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Kinetics of potassium release in sweet potato cropped soils: a case study in the highlands of Papua New Guinea

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Abstract. The present study attempts to employ potassium (K) release parameters to identify soil-quality degradation due to changed land use patterns in sweet potato (*Ipomoea batatas* (L.) Lam) farms of the highlands of Papua New Guinea. Rapid population increase in the region increased pressure on the land to intensify subsistence production mainly by reducing fallow periods. Such continuous cropping practice coupled with lack of K fertilization practices could lead to a rapid loss of soil fertility and soil-resource degradation. The study aims to evaluate the effects of crop intensification on the K-release pattern and identify soil groups vulnerable to K depletion. Soils with widely differing exchangeable and non-exchangeable K contents were sequentially extracted for periods between 1 and 569 h in 0.01 M $CaCl_2$, and K-release data were 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 was released to solution phase within 76 h (first five extractions) with 20–42 % K released in the later parts (after 76 h). Soils from older farms that were subjected to intensive and prolonged land use showed significantly ($P < 0.05$) lower cumulative K-release potential than the farms recently brought to cultivation (new farms). Among the four equations, first-order and power equations best described the K-release pattern; the constant b, an index of K-release rates, ranged from 0.005 to 0.008 mg kg^{-1} h^{-1} in the first-order model and was between 0.14 and 0.83 mg kg^{-1} h^{-1} in the 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 indicating the vulnerability of volcanic soils to K deficiency. The volcanic soils cropped for several crop cycles need immediate management interventions either through improved fallow management or through mineral fertilizers plus animal manures to sustain productivity.

1 Introduction

Sweet potato (*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 sweet potato are also an integral part of the human diet besides being a feed in traditional pig husbandry. In PNG, much of the sweet potato production is through subsistence agriculture with hardly any input of mineral fertilizers and little or no manure use. Traditionally, cropping 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 sweet potato farms may be old farms (cultivated over many seasons and about to be fallowed) or new farms (newly brought into cultivation). Over several years of continuous farming and in the absence of any mineral nutrient inputs, fertility of old farms generally decreases and farmers abandon such farm areas for fallow. The population of the highlands region, however, has been increasing by ~ 3 % each year, thus placing increasing pressure on the land resources 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, which 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 decline in soil fertility and productivity induced by land use change has been reported in 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 potassium (K) deficiency as the major nutrient-related cause for the poor sweet potato productivity in almost a third of sweet potato farms (Bailey et al., 2009; Ramakrishna et al., 2009; Walter et al., 2011). These studies also reported that K deficiency was more of a problem in old farms (which have been cropped for several crop cycles) than in new farms (which are ready for cropping after fallow periods). Potassium requirement for the tuber crops such as sweet potatoes is larger than for other food crops. Sweet potato crops yielding 12 $Mg\,ha^{-1}$ tubers can mine ca. 100 kg K in storage roots and vines, and more than 375 kg K can be removed by sweet potatoes yielding 50 $Mg\,ha^{-1}$ (O'Sullivan et al., 1997). Negative K balances subsequent to several crop cycles have been reported globally. Depletion of K stocks in soil resources has been reported due to suboptimal application rates of K fertilizers and manures in India (Srinivasarao et al., 2013, 2014) and lack of fertilizer application in Africa (Hanao and Baanante, 1999). Changes in land use systems can also affect the status and form of K (Rezapour and Samadi, 2014).

In the absence of any external K inputs in PNG, crop production solely depends on native K supply potential of soils and their release rates to a 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 the 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. In the absence of fertilization, 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 K solution 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 sweet potato 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. The K-release kinetics studies with different extractants including organic acids, nitric acid and dilute salt solutions such as $CaCl_2$ could be used for generating such information (Lopez-Pineiro and Navarro, 1997). For long-term management of K under intensive or prolonged sweet potato 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 K-supplying powers of sweet potato garden soils of the highlands region by the K-release kinetics approach and (2) elucidating the 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 the four highland provinces (Western Highlands, Eastern Highlands, Simbu and Enga) of PNG, with widely differing K fractions were selected for the present study (Table 1). Sites were chosen with a range of available K statuses from optimum ($NH_4OAc\text{-K} > 125\,mg\,kg^{-1}$) to very deficient ($NH_4OAc\text{-K} < 50\,mg\,kg^{-1}$) and with an equal number of old and new farm sites, situated on a range of soil types or parent materials of volcanic and non-volcanic origin. The volcanic soils chosen in the study belonged to the great soil groups Hydrandepts and Endoaquepts in the Enga and Western Highlands provinces (Soil Survey Staff, 2014). Those derived from non-volcanic parent material (e.g., Dystropepts, Eutropepts and/or Tropaqualfs) were dominant in Simbu and Eastern Highlands. Eight soil samples were of volcanic and 17 of non-volcanic origin. In PNG, the majority of the soils belong to Inceptisols (> 50 % of the land area), Entisols (25 %) and Ultisols (14 %), while Alfisols, Histosols and Mollisols occupy smaller parcels of land area (Bourke and Harwood, 2009). Andisols occupy 5.5 % of the land area and yet are agriculturally quite significant because much of population cultivates these soils (Radcliffe and Kanua, 1998). Lithologically, PNG soils are derived from diverse parent material such as lava basalt, andesite, siliciclastic materials, siltstone, limestone, lithic sandstone, mudstone and shale, carbonaceous siltstone and sandstone, Triassic granodiorite, etc. (Davies, 2012).

In this study, older farms are those under continuous sweet potato cultivation without any fallow periods, while new gardens refer to those freshly brought in to cropping either after a fallow or native primary forest. The old farms sampled were under cropping for 3–4 years whilst most of the new farms were due for cropping after fallow for 1–5 years. Details of the site selection and soil sampling are provided in greater detail elsewhere (Walter et al., 2011). Briefly stated, at every farm site soil was sampled from one or two planting stations (at least 10 m apart) from surface (0–10 cm) and sub-

Table 1. Soil management history of the sweet potato farms and physico-chemical properties of the soil samples used in the study.

Sample no.	Province	Soil group	Soil depth	Soil type/origin	Farm type	pH	Total C (%)	NH_4OAc K ($mg\,kg^{-1}$)	1 N HNO_3 K ($mg\,kg^{-1}$)	Non-exchangeable K ($mg\,kg^{-1}$)
1	EHP	Tropohumult	Surface	Non-volcanic	New	6.09	6.82	323	396	73.0
2	EHP	Dystropepts	Surface	Non-volcanic	Old	5.84	3.25	92.0	251	159
3	Enga	Hydrandept	Surface	Volcanic	Old	6.42	3.86	56.9	121	64.1
4	EHP	Tropoaqualf	Surface	Non-volcanic	New	6.46	2.33	88.8	493	404
5	WHP	Hydrandept	Surface	Volcanic	Old	6.13	3.82	68.1	124	55.9
6	EHP	Hydrandept	Surface	Non-volcanic	New	5.93	5.56	120	148	28.0
7	EHP	Hydrandept	Surface	Non-volcanic	Old	4.75	12.4	68.6	119	50.4
8	WHP	Tropoaqualf	Surface	Non-volcanic	Old	6.89	1.62	218	658	440
9	Enga	Hydrandept	Surface	Volcanic	Old	5.42	15.5	102	189	87.0
10	EHP	Tropoaqualf	Surface	Non-volcanic	New	6.29	4.18	166	419	253
11	EHP	Tropohumult	Subsurface	Non-volcanic	New	5.96	6.93	9.46	177	168
12	EHP	Dystropepts	Surface	Non-volcanic	Old	5.66	3.96	6.55	225	219
13	Enga	Hydrandept	Subsurface	Volcanic	Old	5.41	4.27	6.53	216	210
14	WHP	Hydrandept	Subsurface	Volcanic	Old	6.49	3.94	11.4	148	137
15	Enga	Hydrandept	Subsurface	Volcanic	Old	5.70	4.70	12.6	142	129
16	WHP	Tropoaqualf	Subsurface	Non-volcanic	New	6.36	2.55	5.12	642	637
17	Simbu	Hydrandept	Subsurface	Volcanic	New	6.62	2.93	16.8	333	316
18	EHP	Tropoaqualf	Subsurface	Non-volcanic	Old	6.83	1.55	17.1	601	584
19	Simbu	Hydrandept	Subsurface	Volcanic	Old	5.61	16.6	4.18	127	123
20	EHP	Tropepts	Surface	Non-volcanic	Old	6.00	3.27	110	117	7.00
21	EHP	Aqualfs	Surface	Non-volcanic	New	5.30	5.72	369	701	332
22	EHP	Aquepts	Surface	Non-volcanic	Old	6.50	3.96	86.0	113	27.0
23	Simbu	Andepts	Surface	Volcanic	New	5.40	5.79	215	318	103
24	Simbu	Aquepts	Surface	Non-volcanic	Old	6.50	1.74	161	328	167
25	Simbu	Aquepts	Surface	Non-volcanic	Old	5.80	2.58	168	217	49.0

EHP – Eastern Highlands province, WHP – Western Highlands province.

surface (10–20 cm) using a trowel. The air-dried soil samples were sieved (< 2 mm) and then analyzed for total carbon (C) by the dry combustion method (Nelson and Sommers, 1996) 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 a 0.01 M $CaCl_2$ solution was conducted according to Jalali (2005). About 2 g of a 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 1 to 569 h at 25 °C. After the 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. K content in the supernatant solution was estimated by an inductively coupled plasma/optical emission spectrophotometer (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 latter 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 K contents from the extracts were tested for the mathematical fit to different kinetic equations:

$$\text{power-function equation:} \ln q = \ln a + b \ln t, \tag{1}$$

$$\text{parabolic diffusion:} q = (a + b) t^{1/2}, \tag{2}$$

$$\text{first-order reaction:} \ln(q_0 - q_t) = (a - b) t, \tag{3}$$

$$\text{Elovich equation:} q = (a + b) \ln t, \tag{4}$$

where q_t is the cumulative K 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 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 $SE = [(q - q^*)^2 / (n-2)]^{1/2}$, where q and q^* represent 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-farm soil samples, volcanic and non-volcanic soil samples and surface and subsurface samples prior to statistical analysis. The K-release data at 76 and 569 h (representing K in edge positions and K in internal sites, respectively) and K-release constants (a and b) were analyzed by two-sample t test to reveal differences between means of the two independent groups of

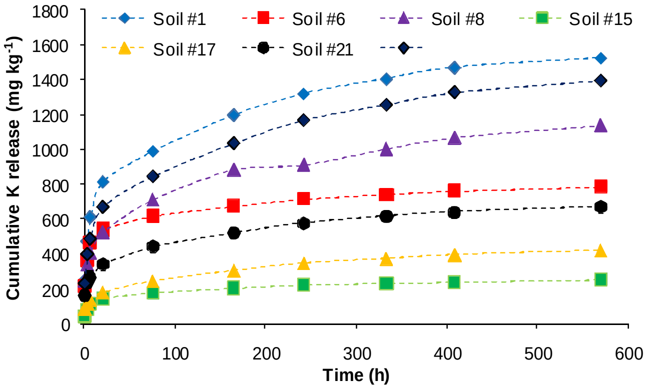

Figure 1. The cumulative K-release pattern in some representative sweet potato farm soils of PNG.

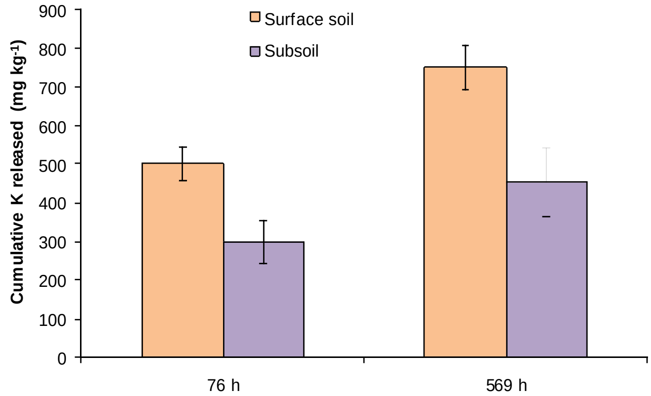

Figure 2. The cumulative K released at 76 and 569 h in surface and subsoils. At both study intervals, K release was significantly different ($P < 0.05$) between surface and subsoils. Error bars indicate standard errors for each group of soil.

samples. At $P < 0.05$, differences between groups were considered significantly different. Statistical analysis was carried out with Statistix 8 software for Windows.

3 Results and discussion

3.1 Potassium status of soils

Soils selected for this study varied with respect to geological origin and past management practices (Table 1). Soils selected were moderate to strongly acidic with pH values ranging from 4.75 to 6.62. The total C contents varied between 1.55 and 15.5 %. Two soil samples had surprisingly high total C contents of above 10 %, which is not unusual for soils of PNG (Ruxton, 2003). The NH_4OAc-K content 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 (Srinivasarao et al., 2007; Walter et al., 2011). About 76 % of the samples were "low" (non-exchangeable K contents <300 mg kg^{-1}) in the non-exchangeable K supply, while 20 % of samples were "medium" (300–600 mg kg^{-1}) and only 4 % of samples were in the "high" (> 600 mg kg^{-1}) category. About 40 % of samples were "low" in plant-available K (exchangeable K content below 50 mg kg^{-1}), 40 % of samples were "medium" (K content of 50–125 mg kg^{-1}) and only 20 % of samples were "high" (K content > 125 mg kg^{-1}) in exchangeable K content (Srinivasarao et al., 2007; Walter et al., 2011).

3.2 Potassium-release pattern

The cumulative amounts of K released during successive extractions from some representative soils are presented in Fig. 1. Cumulative K release was greatest (1.53 g kg^{-1}) at 569 h of incubation in soil #1 and smallest (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 the solution phase within 76 h (first five extractions). Quantities ranging between 20 and 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 almost plateaued. To visualize the variations in K-release patterns with time in different parent materials, soil depths and farm management types, K released up to 76 h and between 76 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) representing the amount of K in internal positions. Because in these samples 58–80 % of cumulative K released before 76 h, it can be inferred that a 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 cumulative K released both at edge positions (76 h) and K at interlayer positions (569 h) than that of subsoils, which is an indication of the exhaustion of soil K in the majority of the subsoils (Fig. 2). During crop plantings, the leftover residues, manures, wood ash and other inputs are generally spread on the soil surface and later covered with a thin layer of soil to form mounds. This 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 be 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 common fallow species *Piper aduncum* could add up to 377 kg K ha^{-1} through its root mass in the top 15 cm of soil (Hartemink, 2004). Besides, almost 300 kg K ha^{-1} could be added through the above-ground biomass by way of slash-

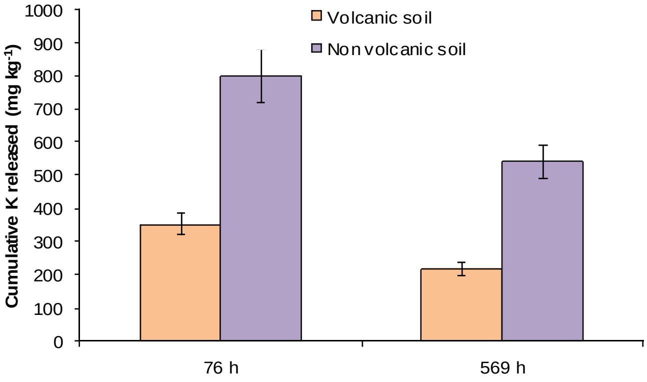

Figure 3. The cumulative K released at 76 and 569 h in volcanic and non-volcanic soils cropped in sweet potatoes. At both study intervals, K release was significantly different ($P < 0.05$) between volcanic and non-volcanic soils. Error bars indicate standard errors for each group of soil.

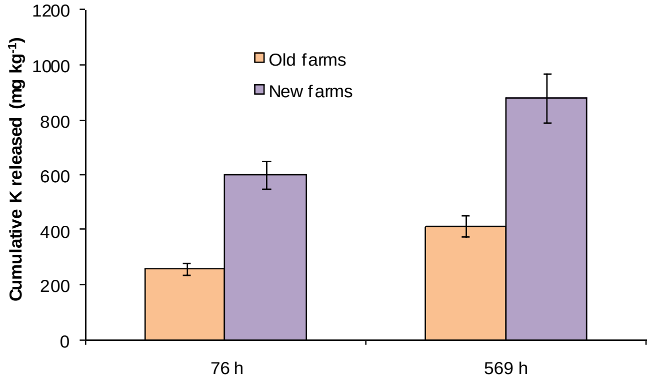

Figure 4. The cumulative K released at 76 and 569 h in old farms and new farms soils cropped in sweet potatoes. At both study intervals, K release was significantly different ($P < 0.05$) between old farms soils and new farms soils. Error bars indicate standard errors for each group of soil.

and-burn practices 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 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 noted in older farms may be due to continuous crop mining with very few additions of fertilizers and manures. Possibly, 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), the calcareous soils of sugar beet (Samadi et al., 2008) and the sweet potato gardens of PNG (Walter et al., 2011). Besides crop mining, an inevitable soil erosion followed by vegetation clearing and cropping are potential causes of land productivity decline when land covers are changed (Leh et al., 2013; Ziadat and Taimeh, 2013).

3.3 Modeling potassium release

The K-release data of some representative soils fitted to mathematical models in describing the release mechanism are shown in Fig. 5. The data fitted to first-order and parabolic diffusion models demonstrate 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 values showed that all equations could be fitted well to the observed K-release rates (Table 2). However, power 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 the 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 $CaCl_2$ is 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 to 0.008 mg kg^{-1} h^{-1} in the first-order model. The constant a (the intercept value) ranged from 5.01 to 6.92 mg kg^{-1} in the first-order model, while the range was from 3.76 to 5.69 mg kg^{-1} in the power model. These ranges were lower than that observed in some Iranian soils (Jalali and Zarabi, 2006; Jalali, 2008). A successful description of K release with power equation in soils (Hosseinpur et al., 2012) and individual soil size fractions (sand, silt and clay) has been reported by Najafi-Ghiri and Jaberi (2013). K-release pattern was also successfully modeled through the 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 first-order, parabolic diffusion and Elovich equations) values were significantly ($P < 0.05$) higher than the volcanic soils (Table 3). Interestingly, the power equation was not able to distinguish between the soils types with regard to the 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 a 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 Sage-

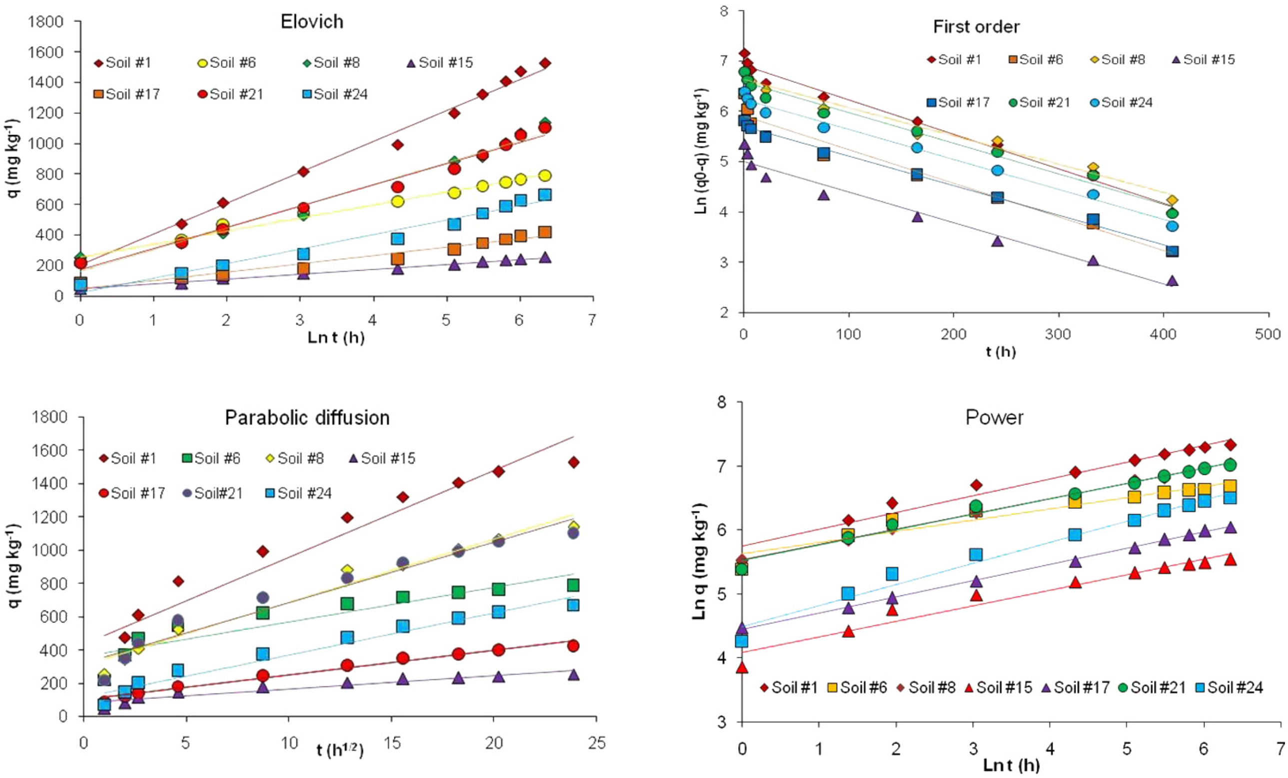

Figure 5. The K-release data fitted to four kinetic models in some sweet potato farm soils

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 (mg kg^{-1})	5.01	6.92	5.88
	constant b (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 (mg kg^{-1})	3.76	5.69	4.94
	constant b (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 (mg kg^{-1})	58.50	432.40	210.10
	constant b (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 (mg kg^{-1})	15.6	257	122
	constant b (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 farm 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})
Farm type	New farms ($N = 17$)	5.96	−0.007	22.7	245	5.12	0.22	145	88.4
	Old farms ($N = 8$)	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

man, 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 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 farms) did not have any significant effect ($P > 0.05$) on the K-release potential (constant a) or release rate (constant b). However, the older farms had lower K-release potential and K-release rates than new farms. 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, as well as crop mining under 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 affect biochemical and microbial properties of the soil (Balota et al., 2014). Land-degradation processes are dominant in surface soil that is exposed due to clearing of vegetation and thus stores 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. The first-order equation differentiated well the K-release constants between surface and subsoil, while the parabolic diffusion model could only make a distinction on K-release potential (constant a).

4 Conclusions

This study made use of the K-release kinetics approach to examine differences due to changes in land use pattern in the highlands of PNG. Results showed that sweet potato farm soils of the 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, farm types and soil depth. The older farms 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 a loss of soil fertility. Poor K-kinetics parameters warrant the application of mineral K fertilizers to compensate for mined nutrient K. Furthermore, improved fallow management practices need to be explored to meet the increased nutrient requirements as an inevitable consequence of crop intensification.

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