Distribution of forms of soil potassium in the Central highlands of Papua New Guinea and its implications to subsistence sweet potato (*Ipomoea batatas*) production

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Abstract
Sweet potato being the important stable food crop of Central highlands of Papua New Guinea, it is essential to ascertain the soil potassium reserves in the gardens. Traditionally, sweet potato is cultivated without addition of any mineral K inputs. Soils from two depths (0-10cm) and (10-20 cm) in two types of gardens (old and new gardens) were assessed for different fractions of soil potassium in volcanic and non volcanic soil groups. Water soluble K content constituted less than 1% of the total K. Exchangeable K content contributed to about 2.0- 3.1 % of the total K, while, non exchangeable K contents was in the range of 2.5-4.2 %. Both, exchangeable K and non exchangeable K were significantly lower, in volcanic soils and old gardens, compared to non volcanic soils and new gardens. Non exchangeable K content was low in more than 95% of the gardens. Especially, older gardens which are in volcanic soil groupings are more susceptible to the K depletion problem due to continuous sweet potato cultivation, possibly owing to their lower mineral K status. Such gardens should be managed either with allowing sufficient fallow period for regeneration of soil fertility or with suitable dose of mineral K fertilizers.

Key Words
Forms of potassium, exchangeable K, non exchangeable K, sweet potato gardens, potassium reserves, garden types.

Introduction
In the highlands of Papua New Guinea, sweet potato (*Ipomoea batatas L.)* is the major stable food crop (Bourke 1985). The population of the highlands region, however, has been increasing by 3% each year and placing increasing pressure on the land to produce extra food for the growing rural populace. Simultaneously, crop productivity appears to be declining in gardens and this decline has been attributed to a reduction in soil fertility linked to the progressive shortening of fallow rejuvenation periods (Allen *et al*. 1995; Sem 1996; Bourke 2005). Results from previous work conducted across four of the highlands provinces on soil and crop variables for old gardens (cultivated over many seasons) and new gardens (newly brought into cultivation) on soils of volcanic and non-volcanic origin suggests that K deficiency was the primary cause of poor crop production (Ramakrishna *et al.* 2009) in almost a third of sweet potato gardens, but was more of a problem in old gardens than in new (Bailey *et al.* 2009). Although these studies clearly identified K deficiency as the major cause of poor sweet potato production, further information on distribution and soil factors affecting K availability in sweet potato farming systems are not available. In particular, 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 K inputs (fertilisers) by simply relying on various improved fallow management practices.

Methods
Study sites and soil sampling
Forty sweet potato gardens, 15 in Eastern Highlands province, 4 in Simbu, 9 in Western Highlands and 12 in Enga, were selected for the purpose of K characterization. About half of the sites were identified on soils derived from volcanic materials while rest of them were developed from non- volcanic parent material. In each of the soil group, about half of the gardens were old (continuously cultivated gardens about to go into fallow), and about half were new gardens (recently reclaimed from fallow). At every site soil samples were collected at two depths; from surface (0-10 cm) and sub surface (10-20 cm). Further details on soil sampling protocols, processing of the soil for physicochemical analysis, and methods followed are given elsewhere (Ramakrishna *et al.* 2009).

Potassium characterization

Soil samples passing through 2mm mesh sieve was extracted for various K fractions. Water soluble K was extracted with deionized water (1: 5 w/v) after shaking for 30 minutes on a mechanical shaker and later contents were centrifuged to separate clear extract (Jackson 1973). Exchangeable K was determined by extracting the soil with neutral normal ammonium acetate, Non-exchangeable K was estimated as the difference between boiling 1N HNO_3 –K and neutral normal ammonium acetate K (De Turk et al 1943). Total K was estimated by the digestion of soil samples (ground to pass through 0.17 mm sieve) in HF-$HClO_4$-HNO_3 acid mixture (McKeague 1978). Lattice or mineral K contents were calculated from the difference between total K content of the sample and the boiling HNO_3- K. K contents in the extracts were measured using an ICP-OES.

Statistics

Soil physico-chemical properties, soil potassium in various forms and crop variables were subjected to analyses of variance (ANOVA) using a general linear model to simultaneously test the main and interactive effects of soil grouping (volcanic versus non volcanic), garden type (old versus new) in different soil depths (top and sub surface). Pearson's correlation coefficient was worked out between and/or among different forms of K. Genstat Discovery Edition was used for the statistical analysis.

Results

The effects of soil groupings (volcanic or non-volcanic) and garden type (old or new) on different K fractions are given in Table 1. Only main effects are presented as interactions between garden types, soil groupings and soil depths were non significant. Water soluble K content is the immediately plant available forms of K. It varied widely among soil groupings, ranging from 2.8 mg/kg to 38.6 mg/kg with significantly higher quantities occurring in non- volcanic soils. Water soluble K content constituted less than 1% of the total K. Exchangeable K content contributed to about 2.0- 3.1 % of the total K, while, non exchangeable K contents was in the range of 2.5- 4.2 %. Both, exchangeable K and non exchangeable K were significantly lower, in volcanic soils and old gardens, compared to non volcanic soils and new gardens (Table 1).

Exchangeable K which forms major pool of immediate plant- available K, was found to be significantly low ($P > 0.05$) in sweet potato gardens on volcanic soils and in older gardens. Potassium reserves (forms of K which are available slowly i.e., in medium to long- term) such as non exchangeable forms of K was found to be significantly low in volcanic soils and in old gardens (Table 1). Characterization of non exchangeable pools of K is quite important from the point of K nutrition in the long run. Non exchangeable K content was low in more than 95% of the top soil samples according to the criteria proposed for most of the field crops. According to categorization of non exchangeable K proposed by Srinivasarao et al (2007) soils with non exchangeable K contents less than 350 mg/kg are considered to be low in reserve K. Such soils should be managed with external application of potassium fertilizers. Old gardens showed lower non-exchangeable K contents than the new gardens despite the fact that they have greater contents of lattice and total K, indicating exhaustion of K reserves due to several cycles of sweet potato cultivation. In the new gardens which are due to go for planting, replenishment of K to non exchangeable pools could be expected. Due to the weathering action of soil minerals and release of K from residues and vegetation debris, K might be set free to soil solution which can inturn enter the inter lattice spaces. Non volcanic soils supporting sweet potato were in general rich in non exchangeable and lattice K reserves. Volcanic soils of PNG (Andosols) are reported to be dominated in hydroxy inter- layered vermiculite, imogolite/ allophane and volcanic glass (Bleeker and Sageman 1990; Rijkse and Trangmar 1995) while, non volcanic soils might have greater preponderance of illite, muscovite mica and K-feldspars (Sharpley 1989; Rubio and Gil- Sotres 1997; Rezapour et al.2009)

In the present study water soluble K content had no significant relation with exchangeable K and non exchangeable K (Table 2) which is in conformity to the some of the previous reports (Singh et al 1985; Sharma et al 2006). At any given point of time pool size of water soluble K is related to the pool size of exchangeable K. Exchangeable K which is the major form of plant available K, was highly significantly related to non exchangeable K and water soluble K in these soils. This indicates that there exists a dynamic equilibrium relationship between K in water soluble and K in inter-lattice spaces through exchangeable form of K. Depleted non exchangeable K could be replenished from the K in mineral fractions as indicated by strong positive correlation coefficient (r= 0.728***), how ever, this is relatively time consuming, slow process depending on various soil and climatic factors.

Conclusion

The present study describes the status of different forms of K in sweet potato growing gardens of central highlands of Papua New Guinea. Although total K content of these soils are in acceptable range to that reported in other parts of the world, water soluble, exchangeable and non exchangeable forms of K are considerably low in older gardens. Especially, older gardens which are in volcanic soil groupings are more susceptible to the K depletion problem due to continuous sweet potato cultivation, possibly owing to their lower mineral K status. Such gardens should be managed either with allowing sufficient fallow period for regeneration of soil fertility or with suitable dose of mineral K fertilizers.

Table 1. Effect of soil groupings, garden types and soil depths on the distribution of K in different forms (mg/kg soil) in the sweet potato gardens of Central Highlands provinces of Papua New Guinea.

	Water soluble K	Exchangeable K	Non exchangeable K	Lattice K	Total K
Soil groupings					
Volcanic	10.51	63.80	75.57	2481.3	2625.7
Non-volcanic	14.41	97.81	189.1	5818.6	6101.7
F test significance					
	*	*	***	***	***
Garden type					
Old gardens	12.74	64.28	111.8	4166.1	4390.8
New gardens	12.18	97.33	152.8	4133.9	4336.5
F test significance					
	ns	*	*	ns	ns
Soil depth					
Top soil	12.13	95.50	132.0	4722.7	4955.0
Sub surface soil	12.80	66.13	132.7	3522.7	3772.4
F test significance					
	ns	ns	ns	ns	ns

Statistical significance of differences between mean values: P > 0.05, ns; * P < 0.05; *** P < 0.001

Table 2. Pearson's correlation coefficients (r) between /and among different forms of K.

	Exchangeable K	Non exchangeable K	Lattice K	Total K
Water soluble K	0.254^{*}	0.250*	0.242^{ns}	0.121^{ns}
Exchangeable K		0.324**	0.223^{ns}	0.242^{ns}
Non exchangeable K			0.728***	0.746***
Lattice K				0.999***

P > 0.05, ns; * P < 0.05; *** P < 0.001

References

Allen BJ, Bourke RM, Hide RL (1995) The sustainability of Papua New Guinea agricultural systems: the conceptual background. *Global Environmental Change* **5**, 297-312

Bailey JS, Ramakrishna A, Kirchhof G (2008) An evaluation of nutritional constraints on sweet potato (*Ipomoea batatas*) production in the central highlands of Papua New Guinea. *Plant and Soil* **316**, 97 - 106

Bleeker P, Sageman R (1990) Surface charge characteristics and clay mineralogy of some variable charge soils in Papua New Guinea. *Australian Journal of Soil Research* **28**, 901- 917.

Bourke RM (1985). Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. *Papu a New Guinea Journal of Agriculture, Forestry and Fisheries* **33**, 89-108.

Bourke RM (2005) Sweet potato in Papua New Guinea: the plant and people. In 'The Sweet Potato in Oceania: a Reappraisal'. (Eds. C Ballard, P Brown, RM Bourke and T Harwood) pp. 15-24. (The University of Sydney, Australia)

De Turk EE, Wood LK, Bray RH (1943) Potassium fixation in corn belt soils. *Soil Science* **55**, 1 – 12 Jackson ML (1973). Soil chemical analysis. (Oxford and IBH, New Delhi:)

Mc Keague JA (1978). Manual on soil sampling and methods of analysis- 2nd Edition. (Canadian Society of Soil Science, Suite 907, 151 Slater St., Ottawa, Canada)

Ramakrishna A, Bailey JS, Kirchhof G (2009) A preliminary diagnosis and recommendation integrated system (DRIS) model for diagnosing the nutrient status of sweet potato (*Ipomoea batatas*). *Plant and Soil* **316**, 107-113.

Rezapour S, Jafarzadeh AA, Samadi A, Oustan S (2009) Impacts of clay mineralogy and physiographic units

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

on the distribution of potassium forms in calcareous soils in Iran. *Clay Minerals* **44**, 327-337.

Rijkse WC, Trangmar BB (1995) Soil- landscape models and soils of Eastern high lands, Papua New Guinea. *Australian Journal of Soil Research* **33**, 735- 755.

Rubio B, Gil-Sotres F (1997) Distribution of four major forms of potassium in soils of Galicia (N.W. Spain), *Communications in Soil Science and Plant Analysis* **28**, 1805- 1816.

Sem G (1996) Land -use change and population in Papua New Guinea. In 'Population, Land Management, and Environmental Change'. (Eds. JI Uitto, O Akiko), (The United Nations University, Tokyo, Japan)

Sharma BD, Mukhopadhyay SS, Sawhney JS (2006) Distribution of potassium fractions in relation to landforms in a Himalayan catena.. *Archives of Agronomy and Soil Science* **52**, 469- 476

Sharpley AN (1989) Relationship between soil potassium forms and mineralogy. *Soil Science Society of America Journal* **53**, 1023- 1028.

Singh YP, Singh, M, Singh R (1985) Forms of soil potassium in Western parts of Haryana. *Journal of Indian Society of Soil* Science **33**, 284-291.

Srinivasarao Ch, Vittal KPR, Tiwari KN, Gajbhiye PN, Kundu S (2007) Categorisation of soils based on potassium reserves and production systems: implications in K management. *Australian Journal of Soil Research* **45,** 438–447.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.