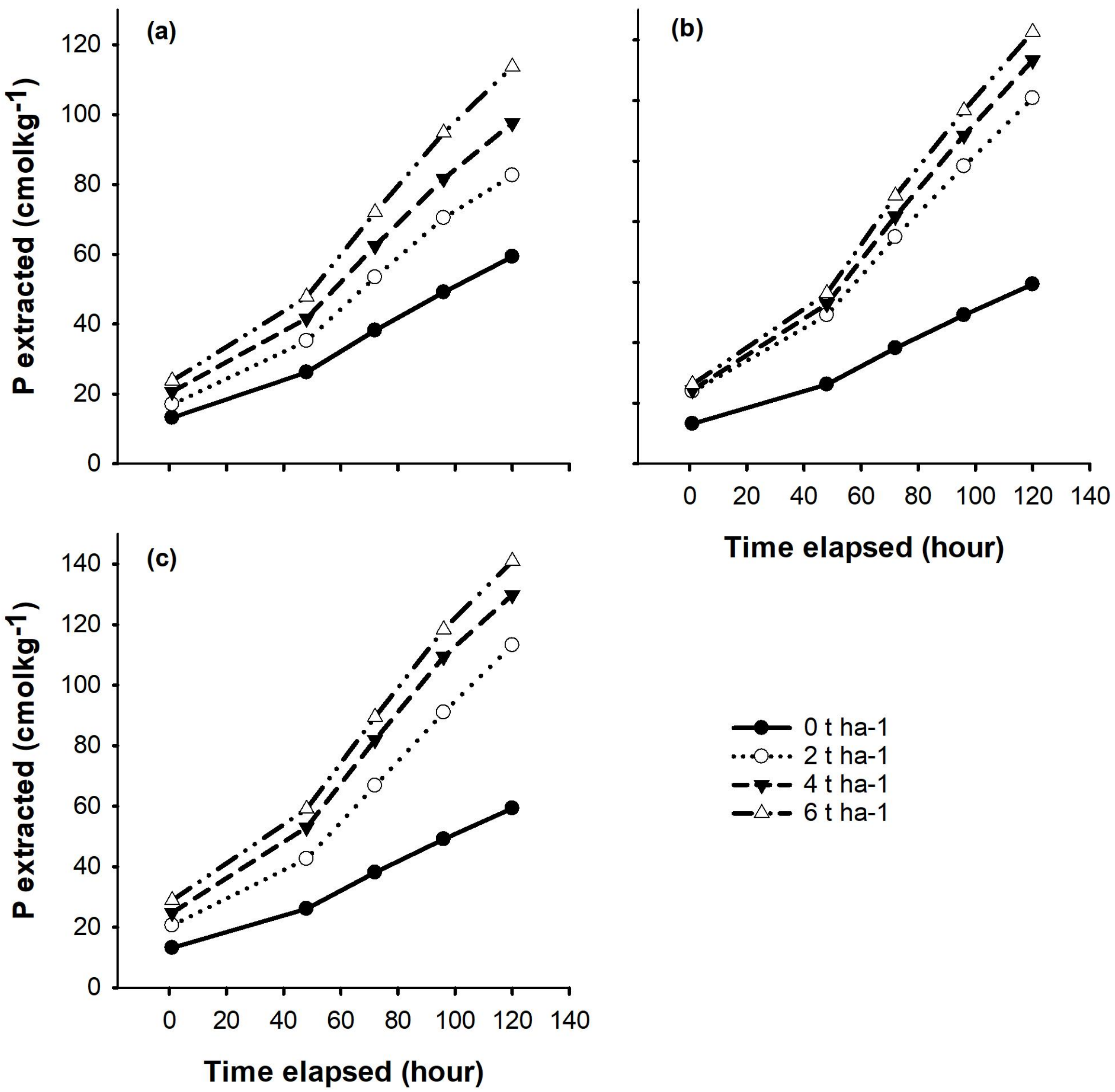

Figure 1: P extracted at different times from (a) Poultry manure (b) Goat manure and (c) Pig manure

Table 2: Kinetic model parameters (Elovich, parabolic diffusion and power function) for P release in soils treated with different levels of poultry, goat and pig manures

	Rate (tha^{-1})	Elovich				Parabolic diffusion				Power function			
		a	**b**	**R^2**	**RMSE**	**A**	**b**	**R^2**	**RMSE**	**a**	**b**	**R^2**	**RMSE**
Poultry manure	0	13.483	-0.464	0.998	0.783	0.076	0.074	0.884	4.963	2.605	-0.039	0.998	0.856
	2	17.585	-0.304	0.995	1.769	0.054	0.077	0.883	7.330	2.872	-0.022	0.995	2.128
	4	21.182	-0.475	0.998	1.439	0.061	0.076	0.878	8.637	3.056	-0.026	0.998	1.617
	6	24.290	-0.443	0.998	1.488	0.056	0.076	0.874	10.306	3.192	-0.021	0.998	1.673
Goat manure	0	13.483	-0.464	0.998	0.783	0.076	0.074	0.884	4.963	2.605	-0.039	0.998	0.856
	2	24.243	-0.024	0.999	1.011	0.042	0.076	0.868	11.126	3.188	-0.001	0.999	1.069
	4	24.875	0.510	0.999	1.397	0.024	0.078	0.868	12.575	3.212	0.020	0.999	1.512
	6	26.856	0.481	0.998	1.691	0.025	0.078	0.869	13.380	3.289	0.017	0.998	1.907
Pig manure	0	13.467	-0.459	0.998	0.744	0.076	0.074	0.882	5.010	2.604	-0.039	0.998	0.814
	2	20.598	0.584	1.000	0.460	0.017	0.077	0.847	11.621	3.025	0.026	1.000	0.505
	4	25.593	0.105	0.996	2.432	0.034	0.078	0.876	12.080	3.243	0.002	0.996	2.912
	6	29.634	-0.410	0.997	2.235	0.051	0.077	0.181	63.563	3.392	-0.017	0.997	2.571

a- amount of P released at a equilibrium, b-intercept, R^2-coefficient of determination

3.4 Correlation of P released and Some Soil properties

The relationships as presented in Table 3 showed that, P released showed significant positive relationship with pH at 1% probability levels and EC, OM, P, K, Ca, Mg, BS, Silt and Clay at 5% level. This shows that this soil properties contributed significantly to the released of P while negative relationship were observed with Exchangeable Acidity and Sand, making no contribution to the P released.

4. Conclusion and Recommendation

Conclusion drawn in this study showed that application of animal manure did not change the texture soil which was loamy sand. Soils amended with animal manures increased soil pH when compared to unamended soils. The values ranged from 4.40 to 5.60 (Pig manure) > 4.40 to 5.20 (Goat manure) > 4.40 to 5.00 (Poultry manure). The mean pH was 4.82 higher than the control being 4.40. The Electrical conductivity was higher than the control by 2%, Organic matter content was higher in the amended soils with a mean of 4.20% compared to unamended soil with a value of 3.76%. Total Nitrogen was higher than control by 2%, available P ranged from 6.20mgkg^{-1} in control to a mean of 6.76mgkg^{-1}. The Cation Exchange Capacity of the soil were slightly higher than the control. The order of abundance ranged from Calcium (2.16 cmolkg^{-1}) > Potassium (1.00 cmolkg^{-1}) > Magnesium (0.28 cmolkg^{-1}) > Sodium (0.09 cmolkg^{-1}), Exchange acidity value decreases with the rates of application of manure. The mean values ranged from 1.48 cmolkg^{-1} (Control) to 1.43 cmolkg^{-1} (amended soil). Effective cation exchange capacity and percentage base saturation also increases.

The results also indicated that soils amended with animal manure released more P than unamended soils. The trend were: Pig manure ranged from 13 to 29.6 (mgkg^{-1}) > Goat manure ranged from 13.5 to 26.9 (mgkg^{-1}) > Poultry manure ranged from 13.5 to 24.3 (mgkg^{-1}) in Elovich model. Pig manure ranged from 2.61 to 3.39 (mgkg^{-1}) >Poultry manure ranged from 2.60 to 3.30 (mgkg^{-1}) > Goat manure ranged from 2.61 to 3.19 (mgkg^{-1}) in Power function model. Pig manure ranged from 0.06 to 0.08 (mgkg^{-1}) > Poultry manure ranged from 0.05 to 0.08 (mgkg^{-1}) > Goat manure ranged from 0.03 to 0.08 (mgkg^{-1}) in Parabolic diffusion. The concentration of P release increased with increasing time of extraction, the hours of 120 recorded the highest concentration. It also indicated that concentration of P released significantly correlated with Soil pH, OM, P, K, Ca, Mg, BS, Silt and Clay.

Comparing the best fitted models, Elovich model successfully described the P release in the soils with the highest R^2 values of 0.999 and Elovich model is recommended and addition of animal manure in soils will improve nutrient availability.

Table 3: Correlation of P released and some soil properties

	Cumulative P released	pH	EC	OM	P	K	Ca	Mg	Na	EA	ECEC	BS	Sand	Silt
pH	0.753**													
EC	0.580*	0.938**												
OM	0.634*	0.944**	0.885**											
P	0.671*	0.970**	0.944**	0.928**										
K	0.823**	0.890**	0.780**	0.807**	0.875**									
Ca	0.247	0.544	0.483	0.638*	0.686*	0.536								
Mg	0.649*	0.865**	0.820**	0.811**	0.911**	0.941**	0.711**							
Na	0.553	0.911**	0.979**	0.860**	0.892**	0.701*	0.360	0.721**						
EA	-0.775**	-0.742**	-0.655*	-0.692*	-0.687*	-0.818**	-0.324	-0.785**	-0.641*					
ECEC	0.459	0.728**	0.652*	0.771**	0.835**	0.752**	0.959**	0.873**	0.530	-0.520				
BS	0.632*	0.844**	0.754**	0.853**	0.905**	0.892**	0.849**	0.960**	0.651*	-0.726**	0.960**			
Sand	-0.728**	-0.824**	-0.845**	-0.721**	-0.779**	-0.635*	-0.166	-0.552	-0.891**	0.601*	-0.350	-0.496		
Silt	0.696*	0.904**	0.930**	0.856**	0.845**	0.742**	0.243	0.679*	0.959**	-0.695*	0.447	0.609*	-0.932**	
Clay	0.669*	0.652*	0.665*	0.511	0.625*	0.460	0.075	0.369	0.721**	-0.442	0.219	0.332	-0.943**	0.758*

* significant at 5% probability level; ** Significant at 1% probability level.

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