Journal of Agriculture and Ecology Research International

16(3): 1-12, 2018; Article no.JAERI.15004
ISSN: 2394-1073

Phosphorus Release Dynamics in Sweet Potato Production

Isiaka Kareem[1*], E. A. Akinrinde[2], O. F. Adekola[1], T. B. Salami[3] and Yusuf Oladosu[4]

[1]*Department of Agronomy, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria.*
[2]*Department of Agronomy, University of Ibadan Ibadan, Nigeria.*
[3]*Department of Agricultural Education, Emmanuel Alayande College of Education Oyo, Oyo State, Nigeria.*
[4]*Institute of Tropical Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.*

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2018/15004
Editor(s):
(1) Krzysztof Skowron, Department of Microbiology, Nicolaus Copernicus University in Toruń, Collegium Medicum of L. Rydygier in Bydgoszcz, Poland.
(2) Dr. Ahmed Esmat Abdel Moneim, Department of Zoology, Helwan University, Egypt and Institute of Biomedical Research Center, University of Granada, Spain.
Reviewers:
(1) Denise Aparecida Chiconato, Department of Biology Applied to Agriculture, Sao Paulo State University, Brazil.
(2) Elouaer Mohamed Aymen, Department of Horticulture Sciences, High Institute of Agronomy, Chott Mariem, Tunisia.
(3) Angelo Maria Giuffre, Università Degli Studi Mediterranea di Reggio Calabria, Italy.
Complete Peer review History: http://www.sciencedomain.org/review-history/27027

Original Research Article

Received 01 November 2014
Accepted 07 January 2015
Published 03 November 2018

ABSTRACT

Soil phosphorus (P) toxicity in tuber production is a significant issue and to solve this problem and have optimum tuber yield at a lesser cost of P-fertilization, knowledge in depth on the dynamics of phosphorus release in sandy loamy soil is necessary. Therefore, the present work was carried out to assess the trend of P-release from the application time to the period of its optimum release along with its effects on sweet potato growth and tuber production. For obtaining so, a 5-week incubation study under laboratory conditions was performed to study P-release dynamics using different P sources. Another similar field experiment was concurrently conducted using the same P sources and application rates to monitor the influence of P-release rate on sweet potato production. Various parameters, namely leaves, vine length, tuber yield, soil extractable phosphorus and leaf phosphorus uptake were taken into consideration. Relationships were also established between P-uptake and tuber yield, number of leaves and vine length. The curve of the trend of the phosphorus release was S-shaped. Also, P-application improved the

**Corresponding author: Email: abdulkareemishaaq@gmail.com;*

production of leaf and vine length while tuber yield was suppressed. The study recommended that P-fertilizer should not be applied at close intervals even if its effects are yet to be felt on plants.

Keywords: Incubation; phosphorus sources; phosphorus uptake; P-release dynamics and tuber yield.

1. INTRODUCTION

Phosphorus (P) as a non-renewable resource is now being focused by researchers as they are expecting peak in agricultural production in the nearest future [1,2]. It is one of the essential plant macronutrients and it is added to the soil using phosphorus fertilizers. The importance of P hinges on the pivotal role it plays in energy transfer in both plants and animals [3]. Despite the importance of P in agricultural production, its availability in the soil is checked by slow diffusion as well as high level of fixation which now make it a limiting factor in crop production [4]. Furthermore, phosphorus limits both growth and yield in unfertilized soil especially when the soil is laden with calcium carbonate which makes P accessibility a difficulty by reducing its availability [5]. Uptake of P and its utilization are very important in the determination of crops' final yield. P adsorbs on different clay minerals as well oxides of aluminum and iron. Such adsorbed P can only be freed through desorption processes [6]. Furthermore, the use efficiency of applied P is generally very low ranging from 10 to 30% in the year of application. In spite of the considerable addition of P-fertilizers in most soils, the amount available for plant use is usually low as a result of its reaction with the soil constituents [7]. In the same vein, Grotz and Guerinot [8] explained that when P-fertilizer is applied, 80% of the total available P is made inaccessible through fixation while only 20% is left for plant use. In addition to fixation, mobility of phosphorus is not like those of nitrogen and potassium. Moreover, increase in ionic strength can aid P adsorption in the soil while further reactions in the soil may lead to occlusion of P in nanopores of aluminum and iron oxides to prevent P availability to plants [9].

The dynamics of P in the soil-plant system is a function of joint effect of P transformation, its availability as well as its utilization [6]. Dynamics of soil P has to be understood because soil phosphorus exists in organic and inorganic forms and as a result of that, their behavior and fate in the soil differ [10]. The stable forms of organic P include phosphanates and inositol phosphates while its active forms include organic poly-phosphates, labile orthophosphate mono-esters and orthophosphate diesters [11].

The release of organic P could be achieved via mineralization processes with mediation of phosphatase secretion, soil organisms and plant roots. The process of mineralization is greatly affected by surface physical and chemical properties, temperature, soil moisture and pH [6].

Sweet potato is a food crop which responds favourably to P fertilizers and is majorly produced by subsistence farmers to achieve food security when there is prevalence of food scarcity especially in the tropics [12].Sweet potato is considered a food item that can be used to conquer hunger and achieve reduction in food shortage [13]. Its high biomass production has earned it superiority as an industrial material for medicinal purposes [14], starch and alcohol production [15]. At present there is dearth of information on dynamics of phosphorus in sandy loamy soil although such information is found on other soil types. This knowledge is needed for better crop production and soil nutrient management. Therefore, this research was conducted to investigate the trend of P-release from time of application to its optimum release in sandy loamy soil and determine its effect on sweet potato growth and tuber production. To understand the trend of P release in the soil and use the knowledge for better crop production.

2. MATERIALS AND METHODS

2.1 Experimental Site

The research was carried out at the Teaching and Research Farm of Agronomy Department, Parry Road, University of Ibadan, Ibadan, Oyo State (7.27°N 3.54°E). The temperature range was between 22°C and 28°C with the annual rainfall between1000 mm and 1600 mm.

2.2 Field Preparation and soil Characteristics

The field was manually cleared and stumped using cutlass and hoe to ease the workability of the soil. The field was then manually ridged for enhancement of tuber development. The whole area was then divided into twelve plots. The soil type for both field and laboratory experiments was sandy loam with 8.8% clay, 20% silt and 71.20% sand. The soil pH (water) was 4.90 and its phosphorus content was 6.80 mg/kg.

2.3 Experimental Treatments and Design

The four treatments used in this study were pacesetter organic fertilizer (POF) at the rate of 5t/ha, single super phosphate (SSP) at the rate of 500 kg/ha, crystallizer at the rate of 500kg/ha and the control (zero fertilizer).The field experiment was laid out in randomized complete block design (RCBD) while the laboratory study was laid out in completely randomized design (CRD).

2.4 Crop Husbandry

On the field, 25 cm long sweet potato vines of Shaba variety were planted at an angle of 45° with two thirds of the vine under the soil for proper establishment. The plant spacing was 30 cm by 100 cm with a total of 18 plants per plot to give plant density of 33,333 plants per hectare. At four weeks after planting, fertilizer treatments were applied. Weed control was through hoeing at the initial stage. After the spread of the vines, hand weeding was resorted to for safeguarding the vines from mechanical damage.

2.5 Soil Incubation Study

Systemic soil sampling method was used to collect plot representative samples for incubation study. The samples were then air dried on sheets of paper and passed through 2 mm sieve. The prepared soil samples were used to fill twelve new bower vessels. Each bower vessel represented a plot on the field. The moisture level of the soil samples was maintained at 60% field capacity. The fertilizer treatments were applied the same way as it was done on the field and the experiment was left in the laboratory for phosphorus release to occur. At the end of the fifth week, a sample each was taken from each bower vessel, air-dried on sheets of paper and then analysed for phosphorus content. The extraction method used was Bray-1 method and the determination was through molybdenum blue procedure [16].

2.6 Data Collection

Three representative plants from each plot were randomly selected and tagged with exclusion of the border rows. Data on number of leaves and vine length per plant were taken on weekly basis from the first week to the fifth week after fertilizer application. At final harvest (three months after planting), leaves of the sampled plants were collected and prepared for P extraction and determination using Bray-1 method [16]. Phosphorus uptake was then calculated as follows:

Phosphorus uptake= Plant P concentration x dry matter used [17].

2.7 Statistical Analysis

The collected data were analysed using analysis of variance (ANOVA) with GENSTAT statistical package while significant means were separated using least significant difference (LSD) at 5% probability level.

3. RESULTS

3.1 Effect of Time Passage on Phosphorus Release Kinetics in the Soil

It was found that passage of time influenced the level of phosphorus found in the soil at any instance after application of phosphorus fertilizers. The trend of P-release in all the P-fertilizers used was that after the P-release at the first week after fertilizer application, all the treatments had lower P in the second week than that of the first week. The third week witnessed a rise again from all the treatments except

Table 1. Kinetics of P release in the soil used

	Weeks after fertilization				
Treatments	**1**	**2**	**3**	**4**	**5**
Control	8.07	7.42	8.11	6.38	6.6
POF	8.65	7.89	9.63	8.73	7.12
SSP	17.92	10.92	15.59	13.48	9.85
Crystallizer	6.58	7.1	7.1	6.5	6.08
LSD 0.05	ns	ns	ns	ns	ns

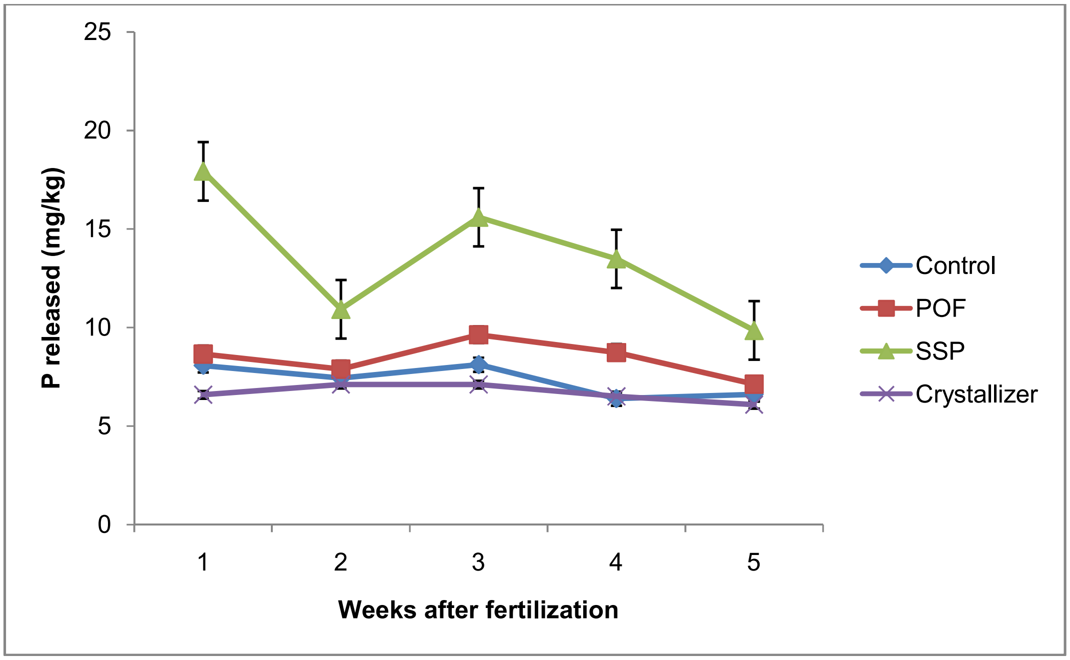

Fig. 1. Kinetics of phosphorus release in the soil used. The bars are standard error bars

crystallizer that maintained what it had in the second week. After this, the fourth and fifth weeks had a progressive decrease in P release. The highest P-release was from SSP while the lowest P-release was from crystallizer in all the treatments (Fig.1, Table 1). The soil P release positively influenced leaf P uptake (Fig. 8).

3.2 Effect of P-release Kinetics on Sweet Potato Vine

It was obvious in this experiment that the rate of P release had impact on vine production. All the fertilizer treatments were better than the control except during the first two weeks of data collection where only crystallizer performed better than the control. The order of vine increase among the treatments at the first week after fertilization (WAF) was crystallizer >control > POF >SSP. For the second week after fertilization, the order was crystallizer> control> SSP> POF. For the third, fourth and fifth weeks after fertilization, the trend was crystallizer > SSP >POF> control (Fig. 2, Table 2).

3.3 Effect of P-release Kinetics on Sweet Potato Leaves

The progressive release dynamics of P positively influenced leaf production in sweet potato as it did for vine growth. For the first and the second weeks after fertilization, only POF could not produce higher number of leaves than the control. But for rest periods of observation and data collection, all the P fertilizer treatments produced higher number of leaves than the control. Crystallizer was the overall best followed by SSP. POF was next to SSP in performance except for the first week after fertilization when both POF and the control were the same and the second week when POF was less than the control (Fig. 3, Table 3)

Table 2. Effect of P release kinetics on vine growth (cm)

	Weeks after fertilization				
Treatments	**1**	**2**	**3**	**4**	**5**
Control	46.7	54.1	77.6	94.3	112
POF	39.7	44.2	92.8	104.8	117.9
SSP	37.2	49.6	111.7	126.8	133.1
Crystallizer	64.6	72.3	111.9	129.1	144.6
LSD 0.05	ns	ns	ns	ns	ns

Table 3. Effect of P release kinetics on leaf production

	Weeks after Fertilization				
Treatments	**1**	**2**	**3**	**4**	**5**
Control	44	28	55	77	83
POF	44	23	66	84	106
SSP	50	26	69	87	109
Crystallizer	52	31	88	91	115
LSD 0.05	ns	ns	ns	ns	ns

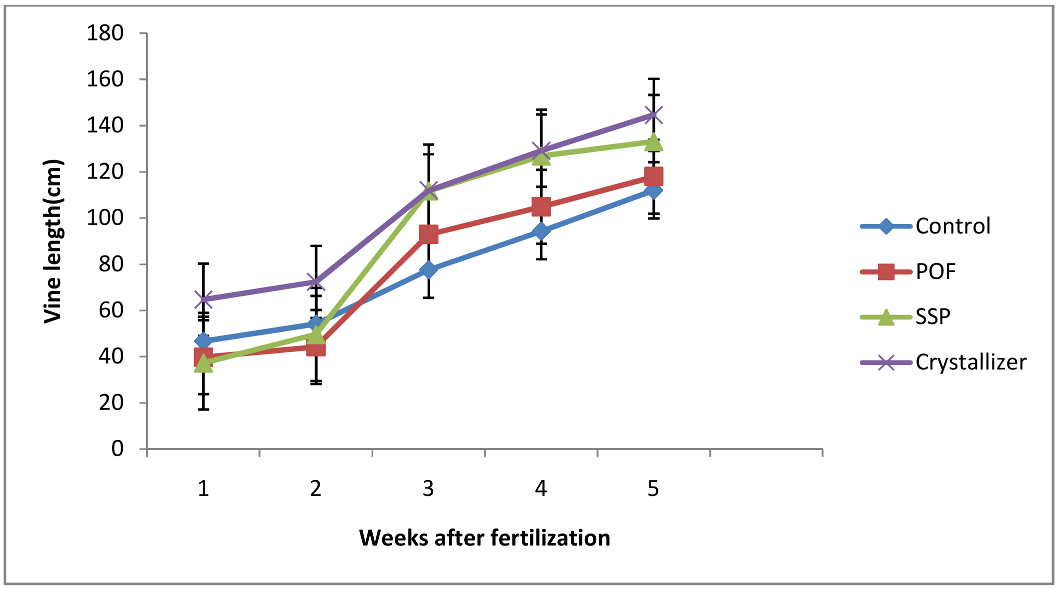

Fig. 2. Effect of phosphorus releasekinetics on vine growth (cm). The bars are standard error bars

3.4 Effect of P-releasekinetics on P Uptake of Sweet Potato Leaves

All the P fertilizers except POF enhanced leaf P uptake above the control. The highest P uptake per plant was observed in crystallizer treated plants while the least was from POF treatment (Fig. 4). The P uptake highly correlated with vine length and number of leaves produced per plant (Fig. 9, and10).

3.5 Effect of P-releasekinetics on Tuber Yield

Tuber yield was generally supressed by all the P fertilizers applied. POF was next to the control in tuber production while crystallizer treatment had the lowest yield (Fig. 5). Tuber yield indirectly related to both soil P and leaf P uptake (Figs. 6 and 7). However, leaf and vine productions had direct relationships with both soil P and P uptake (Fig. 11 and 12; Table 4).

4. DISCUSSION

The passage of time influenced the level of phosphorus found in the soil at any instance after application of phosphorus fertilizers. The release of P is based on desorption capacity of the soil. Soil nutrients like P adhere to the clay mineral and gets detached with availability of moisture [6]. This implies that desiccation could cause fixation of the nutrient that should have been desorbed or released. The observed low P in soil treated with crystallizer could be the result of strong adherence of nutrients to the clay minerals [18]. It could also be that crystallizer had suppressive power which prevented the release of innate P and that made the result from crystallizer to be lower than the control. This performance of crystallizer could be advantageous in successful treatment of soil that isextremely high in phosphorus level if our target crop requires low P as against the high innate P detected through soil testing.

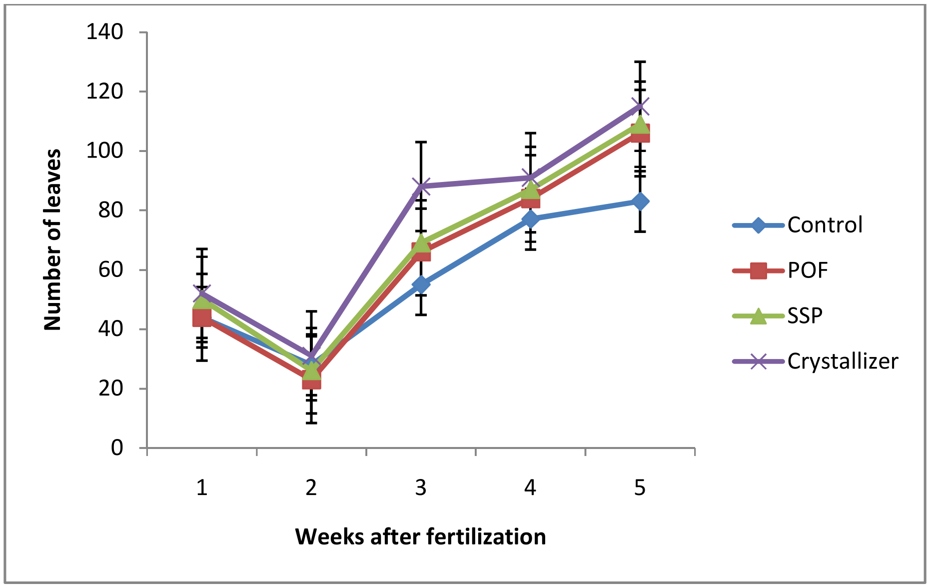

Fig. 3. Effect of phosphorus release kinetics on leaf production. The bars are standard error bars

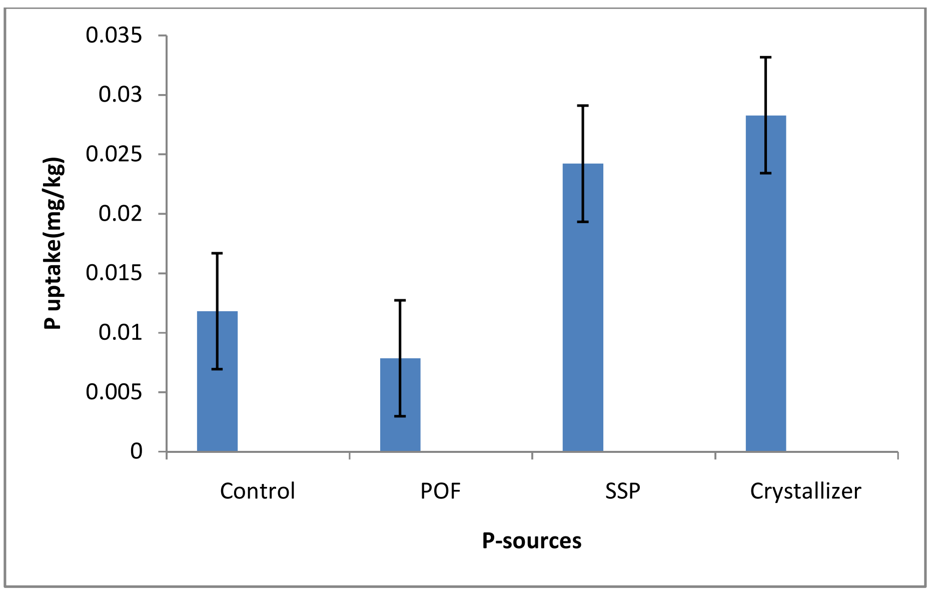

Fig. 4. Effect of soil phosphorus on P uptake of sweet potato leaves (mg/kg). The bars are standard error bars

The amount of P released by each of the P fertilizers did not commensurate with the applied P in the soil except for the control in which the native P was 6.80 mg/kg as at the commencement of the experiment. In the control, it was realized that when water was available for P desorption, the P availability increased and followed the trend found in the other P treated soils. All the P–fertilizers used (POF, SSP and crystallizer) did not release P to measure up with the concentration of the applied P sources. This is because the soil P might have been converted to unavailable form by its reaction with the soil constituents [7]. Furthermore, 80% of the total P available is made inaccessible through fixation whenever P-fertilizer is applied. So, only 20% is left for plant use [8]. In addition to fixation, phosphorus is not as mobile as nitrogen and potassium and this immobility could prevent unused P from being leached.

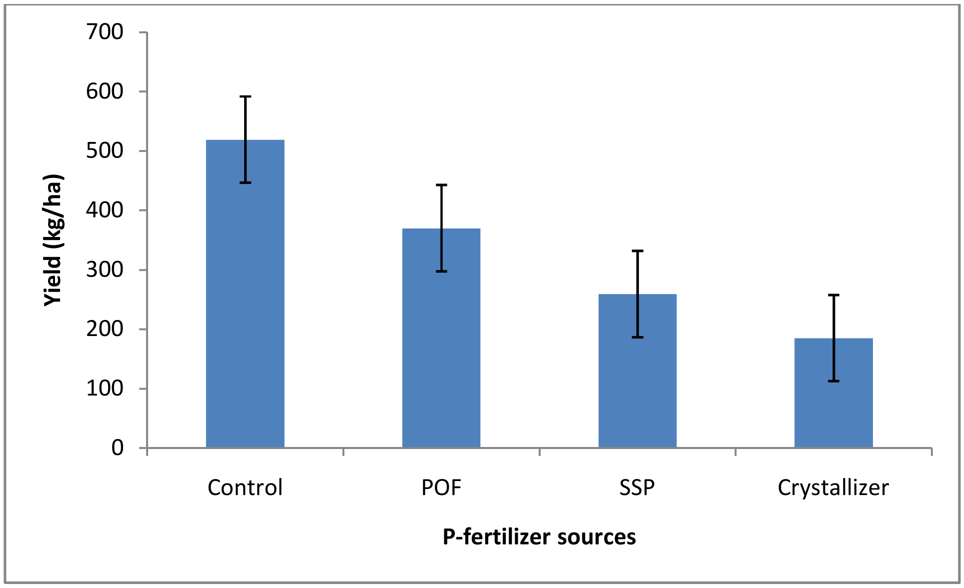

Fig. 5.Effect of soil phosphorus on sweet potato yield (kg/ha). The bars are standard error bars

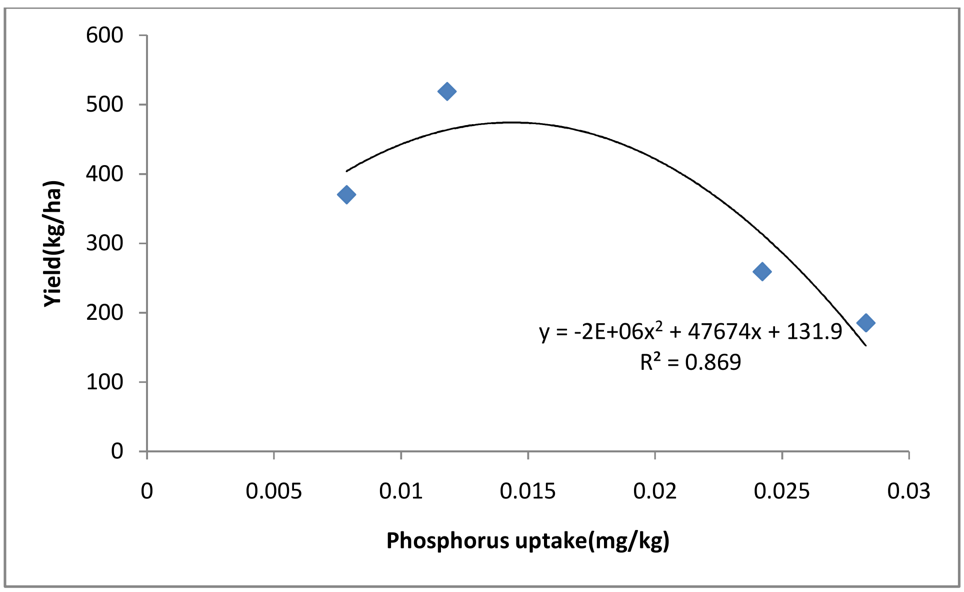

Fig. 6. Relationship between phosphorus uptake and tuber yield

The vines and leaves which represent the vegetative life of sweet potato responded positively to phosphorus application right from the third to the fifth week of observation. The increase in vine length as well as the number of leaves followed the trend of phosphorus uptake. In the light of this, it is evident that the role played by P in vegetative life of sweet potato corresponds with the established role of nitrogen. This is because adequacy of P in the soil stimulates growth and hastens maturity [19]. So, it could be said that P fertilization can be used to enhance vegetative life of sweet potato. This is because when P is applied at the optimum level, the energy required for plant metabolism is released and chemically stored as adenosine triphosphate (ATP).It is then released as required so that important growth chemical processes will be steadily driven [3]. Furthermore, it has also been established that Papplication positively increases sweet potato productivity [7] and these increments are attributed to beneficial effect of P on the activation of photosynthesis and metabolic processes of organic compounds in plants. The changes are also attributed to the important role of phosphorus as an essential component of many plant organic compounds like phospholipids, nucleic acids and nucleotides which might have positive indirect influence on the plant [20].

The phosphorus uptake followed the trend of vegetative growth of sweet potato. Since P has been discovered to aid vegetative yield of sweet potato, the P uptake was, therefore, higher whenever vegetative growth was equally higher. The available soil P can explain more than 90% of the uptake (Fig. 8). Crystallizer treated plants produced the highest vegetative yield which resulted in highest P uptake per plant. The least P uptake was from the control because of low leaf production since the amount of leaf produced is a determinant of nutrient uptake according to the formula used [17]. Despite high fixation experienced by crystallizer, luxuriant growth of the crop was not disturbed and such resulted in higher P uptake. This P recovery or uptake is between 15% and 30% while about 60% of the P-fertilizer is adsorbed or fixed by the soil [21]. So, a certain amount of P is added every year to top the amount already present in the soil.

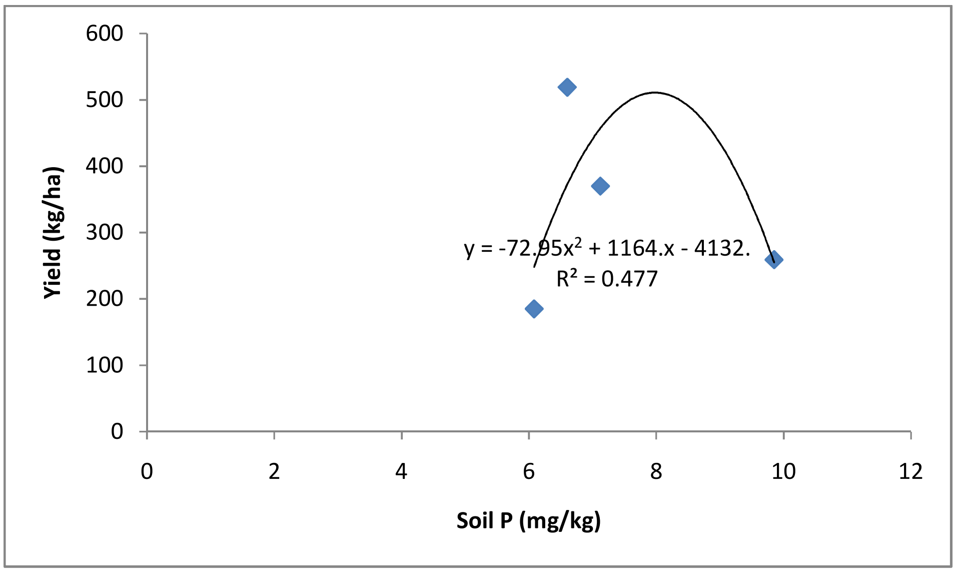

Fig. 7. Relationship between soil P and tuber yield

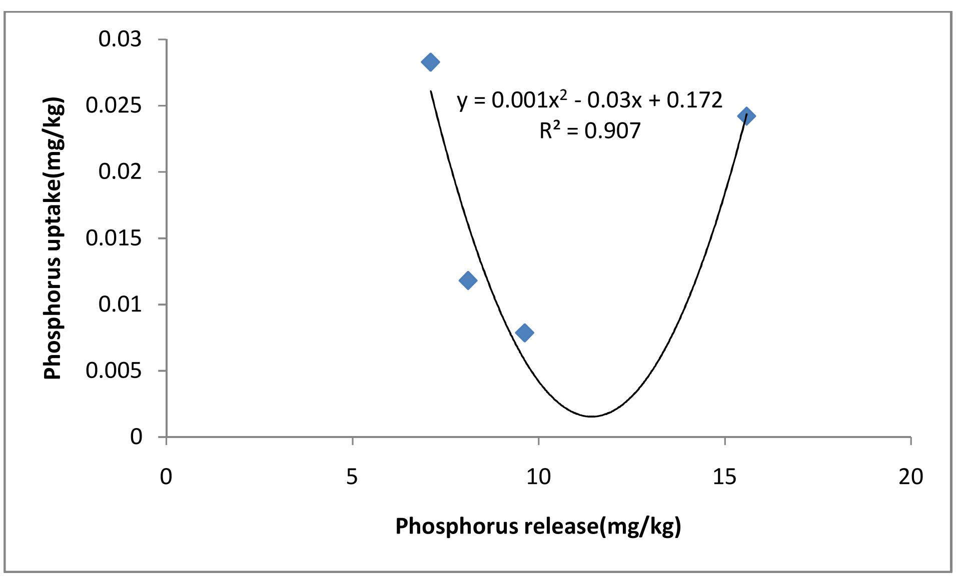

Fig. 8. Relationship between phosphorus release and uptake

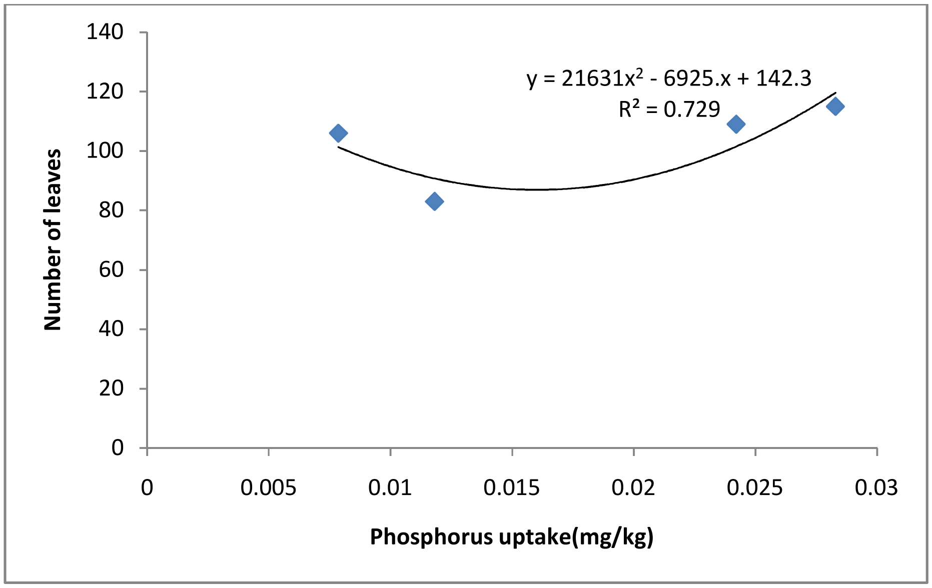

Fig. 9. Relationship between phosphorus uptake and leaf production

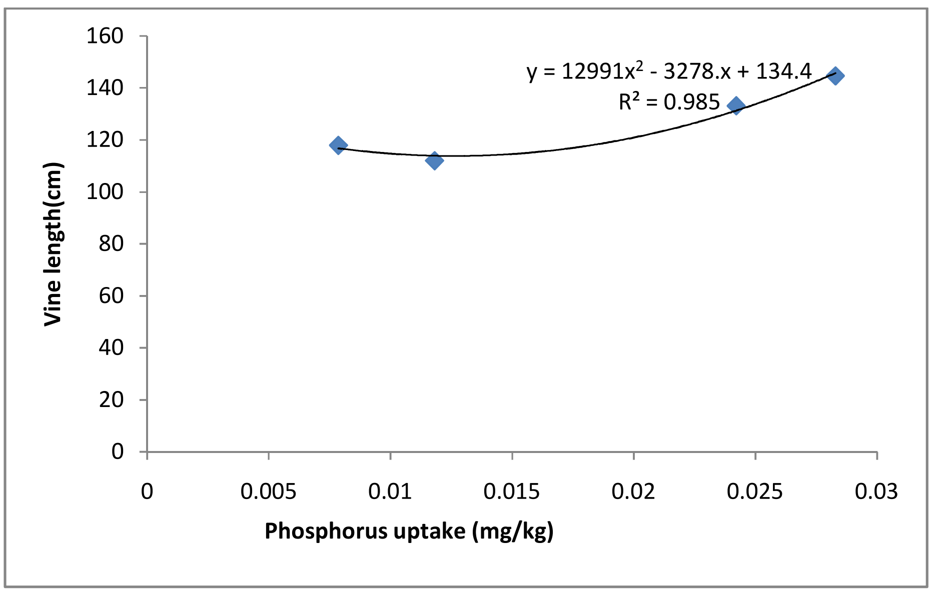

Fig. 10. Relationship between phosphorus uptake and vine length

Table 4. Effect of P release on P uptake and tuber yield of sweet potato

Treatments	Puptake (mg/kg)	Yield (Kg/ha)
Control	0.01181	519
POF	0.007853	370
SSP	0.024212	259
Crystallizer	0.028291	185
LSD 0.05	ns	ns

POF=Pacesetter organic fertilizer and SSP= Single super phosphate

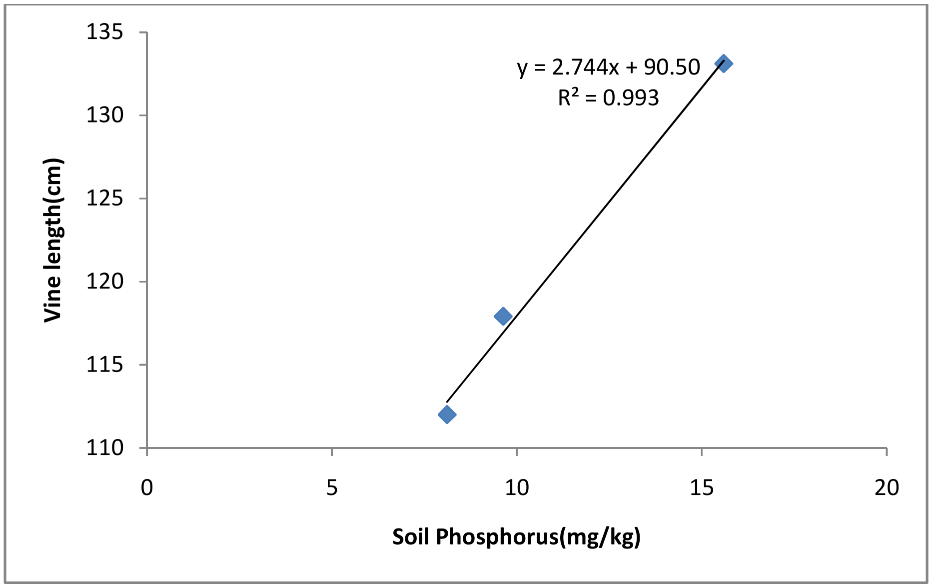

Fig. 11. Relationship between soil P and vine length

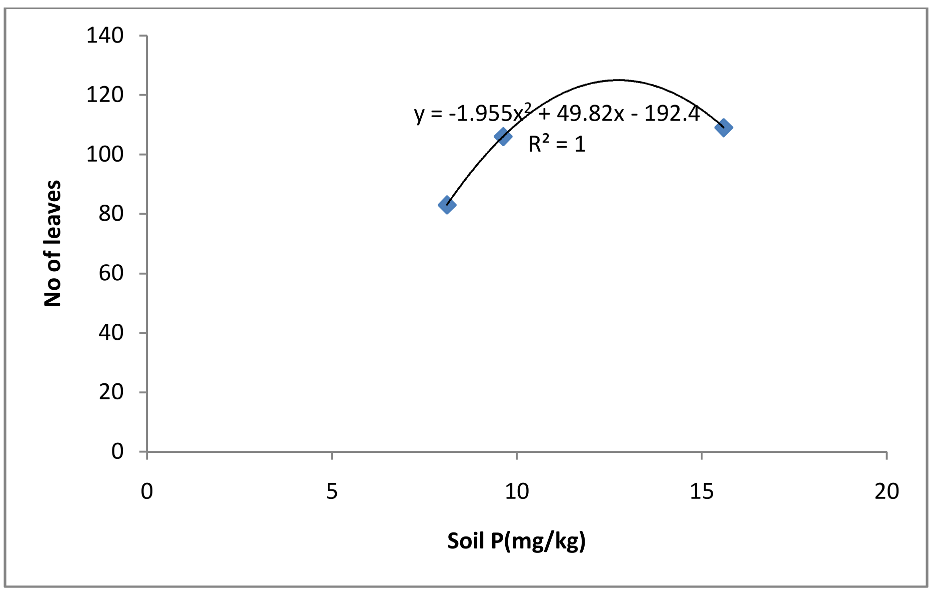

Fig. 12. Relationship between soil P and number of leaves discussion

Tuber production had inverse relationship with leaf P uptake and soil P (Figs. 6 and 7). This indicates that phosphorus uptake from the soil must be low for achievement of higher tuber yield. It also depicts that phosphorus has suppressive power on tuber production of sweet potato. Therefore, phosphorus has to be kept to the bare minimum for successful sweet potato production. As revealed by this work, the innate phosphorus content of the soil was enough to produce substantial tuber yield without ado. Therefore, introduction of more phosphorus into the soil may be detrimental to the life of the plant as it might result in nutrient imbalance and toxicity. The effect of high P-releasing fertilizers on sweet potato tuber production in this experiment was completely different from our expected result (i.e. the more the phosphorus in the soil; the more the tuberous yield). This could be linked to nutrient imbalance that might have resulted from additional phosphorus fertilization. The outcome of this research further establishes that bulking of the tuberous roots does not require phosphorus, but rather it needs a lot of potassium nutrition. As found in this work, high phosphorus level in the soil suppressed sweet potato tuber development. So, elimination of phosphorus from the nutrition of sweet potato would not affect its yield in the least [22].

5. CONCLUSION

From this work, it was found that the trend of phosphorus release was S shape (Sigmoid shape). Furthermore, leaf production and vine growth were improved by P application while tuber yield was suppressed. Finally, it is advisable that P-fertilizer should not be applied at close intervals even if its effects are yet to be felt on plants because of the trend of its release over a period of time.

COMPETING INTERESTS

Authors have declared that there are no competing interests.

REFERENCES

1. Cordell D, Drangert JO, White S. The story of phosphorus: Global food security and food for thought. Glob Environ Change. 2009;19:292–305.
2. Gilbert N. Environment: The disappearing nutrient. Nature. 2009;461:716–718.
3. Soetan KO, Olaiya CO, Oyewole OE. The importance of mineral elements for humans, domestic animals and plants: A review. African Journal of Food Science. 2010;4(5):200-222.
4. Rehman OU, Mehdi SM, Sarfraz M, Shakir MA, Shabir G. Phosphorus dynamics in Rasulpur soil series typic camborthid under rice based cropping system. J. Anim. Plant Sci. 2013;23(2):480-486.
5. Ibrikci H, Ryan J, Ulger AC, Buyuk G, Cakir B, Korkmaz K, Karnez E, G. Ozgenturk G, Konuskan O. Maintenance of P fertilizer and residual P effect on corn production. Nigerian J. of Soil Sci. 2005;2: 1279-86.
6. Shen J, Yuan L, Zhang J, Li H, Bai Z, Chen X, Zhang W, Zhang F. Phosphorus dynamics: From soil to plant 1 plant physiology. 2011;156:997–1005.
7. Hassan MA, El-Seifi SK, Omar EA, Saif El-Deen UM. Effect of mineral and biophosphate fertilization and foliar application of some micronutrients on growth, yield and quality of sweet potato (*Ipomoea batata*, L). 1- Vegetative growth, yield and tuber characteristics. J. Agric. Sci. Mansoura Univ. 2005;30(10):6149-6166.
8. Grotz N, Guerinot ML. Limiting nutrients: An old problem with new solutions. Plant Biol. 2002;5:158-163.
9. Arai Y, Sparks DL. Phosphate reaction dynamics in soils and soil minerals: A multiscale approach. AdvAgron. 2007;94: 135–179.
10. Hansen JC, Cade-Menun BJ, Strawn DG. Phosphorus speciation in manure-amended alkaline soils. J Environ Qual. 2004;33:1521–1527.
11. Turner BL, Papha´zy MJ, Haygarth PM, McKelvie ID. Inositol phosphates in the environment. Philos Trans R SocLond B Biol Sci. 2002;357:449–469.
12. Were BA, Onkware AO, Gudu S. Yield and storage quality of improved sweet potato (*Ipomoea batatas* [L] Lam.) cultivars in the lake Victoria Basin, Kenya. E. Afr. Agric. For. J. 2003;68(4):197–204.
13. Kassali R. Economics of sweet potato production. International Journal of Vegetable Science. 2001;17:313-321.
14. Berberich T, Takagi T, Miyazaki A, Otani M, Shimada T, Kusano T. Production of mouse adiponectin, an anti-diabetic protein in transgenic sweet potato plants. Journal of Plant Physiology. 2001;162:1169-1176.
15. Yasmin F, Othman R, Sijam K, Saad MS. Effect of PGPR inoculation on growth and yield of sweet potato. Journal of Biological Science. 2007;7:421-424.
16. Kuo S. Phosphorus. In: Sparks DL (Editor). Methods of soil analysis Part 3 – Chemical methods, SSSA Book Series 5, Madison, Wisconsin, USA. 1996;869–920.
17. Moustakas NK, Akoumianakis KA, Passam HC. Patterns of dry biomass accumulation and nutrient uptake by okra (*Abelmoschus esculentus* (L.) Moench) under different rates of nitrogen application. Australian Journal of Crop Science. 2011;5(8):993-1000.
18. Devau N, Le Cadre E, Hinsinger P, Ge´rard F. A mechanistic model for understanding root-induced chemical changes controlling phosphorus availability. Ann Bot (Lond). 2010;105:1183–1197.
19. Sharma S, Mahotra P, Bhattacharyya AK. Effect of electroplating industrial waste on ‘‘available phosphorus’’ of soil in relation to other physico-chemical properties. Afr. J. Environ. Sci. Technol. 2008;2(9):257-264.
20. Kareem I. Growth, yield and phosphorus uptake of sweet potato (*Ipomoea batatas*)

under the influence phosphorus fertilizers. Res. J. Chem. Env. Sci. 2013;1(3):50-55.

21. Olusola OA. Understanding soil and plant nutrition. Salman Press & Co. Nig. Ltd, Keffi, Nassarawa State, Nigeria; 2009.

22. FAO. Fertilizer use by crop in Ghana. Food and Agriculture Organization of the United Nations (FAO). Food and Nutrition Series. 2005;28:190.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/27027