Solid Earth Discuss., 6, 2843–2865, 2014
www.solid-earth-discuss.net/6/2843/2014/
doi:10.5194/sed-6-2843-2014

Solid Earth
Discussions
Open Access

Effects of land use changes on kinetics of potassium release in sweetpotato garden soils of the highlands, Papua New Guinea

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Received: 9 September 2014 – Accepted: 9 September 2014 – Published: 29 September 2014

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The present study attempts to employ K release parameters to identify soil quality degradation due to changed land use pattern in sweetpotato (*Ipomoea batatas* (L.) Lam) gardens of Highlands of Papua New Guinea. Soils with widely differing exchangeable and non-exchangeable K contents were successively extracted 569 h in 0.01 M $CaCl_2$ and K release data was fitted to four mathematical models: first order, power, parabolic diffusion and Elovich equations. Results showed two distinct parts in the K release curves and 58–80 % of total K were released to solution phase within 76 h (first 5 extractions) with 20–42 % K released in the later parts (after 76 h). Soils from older gardens which were subjected to intensive and prolonged land use showed significantly ($P < 0.05$) lower cumulative K release potential than the gardens which are recently brought to cultivation (new gardens). Among four equations, first order and power equations best described the K release pattern and the constant *b*, an index of K^+ release rates, ranged from 0.005–0.008 $mg\,kg^{-1}\,h^{-1}$ in first order model, and was between 0.14 and 0.83 $mg\,kg^{-1}\,h^{-1}$ in power model for the soils. In the non-volcanic soils, model constant *b* values were significantly ($P < 0.05$) higher than the volcanic soils thus indicative of vulnerability of volcanic soils to K deficiency. The food garden soils need management interventions either through improved fallow management or through mineral fertilizers plus animal manures to sustain productivity.

1 Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam) is the major staple food crop in highlands of Papua New Guinea (PNG) with production and consumption of tubers well over 1.5 million tonnes (Bourke, 2005). The vine tips of sweetpotato are also an integral part of human diet, besides being a feed in traditional pig husbandry. In PNG, much of the sweetpotato production is through subsistence agriculture with hardly any input of mineral fertilizers and little or no manure use. Traditionally, garden areas are cleared of shrubs and other vegetation and the slashed vegetation is burnt to give a nutrient rich ash (Bailey et al., 2008). The sweetpotato gardens could be old gardens (cultivated over many seasons and about to be fallowed) or new gardens (newly brought into cultivation). Over several years of continuous gardening and in the absence of any mineral nutrient inputs, fertility of old gardens generally decreases and farmers abandon such gardens for fallow. The population of the highlands region, however, has been increasing by $\sim 3\,\%$ each year and thus placing increasing pressure on the land resource to produce extra food for the growing populace as observed in other parts of the World (Abu Hammad and Tumeizi, 2012). Simultaneously, crop productivity appears to be declining and this decline has been attributed to a degradation of soil fertility linked to the progressive shortening of the fallow rejuvenation periods (Allen et al., 1995; Sem, 1996; Bourke, 2005; Walter et al., 2011). Pressure on land resources has increased dramatically because of the population growth; fallow periods between cropping cycles have been shortened from several decades to less than 1 year in the recent past. Such land use change induced decline in soil fertility and productivity have been reported from Africa, Mediterranean regions and Asia (Biro et al., 2013; Abu Hammad and Tumeizi, 2012; Liu et al., 2014).

Previous work conducted across four of the Highland provinces (Southern highlands, Eastern highlands, Simbu and Enga) established soil fertility status in relation to sweetpotato productivity and found that potassium (K) deficiency was the major nutrient-related cause for the poor crop productivity in almost a third of sweetpotato gardens, but that it was more of a problem in old gardens than in new gardens (Bailey et al., 2009; Ramakrishna et al., 2009; Walter et al., 2011). K requirement for the tuber crops such as sweetpotato is larger compared with other food crops. Sweetpotato crop yielding $12\,\mathrm{Mg\,ha^{-1}}$ tubers can mine ca. 100 kg K in storage roots and vines, and more than 375 kg K can be removed by sweetpotato yielding $50\,\mathrm{Mg\,ha^{-1}}$ (O'Sullivan et al., 1997). In the absence of any external K inputs crop production solely depends on native K supply potential of soils and their release rates to soil solution from non-exchangeable pools. Non exchangeable K from reserves makes an important contribution to plant

K supply (Mengel and Uhlenbecker, 1993). For optimal nutrition of crop, the replenishment of a K-depleted soil solution is affected predominately by the release of non-exchangeable K from clay minerals and organic matter. Under intensive cropping with tropical conditions of high rainfall and leaching, labile “K pool” may be rapidly depleted. How well it is replenished depends largely on the amount of K in non exchangeable pools and their release rates (Steffens and Sparks, 1997). As many well-weathered tropical soils have predominantly kaolinitic clay and low K reserves (Malavolta, 1985), it is expected that their solution K would be rapidly depleted, especially under intensive cropping. From a sustainability perspective, it is essential to ascertain if soil reserves alone are sufficiently large and sufficiently accessible to sustain sweetpotato production in the medium- to long-term (decades to centuries), in the absence of external inputs (fertilizers). Because plants use varying proportions of non-exchangeable K, measurement of exchangeable K (NH_4OAc-K) is not always a reliable measurement of plant availability or accessibility. Thus, more information is needed on the nature and rates of non-exchangeable K release in these soils. Potassium release kinetics has been traditionally used for this purpose and could be determined by using different extraction methods including organic acids, nitric acid and dilute salt solutions such as $CaCl_2$ (Lopez-Pineiro and Navarro, 1997). For long-term management of K under intensive or prolonged sweetpotato cropping, knowledge of the release potential and release rates of K from soil mineral pools is vital. Therefore, the present study was initiated with the objectives of (1) evaluating the potassium supplying powers of sweetpotato garden soils of highlands region by the potassium release kinetics approach and (2) to elucidate relationship between K supply potentials and rates of K release in these soils with the soil types, soil sampling depth and garden types.

2 Material and methods

2.1 Study location and sampling sites

A range of soil samples used by Walter et al. (2011) from four Highland provinces of PNG, with widely differing K fractions are selected for the study (Table 1). Sites for the present study were chosen with a range of available K status, that is, from optimum to very deficient, and with an equal number of old and new garden sites, situated on a range of soil types or parent materials of volcanic and non-volcanic origin. Volcanic soils chosen belonged to great soil groups, Hydrandepts and Andaquepts, in the Enga and Western highlands provinces. Those derived from non-volcanic parent material (e.g. Dystropepts, Eutropepts and/or Tropaqualfs) were dominant in Simbu and Eastern Highlands. Older gardens are those which are under continuous sweetpotato cultivation without any fallow periods while new garden refers to those gardens which are freshly brought in to cropping either after a fallow or native primary forest. Details of the site selection and soil sampling are provided in greater detail elsewhere (Walter et al., 2011). Briefly, at every garden site, soil were sampled from one or two planting stations (at least 10 m apart) from surface (0–10 cm) and subsurface (10–20 cm) using a trowel. The air-dried soil samples were sieved (< 2 mm) and then analyzed for total C by dry combustion, and for pH in a 1 : 5 soil : water extract. Water soluble K was extracted with de-ionized water (1 : 5 w/v) after shaking for 30 min on a mechanical shaker. Non-exchangeable K was estimated as the difference between boiling 1N HNO_3-K and 1N NH_4OAc- K (Walter et al., 2011).

2.2 Potassium release study

A sequential extraction of soil K reserves with 0.01 M $CaCl_2$ solution was conducted (Jalali, 2005). About 2 g of 2 mm-sieved soil sample was treated with 20 mL of $CaCl_2$ solution in a 50 mL centrifuge tube. The soil-suspension was equilibrated for periods ranging from 1 to 569 h at 25 °C. After addition of $CaCl_2$ solution, the soil suspension was shaken in a rotary shaker for 15 min (200 rpm) and later centrifuged at 4000 rpm. Potassium content in the supernatant solution was estimated by Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES) (Varian 700ES model). Sequential extractions were followed at 1, 4, 7, 21, 76, 165, 242, 333, 408 and 569 h. The K extracted over time was used to construct K release curves. The K-release curves have two distinct parts: the initial part (1–76 h) was used to compute the amount of K in edge position, and the later part (76–569 h) was used to compute the amount of K in internal positions.

2.3 Mathematical and statistical analysis

The K release data obtained from the analysis of potassium contents from the extracts were tested for the mathematical fit to different kinetic equations namely,

Power function equation: $\ln q = \ln a + b \ln t,$ (1)

Parabolic diffusion: $q = (a + b)t^{1/2}$ (2)

First-order reaction: $\ln(q_0 - q_t) = (a - b)t$ (3)

Elovich equation: $q = (a + b)\ln t$ (4)

Where, q_t is the cumulative potassium released (mg kg^{-1}) at time t (h), q_0 is the maximum cumulative K released (mg kg^{-1}) and a and b are constants. Four models were tested by the least square regression analysis to determine which equation describes the non exchangeable K release in a better manner. Standard error of estimate (SE) was computed as $\text{SE} = [(q - q^*)^2/(n-2)]^{1/2}$, where q and q^* represents the measured and calculated amounts of non-exchangeable K in soil at time t, respectively, and n is the number of data points evaluated. Samples were grouped into old and new garden soil samples, volcanic and non-volcanic soil samples and surface and sub-surface samples prior to statistical analysis. The K release data at 76 h and 569 h (representing K in edge positions and K in internal sites, respectively) and K release constants (*a* and *b*) were analysed by two sample t- test to reveal differences between means of two independent groups of samples. Statistical analysis was carried out with Statistixs 8 software for Windows.

3 Results and discussion

3.1 K status of soils

Soils selected for the study varied with respect to geological origin and past management practices (Table 1). Soils developed from volcanic deposits accounted for 8 samples and 17 soil samples were from non-volcanic origin. About 48 % samples were from old gardens and 52 % were from new gardens. Soils selected were moderate to strongly acidic with pH values ranging from 4.75 to 6.62. The total carbon contents varied between 1.55 % and 15.5 %. Two soil samples had surprisingly high total carbon contents of above 10 % which is not unusual for soils of PNG (Ruxton, 2003). NH_4OAc-K contents varied widely and ranged from 2.3 mg kg^{-1} to as high as 369 mg kg^{-1}. Non exchangeable K in most of the samples ranged from low- to medium-category (Srinivasarao et al., 2007; Walter et al., 2011). According to this categorization 40 % samples were “low” in exchangeable (or available) K, 40 % samples were “medium” and only 20 % samples were “high” in exchangeable K contents. About 76 % of the samples were low in non exchangeable K supply, while 20 % samples were medium and only 4 % samples were in high category.

3.2 K release pattern

The cumulative amounts of K released during successive extractions from some representative soils is presented in Fig. 1. Cumulative K release was greatest (1.53 g kg^{-1}) at 569 h of incubation in soil # 1; smallest amount of K was released (256 mg kg^{-1}) in soil # 15; thus samples showed wide variation in total K release. Among the samples, maximum amounts of K (58–80 % of total K) were released to solution phase within 76 h (first 5 extractions). Quantities ranging between 20–42 % were released in the later parts (after 76 h) of the study. K release greatly varied in the initial 4–5 extractions, later, they showed almost plateau up to last extraction. To visualize the variations in K release pattern with time, in different parent materials, soil depths and garden management types, K released up to 76 h and between 76 h and 569 h were separately subjected to a two sample t test. This was necessary as the K-release curves had two distinct parts: the initial part (1–76 h) corresponding to K in edge position and the later part (76–569 h) is representing the amount of K in internal positions. As in these samples 58–80 % of cumulative K released before 76 h, it can be inferred that, major chunk of the plant available K is present in edge positions. These soils may contain some illite and vermiculite minerals with surface, edge, and interlayer sites that hold K (Jalali, 2005).

The surface soils had significantly ($P < 0.05$) greater K; both at edge positions (76 h) and K at interlayer positions (569 h) than that of subsoils, an indicative of exhaustion of soil K in majority of the subsoils (Fig. 2). During garden plantings, the crop residues, manures, wood ash and other inputs are generally spread on the soil surface; later, covered with thin layer of soil to form mounds. Such practice probably leads to very little mixing of inputs and plant nutrients with the subsoil. Distinct absence of manure-soil mixing techniques, tillage and land preparation in PNG could also partly the reason for K depletion in subsoils. Traditionally, farmers perform shallow manual digging with digging sticks and spades. Besides, during fallow periods substantial subsoil nutrients are mined by fallow vegetation species and added to topsoil. For example, a fallow species *Piper aduncum* could add up to 377 kg K ha^{-1} through its root mass in to the top 15 cm soil. Besides, almost 300 kg K ha^{-1} could be added through the above-ground biomass (Hartemink, 2004), through slash and burn practiced in the cultivation cycle, thus increasing K status and consequently K release.

Mean cumulative K release in soils of volcanic and non-volcanic origin were significantly ($P < 0.05$) different at 76 h and 569 h (Fig. 3). The volcanic soils were poorer in cumulative releasable K compared to non-volcanic soils. Several of the volcanic soils are reported to have lower non exchangeable K and low K-fixing abilities mainly due to the predominance of minerals such as volcanic glass, feldspars, pyroxenes and amphiboles (Moss and Coulter, 1964; Zharikova and Golognaya, 2009) and such minerals show inherently lower K release potentials. The soils from older gardens had significantly ($P < 0.05$) lower quantities of K on edge (up to 76 h) and internal sites (76–569 h) compared to new garden soils (Fig. 4). Severe K depletion or exhaustion in older gardens due to continuous crop mining with very little additions of fertilizers and manures. The short-fallow periods do not provide ample opportunity for revitalization of soil fertility with respect to K. Continuous crop cultivation is known to exhaust exchangeable and non-exchangeable K reserves in the sugarcane fields in Fiji (Gawander et al., 2002), calcareous soils under sugar beet (Samadi et al., 2008) and sweetpotato gardens of PNG (Walter et al., 2011). Inevitable soil erosion followed by vegetation clearing and cropping are a potential causes of land productivity decline when land covers are changed (Leh et al., 2013; Ziadat and Taimeh, 2013).

3.3 Modelling potassium release

The K release data of some representative soils fitted to mathematical models in describing release mechanism are shown in Fig. 5. The data fitted to first order and parabolic diffusion models demonstrated two distinct parts representing two phases of K release which corroborates with Rubio and Gil-Sotres (1997) and Jalali (2005). The coefficient of determination (R^2) and standard error (SE) values showed that all equations could be fitted well to the observed K release rates (Table 2). However, power equation and first-order equations were the best of the kinetic equations to describe the K release pattern in 0.01 M $CaCl_2$. These two equations showed overall highest values of R^2 and lowest values of SE. The order of application of various kinetics models to describe K release data in 0.01 M $CaCl_2$ was power function > first order > parabolic diffusion > Elovich models. The constant *b* represents the slope and can be used as an index of ionic K release rates, ranged from 0.005–0.008 mg kg^{-1} h^{-1} in first order model. The constant *a* (the intercept value) ranged from 5.01–6.92 mg kg^{-1} in first order model, while the range was from 3.76 to 5.69 mg kg^{-1} in power model. These ranges were in the lower side than that observed in some Iranian soils (Jalali and Zarabi, 2006; Jalali, 2008). Successful description of K^+ release with power equation in soils (Hosseinpur et al., 2012) and individual soil size fractions (sand, silt and clay) have been reported by Najafi-Ghiri and Jaberi (2013). K release pattern was also successfully modeled through Elovich equation to discriminate between K fertilizer management zones in oil palm plantations of Milne Bay, PNG (Steven, 2010).

In non-volcanic soils, model constant *b* (in equations first order, parabolic diffusion and Elovich) values were significantly ($P < 0.05$) higher than the volcanic soils (Table 3). Interestingly, power equation was not able to distinguish between the soils types with regard to rate of K release. The values of constant *a* were also greater for the non-volcanic soils compared to volcanic soils in all four models in the study thus confirming greater K supply potential of non-volcanic soils. Volcanic ash soils in many sites of the Highlands of PNG were known to be high in non-crystalline aluminosilicate mineral (allophone/imogolite), hydroxy interlayered vermiculite and volcanic glass (Bleeker and Sageman, 1990; Rijkse and Trangmar, 1995). Soils with appreciable quantities of these minerals are likely to be inherently low in non-exchangeable K owing to the absence of interlayer spaces in the clay-sized mineral particles compared with those with a preponderance of mica type of minerals (Rubio and Gil-Sotres, 1997; Rezapour et al., 2009). The high non-exchangeable K status of non-volcanic soils may be an indication of the presence of comparable amounts of K-rich micaceous and other 2 : 1 minerals. Length of cropping (represented by old and new gardens) did not had any significant effect ($P > 0.05$) on the K release potential (constant *a*) or release rate (constant *b*). Yet, the older gardens had lower K release potential and K release rates than that of new gardens. Serious soil fertility degradation (regarding available K contents) could occur in certain soils due to inherently lower nutrient status or lower rates of nutrient release from resistant soil parent materials (Hartemink and Bridges, 1995). Irrespective of cropping system, soils degrade with respect to K to an extent of 0.018 cmol kg^{-1} year^{-1}

which could also due to soil degradation processes such as soil erosion and nutrient runoff besides the crop mining under the tropical conditions (Lal, 1996). New land uses trigger soil erosion and degradation processes during and after land abandonment (Cerda et al., 2010). Besides affecting physical properties, long-term intensive land use can affects biochemical and microbial properties of the soil (Balota et al., 2014). Land degradation processes are dominant in surface-soil which are exposed due to clearing of vegetation and store less soil moisture (Garcia-Orenes et al., 2009). Surface soils had the greater K release potential and consequently had higher K release rates when tested using four models. First order equation well differentiated both the K release constants between surface and subsoil, while parabolic diffusion model could only make a distinction on K release potential (constant *a*).

4 Conclusions

The study made use of K release kinetics approach to examine differences due to changes in land use pattern in highlands of PNG. Results showed that sweetpotato garden soils of study region are inferior in potentially releasable K and K release rates. The potential and rates of non-exchangeable K release varied greatly among the soil types, garden types and soil depth. The older gardens in volcanic soils were particularly inferior in K release potential and rate of K release. Due to continuous nutrient exploitation by the crops and fallow species, subsoils (10–20 cm) were markedly lower in K release parameters. Soil degradation processes such as vegetation loss and soil erosion due to intensive crop production resulted in loss of soil fertility. Poor K-kinetics parameters warrants application of mineral K fertilizers to compensate for mined nutrient K. Besides, improved fallow management practices needs to be explored to meet the increased nutrient requirements as an inevitable consequence of crop intensification.

Acknowledgements. Author expresses his gratitude to Research Committee, PNG University of Technology for the funding awarded towards soil analysis and to ACIAR project with PNG-NARI under which the soil samples were collected.

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Table 1. Soil management history of the sweetpotato gardens and physico-chemical properties of the soil samples used in the study.

Sample No	Soil Group	Soil Depth	Soil Type/ origin	Garden Type	pH	Total C (%)	NH_4OAcK (mg kg^{-1})	1 N HNO_3 K (mg kg^{-1})	Non exchangeable K (mg kg^{-1})
1	Tropohumult	Surface	Non Volcanic	New	6.09	6.82	323	396	73.0
2	Distropepts	Surface	Non Volcanic	Old	5.84	3.25	92.0	251	159
3	Hydrandept	Surface	Volcanic	Old	6.42	3.86	56.9	121	64.1
4	Tropoaqualf	Surface	Non Volcanic	New	6.46	2.33	88.8	493	404
5	Hydrandept	Surface	Volcanic	Old	6.13	3.82	68.1	124	55.9
6	Hydrandept	Surface	Non Volcanic	New	5.93	5.56	120	148	28.0
7	Hydrandept	Surface	Non Volcanic	Old	4.75	12.4	68.6	119	50.4
8	Tropoaqualf	Surface	Non Volcanic	Old	6.89	1.62	218	658	440
9	Hydrandept	Surface	Volcanic	Old	5.42	15.5	102	189	87.0
10	Tropoaqualf	Surface	Non Volcanic	New	6.29	4.18	166	419	253
11	Tropohumult	Sub-surface	Non Volcanic	New	5.96	6.93	9.46	177	168
12	Distropepts	Surface	Non Volcanic	Old	5.66	3.96	6.55	225	219
13	Hydrandept	Sub-surface	Volcanic	Old	5.41	4.27	6.53	216	210
14	Hydrandept	Sub-surface	Volcanic	Old	6.49	3.94	11.4	148	137
15	Hydrandept	Sub-surface	Volcanic	Old	5.70	4.70	12.6	142	129
16	Tropoaqualf	Sub-surface	Non Volcanic	New	6.36	2.55	5.12	642	637
17	Hydrandept	Sub-surface	Volcanic	New	6.62	2.93	16.8	333	316
18	Tropoaqualf	Sub-surface	Non Volcanic	Old	6.83	1.55	17.1	601	584
19	Hydrandept	Sub-surface	Volcanic	Old	5.61	16.6	4.18	127	123
20	Tropepts	Surface	Non Volcanic	Old	6.00	3.27	110	117	7.00
21	Aqualfs	Surface	Non Volcanic	New	5.30	5.72	369	701	332
22	Aquepts	Surface	Non Volcanic	Old	6.50	3.96	86.0	113	27.0
23	Andepts	Surface	Volcanic	New	5.40	5.79	215	318	103
24	Aquepts	Surface	Non Volcanic	Old	6.50	1.74	161	328	167
25	Aquepts	Surface	Non Volcanic	Old	5.80	2.58	168	217	49.0

Table 2. Descriptive statistics of model parameters (constant *a*; constant *b*; coefficient of determination, R^2; and standard error, SE) for the data fitted to different K release equations ($N = 25$).

Release models	Model parameters	Minimum	Maximum	Mean
First order	constant *a* ($\mathrm{mg\,kg^{-1}}$)	5.01	6.92	5.88
	constant *b* ($\mathrm{mg\,kg^{-1}\,h^{-1}}$)	−0.005	−0.008	−0.006
	R^2	0.956^{***}	0.991^{***}	0.978^{***}
	SE	0.04	0.11	0.068
Power	constant *a* ($\mathrm{mg\,kg^{-1}}$)	3.76	5.69	4.94
	constant *b* ($\mathrm{mg\,kg^{-1}\,h^{-1}}$)	0.14	0.83	0.26
	R^2	0.919^{***}	0.997^{***}	0.972^{***}
	SE	0.01	0.12	0.057
Parabolic diffusion	constant *a* ($\mathrm{mg\,kg^{-1}}$)	58.50	432.40	210.10
	constant *b* ($\mathrm{mg\,kg^{-1}\,h^{-1/2}}$)	8.23	52.24	20.99
	R^2	0.836^{***}	0.979^{***}	0.933^{***}
	SE	8.19	69.3	26.0
Elovich	constant *a* ($\mathrm{mg\,kg^{-1}}$)	15.6	257	122
	constant *b* ($\mathrm{mg\,kg^{-1}\,h^{-1}}$)	31.4	203	80.7
	R^2	0.953^{***}	0.999^{***}	0.981^{***}
	SE	2.86	44.1	16.1

*** Indicates $P < 0.001$.

Table 3. Comparison of means of model constants (*a* and *b*) in soils differing in garden type, soil type and soil depth.

		First order		Parabolic		Power		Elovich	
		a (mg kg^{-1})	*b* (mg kg^{-1} h^{-1})	*a* (mg kg^{-1})	*b* (mg kg^{-1} h$^{-1/2}$)	*a* (mg kg^{-1})	*b* (mg kg^{-1} h^{-1})	*a* (mg kg^{-1})	*b* (mg kg^{-1} h^{-1})
Garden type	New gardens (*N* = 17)	5.96	−0.007	22.7	245	5.12	0.22	145	88.4
	Old gardens (*N* = 8)	5.83	−0.006	20.0	191	4.84	0.21	108	76.4
	P value	0.638	0.151	0.597	0.249	0.263	0.397	0.258	0.536
Soil type	Volcanic soils (*N* = 9)	5.47	−0.006	12.6	116	4.38	0.24	64.0	47.9
	Non volcanic soils (*N* = 16)	6.11	−0.007	126	263	5.25	0.25	154	99.2
	P value	0.001	0.016	0.005	0.000	0.000	0.862	0.003	0.004
Soil depth	Surface soils (*N* = 9)	6.03	−0.007	24.3	238	5.06	0.26	136	93.2
	Subsoils (*N* = 16)	5.56	−0.006	14.1	151	4.67	0.22	91.4	54.2
	P value	0.025	0.024	0.041	0.066	0.124	0.455	0.181	0.040

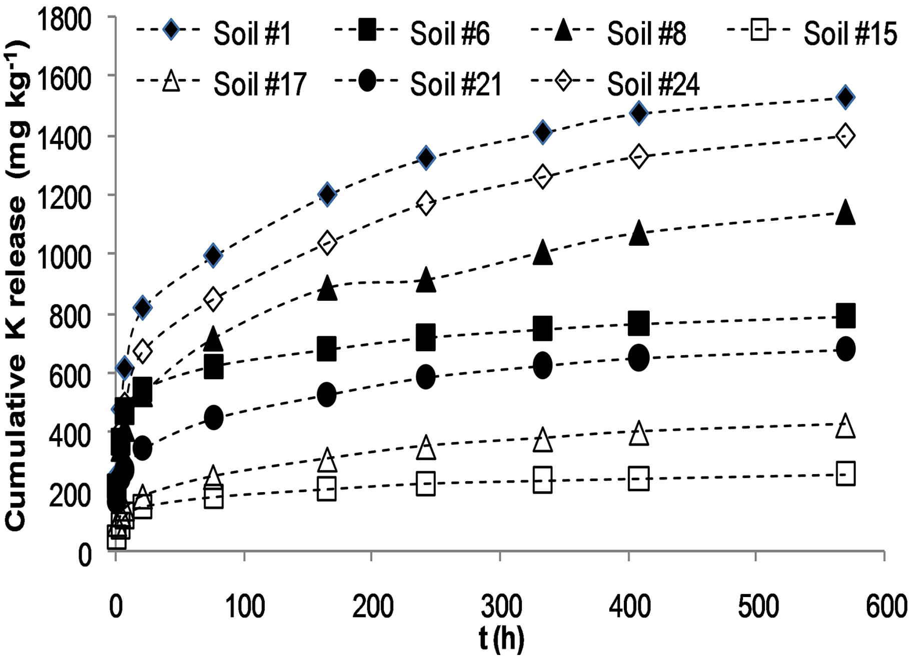

Figure 1. The cumulative K release pattern in some representative sweetpotato garden soils of PNG.

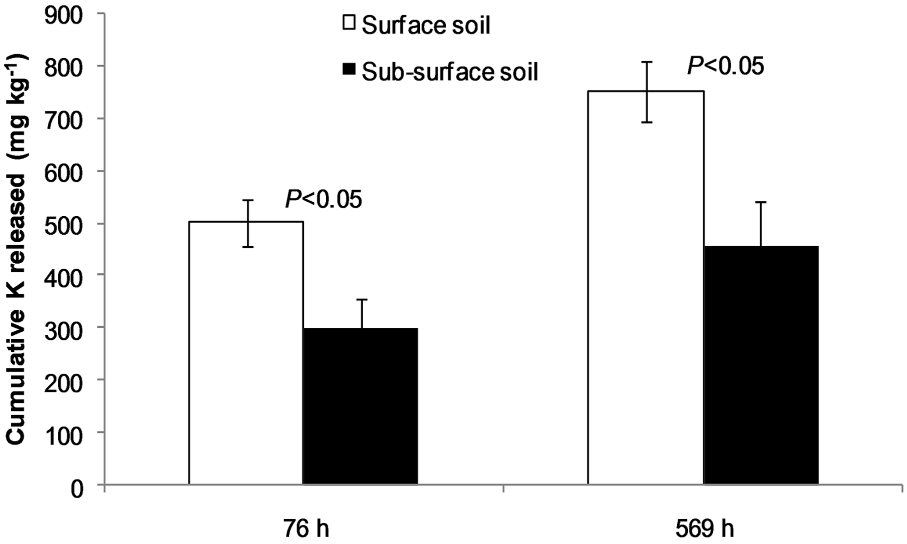

Figure 2. The cumulative K released at 76 h and 569 h in surface and subsoils. Error bars indicates standard error value for each group of soil.

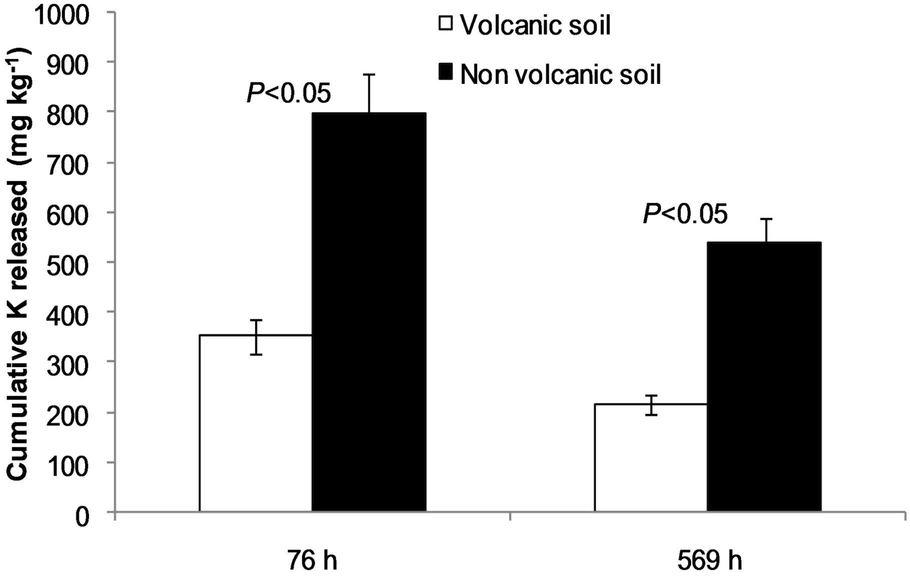

Figure 3. The cumulative K released at 76 h and 569 h in volcanic and non-volcanic soils cropped to sweetpotato. Error bars indicates standard error value for each group of soil.

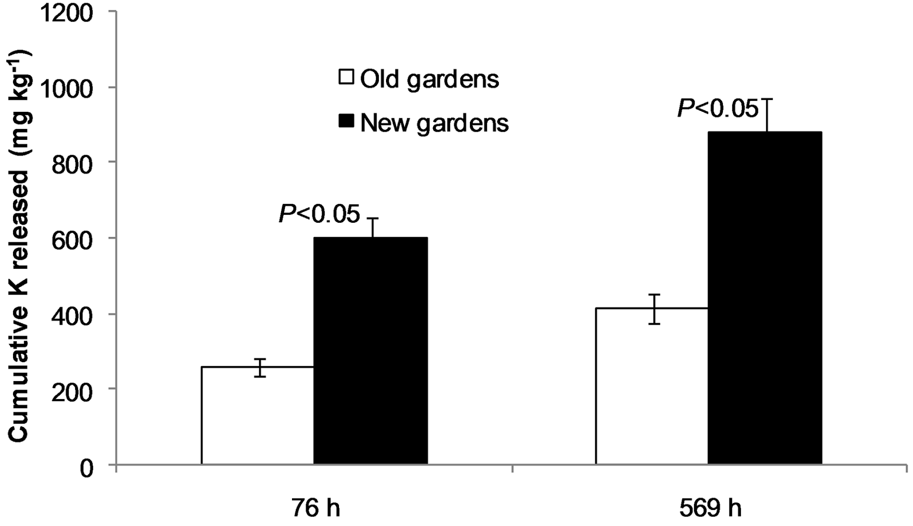

Figure 4. The cumulative K released at 76 h and 569 h in old garden and new garden soils cropped to sweetpotato. Error bars indicates standard error value for each group of soil.

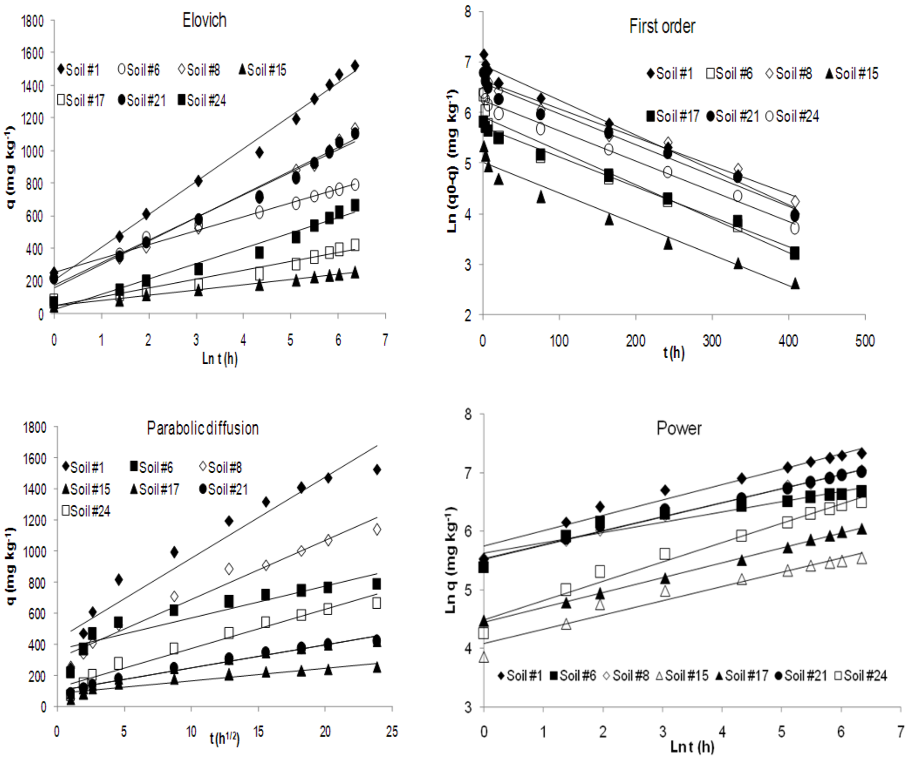

Figure 5. The K release data fitted to four kinetic models in some sweetpotato garden soils.