



THE DYNAMICS OF POTASSIUM (K) IN REPRESENTATIVE SOIL SERIES OF GHANA

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ABSTRACT

The immediate supply of K by soils to growing plants derives mainly from the K that is labile whereas the long term K nutrition of plants depends on the non-labile K. The dynamic relationship between these forms of K constitutes the dynamics of K in soils. Most Ghanaian farmers grow root and tuberous crops which have high K requirements. Knowledge of K dynamics in soils is therefore essential for K management to sustain crop production and management of agro-ecological environments in Ghana. Quantity-Intensity isotherms provide a better overview of K dynamics in soils. Therefore, Quantity/Intensity (Q/I) curves were used in this study to evaluate the dynamics of K in ten soil series representing the major agro-ecological zones of Ghana. K dynamics in the soils were found to be influenced by some soil properties. Significant correlations were found between soil properties and Q/I parameters; and among equilibrium solution parameters and Q/I parameters. There was no significant variation among the mean quantity ($\pm\Delta K$) values of the soils. The savannah soils had higher non-specific K, K-potential, and potential buffering capacity (PBC^K) than the forest soils; and the Akuse series had the highest values for these parameters. However, the forest soils had higher K-intensity. Therefore, the forest soils will require frequent and split K applications since they have lower capacity to maintain long-term supply of K. However, the savannah soils will require less frequent but higher K fertilization to satisfy the exchangeable pool and immediate plant nutrition requirement.

Keywords: potassium dynamics, potential buffering capacity, activity ratio, quantity-intensity isotherms, soil series of Ghana.

INTRODUCTION

Potassium (K) is very instrumental in plant nutrition and physiology. K has been found to activate over sixty (60) enzymes. It also promotes photosynthesis, controls stomata opening, improves the utilization of N, promotes the transport of assimilates and consequently increases crop yields. Also, K influences the microbial population in the rhizosphere and plays key roles in the nutrition and health of man and livestock (Lauchli and Pfluger, 1979; Romheld and Neumann, 2006). Based on the degree of availability to crops, soil K can be partitioned into four forms (Tisdale *et al.*, 1993; Pal *et al.*, 1999):

- a) Soil solution K (1-10 mg/kg) which is usually considered the primary source of K absorbed by plant root; and its concentration is a function of soil weathering, past cropping and K fertilization practices.
- b) Exchangeable K (40-600 mg/kg) which is held by the negative charges on soil clay and organic matter exchange sites.
- c) Non-exchangeable K (50-750 mg/kg) which is held as fixed ions in the lattice structure of clay minerals and that which forms part of the structures of minerals.
- d) Mineral K (5000-25000 mg/kg) which is found in K-bearing minerals in soils depending primarily on the source of the parent material.

The first two forms of soil K are considered to be *labile* and meet the immediate requirements of growing plants, while the last two are considered *non-labile* and are responsible for the long-term supply of K to plants (Askegaard *et al.*, 2004). The interrelationship between the

labile and non-labile K brings into view the dynamics of K in soils. The general aim of K-dynamics is to explain the movement of K in soil-solution-plant systems in relation to driving forces. Two key forces that drive K dynamics are gravitational force (which controls movements of water, solutes and particles in and on soils) and diffusion (which controls movements under concentration gradients) (Frissel, 1978). In the case of K-ions in soil-solution-plant systems, two situations create concentration gradients (Fardeau, 1996). One, when the concentration of solution K decreases due to plant uptake, a positive gradient is created between soil particles and roots through the soil solution; and two, when water-soluble K fertilizers are applied, a positive gradient is established between the K fertilizer molecules and soil particles and/or plant roots through the soil solution. These phenomena operate to achieve K balance between different forms and the rate of equilibration varies with soil.

In tropical soils, the total K content may be quite low because of the origin of the soils, high rainfall and high temperatures. Unlike N and P, which are immediately deficient in most tropical soils due to leaching and/or fixation, the need for K applications frequently arises only after a few years of cropping a virgin soil. In Ghana, there is usually lack of response to K fertilization when soils are brought into cultivation from the fallow state; but even in the more fertile forest soils K can be depleted during relatively short intensive cropping periods (Acquaye, 1973). Due to the paucity of information on the behaviour of K in agro-environments, some farmers in Ghana do not wish to apply K fertilizers even under continuous cropping while others blindly apply K fertilizers in quantities that



could render crop production unsustainable. More so, a significant number of Ghanaian farmers produce root and tuberous crops which are heavy K feeders. Consequently, knowledge of K dynamics in Ghanaian soils is critical to sustaining crop production, especially roots and tubers.

Quantity-intensity evaluation of K dynamics

Among the several laboratory methods used to assess the K supplying power of soils to plants, a fundamental approach based mainly on the labile pool of K was strongly advocated (Beckett, 1964). This approach uses the relationship between the quantity, Q (which indicates the K reserves of non-exchangeable and total elemental K) and the intensity factor, I (which indicates the immediately available K) to describe the buffering capacity, BC (which is a measure of the resistance to a change in the K-potential in soils). Labile soil K may be more reliably estimated by Q/I than by the measurement of exchangeable K with $1\ M\ NH_4OAc$. Higher values of labile K indicate a greater K release into soil solution, resulting in increased K availability. Fertilizer K will also increase labile K. Q/I measure the ability of soil to maintain the intensity of soil solution K and is proportional to the Cation Exchange Capacity (CEC). A high value signifies good K-supplying power (BC), while a low value suggests a need for K fertilization. There are two aspects of K buffering capacity (Adiscott and Talibudeen, 1969): buffering of the potential by the exchangeable pool and buffering of the exchangeable pool by non-exchangeable reserves. Figure-1 is a schematic representation of a typical Q/I isotherm.

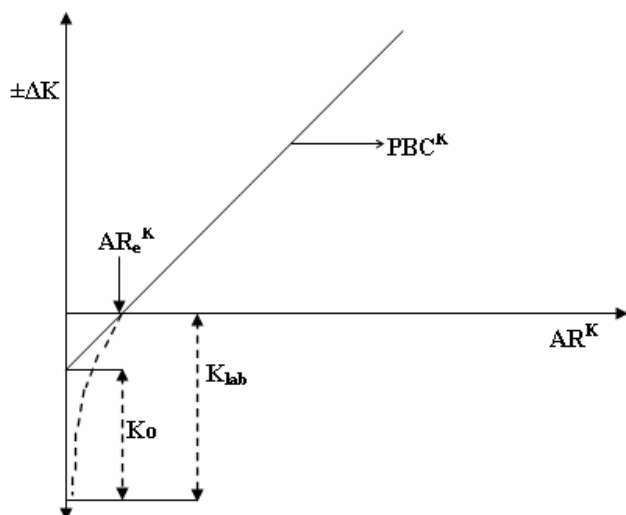


Figure-1. A typical Q/I plot.

From Figure-1, $\pm\Delta K$ represents the quantity (Q) axis and shows the magnitude of K gained or lost by the soil on reaching equilibrium. AR^K is the activity ratio of K and represents the intensity (I) axis. AR_e^K is the equilibrium activity ratio of K (the value of activity ratio when $\Delta K = 0$). The potential buffering capacity of K (PBC^K) is the slope of the linear portion of the Q/I plot.

K_{lab} represents labile K while K_o is a measure of non-specific edge sites.

Efficiency of K fertilizer application is affected by various factors (including soil type, soil original K-supplying capacity, crop varieties, organic matter and the levels of other nutrient elements) (Timsina and Connor 2001; Öborn *et al.*, 2005), which in turn shape the dynamic equilibrium existing among the various forms of soil K (Zeng and Brown, 2000). Knowledge of this dynamic relationship is critical for the efficient management of K in agro-ecosystems. Quantity-Intensity relationships provide insight into the K supplying power of soils. There is paucity of information on the dynamics of K in soils of the major agro-ecological zones of Ghana. The objective of this paper was, therefore, to assess the dynamics of potassium in ten representative soil series of Ghana through the use of Q/I isotherms.

MATERIALS AND METHODS

Top soils (0-22 cm) of ten soil series representing the major agro-ecological zones were obtained from Soil Research Institute (Kumasi, Ghana). It is possible that some of the soils have been cultivated in the past under the bush fallowing system but none of them had been fertilized in the recent past. The soil series used were: Mim series, Murugu series, Akroso series, Kokofu series, Bekwai series (representing the forest zone), Agawtaw series, Kakum series, Akuse series (representing the Coastal Savannah Zone), Pusiga series and Kpelesawgu series (representing the Northern Savannah Zone).

Selected physical and chemical properties of the soils were determined. pH was measured in $0.01\ M\ CaCl_2$ suspension with Beckman Expandomatic pH meter. Organic carbon was determined by the wet oxidation method of Walkley-Black (1934). CEC was determined by the $1\ N\ NH_4OAc$ extraction method; and exchange acidity by the $1\ N\ KCl$ extraction method. Finally, soil texture was determined by the hydrometer method (Bouyoucos, 1951).

Equilibration and Q/I parametric evaluation

A stock solution of K ($10\ mmole\ L^{-1}$) in $0.01\ M\ CaCl_2$ solution was prepared. Graded concentrations of K ($0.0, 0.1, 0.2, 0.4, 1.0, 2.0, 3.0,$ and $4.0\ mmole\ L^{-1}$ in $0.01\ M\ CaCl_2$) were prepared from the stock and used for the equilibration study. For each soil series, 4 g of soil was weighed into each of eight plastic tubes. 40 ml of each of the graded concentrations of K was added respectively to each of the plastic tubes. The suspensions were shaken with a horizontal shaker for half an hour and then allowed to equilibrate overnight. The suspensions were then filtered using Whatmann No. 44 filter papers, and the equilibrium solutions were analyzed for K by an EEL Flame Photometer; and for Ca and Mg by EDTA titration. The gain/loss of K ($\pm\Delta K$) in relation to the adsorbed phase was calculated by measuring the corresponding increase or decrease in the concentration of K in the equilibrium solution, compared to the original solution. The activity



ratio of K was also calculated using the formula: $AR^K = \gamma K / \sqrt{(\gamma Ca + \gamma Mg)}$.

A graph of $\pm\Delta K$ (on the y-axis) and the activity ratio of K (on the x-axis) were plotted. The equilibrium activity ratio was obtained by reading the value on the abscissa where $\pm\Delta K = 0$. Non-specific K was obtained by extrapolating the linear portion of the curve to the ordinate, by drawing a tangent from the point of abscissa where $\pm\Delta K = 0$. Potential Buffering Capacity of K (PBC^K) was represented by the slope of the linear portion of the curve. K-potential was determined by multiplying the non-specific K by the PBC^K . Free energy was calculated by using the equation reported by Beckett (1964):

$$\Delta Gr^o = -RT \times 2.303 \log [{}^aK+ / {}^a(Ca^{2+} + Mg^{2+})^{1/2}] e$$

T = temperature, e = equilibrium condition, R = universal gas constant.

RESULTS AND DISCUSSIONS

Soil properties

The results of the physico-chemical properties of the soils are presented in Table-1. It can be noticed that some of the properties vary appreciably.

Table-1. Selected physical and chemical properties of the soils.

Soil series	pH	Org. carbon (%)	Particle size (%)			Exchangeable bases (Cmolc kg ⁻¹)				Exchange acidity (Cmolc kg ⁻¹)	ECEC (Cmolc kg ⁻¹)
			Clay	Silt	Sand	Ca	Mg	K	Na		
Akroso	4.4	1.6	24.0	5.0	71.0	2.32	1.20	0.21	0.01	0.55	4.29
Pusiga	5.8	1.3	32.0	35.0	33.0	5.20	2.56	0.17	0.01	0.09	8.03
Bekwai	4.7	4.3	14.0	11.0	75.0	6.96	3.12	0.22	0.01	0.54	10.85
Kokofu	3.8	2.8	12.0	17.0	71.0	1.76	1.52	0.18	0.01	3.34	6.81
Murugu	5.3	1.3	18.0	13.0	69.0	2.00	1.04	0.14	0.01	0.07	3.26
Kakum	3.7	3.4	36.0	12.0	52.0	0.88	1.28	0.15	0.01	4.24	6.56
Kpelesawgu	5.9	1.3	37.0	16.0	37.0	3.60	2.40	0.16	0.01	0.09	6.26
Mim	6.2	1.3	11.0	4.0	85.0	3.76	2.40	0.16	0.01	0.10	6.43
Akuse	7.8	0.9	47.0	22.0	31.0	36.4	19.36	0.12	0.02	0.06	35.96
Agawtaw	4.8	2.8	47.0	28.0	25.0	2.72	2.24	0.12	0.01	0.09	5.18

The pH of the soils ranged from 3.7 (Kakum series) to 7.8 (Akuse series). This suggests that, with the exception of Akuse series which was slightly above neutral, the soil series were either acidic or slightly acidic, and the soils from the forest zones were very acidic. The values compare reasonably well with those reported by Acquaye (1973) for some Ghanaian soils. Organic carbon varied from 0.9% (Akuse series) to 4.3% (Bekwai series) while the exchangeable acidity ranged from 0.6 (Akuse series) to 4.24 (Kakum series) Cmolckg⁻¹. From this observation, it can be deduced that the low pH values of the forest soils were of organic sources, apart from high rainfall (Acquaye, 1973). Again, the forest soils had relatively higher exchangeable acidity and organic carbon contents, which can contribute significantly to their CEC. Perhaps, this is due to high litter fall and/or high rainfall leading to leaching of basic cations.

On particle size distribution, the forest soils had relatively high sand fraction, which aids leaching and the creation of acidic conditions. The savannah soils, on the other hand, had relatively high silt and clay fractions, suggesting their ability to retain K. The ECEC values varied from 3.26 (Murugu series) to 35.96 (Akuse series) Cmolckg⁻¹. Also, the Akuse series had the highest Ca²⁺ and Mg²⁺ contents, but together with the Agawtaw series, had the lowest K⁺ content. There is a positive correlation between pH and CEC and an inverse relation between pH and exchange acidity (Evangelou and Blevins, 1998). Consequently, considering the pH and the exchange acidity of Akuse series, the high CEC can be expected.

Parametric evaluation of equilibrium solution and Q/I plots

The mean values of the analytical results of the equilibrium solutions are presented in Table-2.

**Table-2.** Mean values of the analysis of the equilibrium solutions.

Soil series	[K ⁺] (x 10 ⁻³)	[Ca+Mg] (x 10 ⁻³)	I (x 10 ⁻³)	γK	γ (Ca+Mg)	^a K ⁺ (x 10 ⁻³)	^a (Ca ²⁺ + Mg ²⁺) (x 10 ⁻³)	AR _K	±ΔK
Akroso	6.6	1.5	3.3	0.9404	0.2586	6.2	4.0	0.3088	1.3310
Kokofu	6.1	1.4	3.1	0.9433	0.1452	5.7	2.0	0.5394	1.3314
Mim	6.4	1.5	3.2	0.9431	0.2600	5.9	4.0	0.2605	1.3312
Agawtaw	5.5	1.4	2.8	0.9485	0.2682	5.1	4.0	0.2781	1.3320
Pusiga	7.3	1.5	15.0	0.9219	0.2569	6.4	4.0	0.3206	1.3302
Kakum	9.4	1.6	4.7	0.9343	0.2472	8.6	4.0	0.4313	1.3281
Akuse	4.8	1.8	2.4	0.9525	0.2358	4.5	4.0	0.2231	1.3327
Murugu	11.0	1.8	5.5	0.9312	0.2377	10.0	4.0	0.4975	1.3265
Bekwai	11.1	1.9	5.6	0.9262	0.2295	10.1	4.0	0.5069	1.3264
Kpelesawgu	9.9	1.9	5.0	0.9352	0.2309	9.0	3.3	0.4489	1.3276

Key:

[K⁺] = K concentration (mol L⁻¹)

^aK⁺ = activity of K

γCa + Mg = activity coefficient of Ca + Mg

I = ionic strength

±ΔK = gain/loss of K (moles L⁻¹)

γK = activity coefficient of K

[Ca + Mg] = Ca + Mg concentration (mol L⁻¹)

^a(Ca²⁺ + Mg²⁺) = activity of Ca + Mg

AR^K = activity ratio of K

From Table-2, the mean K⁺ concentration ranged from 4.8 (Akuse series) to 11.1 (Bekwai series) mole L⁻¹. The Bekwai, Murugu, Kpelesawgu and Kakum series had high K⁺ concentrations and K activity. The Ca and Mg concentrations ranged from 1.4 to 1.9 moles L⁻¹, with Bekwai, Murugu, Akuse, Kpelesawgu and Kakum series having the highest, while Kokofu and Agawtaw series had the lowest. However, the activity coefficients for both K⁺ and Ca²⁺-Mg²⁺ did not vary significantly; and the same can be said of the activity of Ca-Mg, except for Kokofu series and Kpelesawgu series which had relatively lower values. Soil K⁺ concentration can be used to assess the K status of soils (Mustcher, 1995).

K intensity

The activity ratio of K (AR^K) in a solution in equilibrium with a soil provides a satisfactory estimate of the availability of K. This ratio is a measure of the intensity (I) of labile K in the soil and represents the K that is immediately available to crop roots. From Table-2, the mean values of AR^K ranged from 0.2231 (Akuse series) to 0.5394 (Kokofu series) moles L⁻¹. It was observed during the analysis of the equilibrium solutions that the AR^K values increased with increasing concentrations of the equilibrating solutions for all the soils, except for Kokofu and Akuse series. The range reported here is higher than those reported for some soils: 0.005-0.025 for British soils

(Beckett, 1964a, b), 0.001-0.019 for Canadian soils (Acquaye and Maclean, 1966), 0.001-0.054 for Irish soils (Herlihy and Moss, 1970), and 0.0005-0.009 for some Ghanaian soils (Acquaye, 1973). However, the values were lower than those reported by Abaslou and Abtahi (2008) for some Iranian soils. These differences could be attributed to differences in the concentration of equilibrating solutions, period of equilibration, the Ca and/or Mg contents, and probably due to the differences in the mineralogy of the soils.

K quantity

The quantity factor (Q) indicates the K reserves of non-exchangeable and total elemental K. The change in K quantity is represented by ±ΔK, which, according to Table-2, ranges from 1.3302 (Pusiga series) to 1.3327 (Akuse series). It was observed during the equilibration analysis that these values also increased with increasing concentrations of the equilibration solutions. Obviously, unlike the intensity values, the variation in the quantity values for the soils is not wide. However, the values are higher than those reported by Wild (1971) for Nigerian savannah soils, Nash (1971) for some Mississippi coastal plain soils, Acquaye and Maclean (1966) for Canadian soils, and Beckett (1964b) for British soils.

The parametric evaluations of the Q/I plots are presented in Table-3.

**Table-3.** Parametric evaluations from Q/I plots.

Soil series	AR ₀ K	-K _s	PBC ^K	K-potential	-ΔGr ^o
Akroso	0.05	-0.24	0.05	-0.012	-244.33
Kokofu	0.02	-0.08	0.04	-0.003	-128.35
Mim	0.08	-0.41	0.06	-0.025	-279.67
Agawtaw	0.11	-0.76	0.07	-0.053	-266.04
Pusiga	0.11	-0.64	0.07	-0.045	-236.48
Kakum	0.08	-0.28	0.05	-0.014	-174.86
Akuse	0.07	-0.76	0.10	-0.076	-311.85
Murugu	0.09	-0.55	0.04	-0.022	-145.15
Bekwai	0.12	-0.35	0.03	-0.011	-141.27
Kpelesawgu	0.05	-0.15	0.03	-0.005	-166.54

Key:

AR₀K = equilibrium activity ratio of K (mole L⁻¹)

-K_s = non-specific K [cmol (p+) kg⁻¹]

PBC^K = potential buffering capacity (cmolk⁻¹mole^{1/2}L^{1/2})

K-potential = [{cmol (p+) kg⁻¹ } mole^{-1/2}L^{1/2}]

ΔGr^o = free energy (cal.mole⁻¹)

In Table-3, the equilibrium activity ratio (AR₀K), derived from the Q/I plots, ranged from 0.02 (Kokofu series) to 0.12 (Bekwai series). The high organic carbon and high Ca²⁺ and Mg²⁺ contents of Bekwai series (Table-1) could account for this. According to Diest (1979), the adsorption by humus of divalent ions (Ca²⁺ and Mg²⁺) is much stronger than the adsorption of monovalent ions K⁺ and Na⁺. Even though Bekwai series has low pH and low clay content, some workers have shown that there is no correlation between AR₀K and pH or clay content (Acquaye, 1973; Diatta *et al.* 2006; Abaslou and Abtahi, 2008). In general, the forest soils have higher K intensity compared to the savannah soils, which implies a greater tendency to maintain K supply to crops. However, this can lead to rapid losses of K through leaching.

Non-specific K (-K_s) gives an indication of the K adsorbed to non-specific (planar) sites. From Table-3, -K_s values vary from -0.08 (Kokofu series) to -0.76 (Akuse and Agawtaw series). The results compare favourably with those of Acquaye (1973) for some Ghanaian soils and Graham and Fox (1971) for latosolic soils of Hawaii. The values were generally higher for the savannah soils as compared to the forest soils; and this could be due to the acidity of the forest soils (Graham and Fox, 1971). Less negative K_s values indicate adsorption of K to non-specific sites (Abaslou and Abtahi, 2008) and vice versa; and soils with higher values of -K_s in soils and high organic matter contents reflect the contribution of organic matter to the labile K after mineralization (Olk and Cassman, 1993). Usually in such soils, K-intensity is also high. In this study, the forest soils which had relatively higher organic carbon (and for that matter organic matter) content rather had less -K_s values, indicating preference for adsorption to non-specific sites in the forest soils. The

low K-intensity values of the forest soils indicate possible losses of K through leaching as these soils had higher sand fractions and lower clay fraction (Table-1). Also, it could be attributed to the generally low competitive ability of K for adsorption sites in acidic environments.

Potential buffering capacity (PBC^K)

This is a measure of the ability of soil to maintain the intensity of soil solution K and is proportional to CEC. In general, a high PBC^K value is indicative of greater capacity of the soil to maintain K concentration for longer periods, although it often leads to low K intensity. On the other hand, a soil with low PBC^K value requires frequent K fertilization as it fails to maintain a given supply of K for a considerable period of time.

The PBC^K values range from 0.03 (Bekwai and Kpelesawgu series) to 0.10 (Akuse series). These values are lower than those reported by Wild (1971), Beckett (1964b), Acquaye and Maclean (1966), Nash (1971), Graham and Fox (1971) but are within the range of values reported for Iranian soils by Abaslou and Abtahi (2008). The difference could be attributed to differences in past cropping and management practices. PBC^K is positively correlated with CEC (Wild, 1971; Abaslou and Abtahi, 2008). Therefore, the high PBC^K of the Akuse series can be attributed to its high CEC (Table-1) and a low activity coefficient of Ca-Mg (Table-2). Also, PBC^K values suggest the tendency of the soil to adsorb or release K. Consequently, the high PBC^K of the Akuse series could be attributed to its high clay and Ca-Mg content as compared to Bekwai and Kpelesawgu series (Table-1), suggesting a preference for Ca-Mg over K adsorption (Schneider, 1997).



Further, the K-potential is the product of K_s (K on non-specific planar sites) and PBC^K ; and it is also an essential indicator of K availability in soil solution. From Table-3, the Akuse series has the highest K-potential and K_s , confirming the lower preference for specific adsorption of K. This means, on equilibration, more K is released from non-specific planar sites, leading to a higher PBC^K (Abaslou and Abtahi, 2008). More so, high K^+ saturation can lower PBC^K (Munn and Mclean, 1975; Diatta *et al.*, 2006; Abaslou and Abtahi, 2008); and from Table-2, Akuse series has a lower K^+ while Bekwai, Kpelesawgu and Murugu have the highest K^+ concentrations.

The standard free energy of exchange expresses the potential of the soil for K replenishment. It is an index

of the amount of work that must be done to remove one mole of K^+ from the exchange complex or from the soil solution or to fix it. It depends extensively on soil properties such as clay content and CEC (Talibudeen, 1972). According to Table-3, the free energy of K exchange (or replenishment) ranged from -128.35 (Kokofu series) to -311.85 (Akuse series) cal.mole^{-1} . Thus, the Akuse series has the highest potential to replenish the solution K while Kokofu series has the lowest potential to replenish solution K. This is further supported by the low and high K-potential values of Kokofu series and Akuse series respectively (Table-3). In all, apart from the Akuse series, the rest of the soils have low potential to replenish soil solution K. A cross-correlation between the soil properties and the Q/I parameters are reported in Table-4.

Table-4. Cross-correlation between soil properties and Q/I parameters.

	AR_oK	K_s	PBC^K	K-potential	ΔGr°
pH	0.138	-0.568	0.624	-0.686(*)	-0.633(*)
Organic carbon	0.265	0.281	-0.434	0.379	0.509
Clay	0.164	-0.530	0.592	-0.651(*)	-0.489
Silt	0.331	-0.584	0.477	-0.601	-0.203
Sand	-0.207	0.541	-0.533	0.636(*)	0.369
Ca	0.007	-0.508	0.724(*)	-0.734(*)	-0.546
Mg	-0.025	-0.504	0.742(*)	-0.742(*)	-0.560
K	-0.098	0.622	-0.596	0.658(*)	0.422
Exch. acidity	-0.398	0.538	-0.252	0.435	0.464
ECEC	-0.013	-0.448	0.700(*)	-0.692(*)	-0.493

From Table-4, PBC^K shows strong positive correlations with Ca, Mg and ECEC. This can be explained by the competitive relationship existing between the activity of K and the activity ratio of Ca and Mg. That is, as the concentrations of Ca and Mg in solution increases, release of K into solution is retarded and adsorption of K is enhanced, resulting in higher PBC^K due to K reserves (Diatta *et al.*, 2006). The same explanation accounts for the relationship between ECEC and PBC^K . Thus, these positive, strong correlations are expected and indicate that, in calcareous soils, PBC^K is likely to be controlled more by the activity of Ca and Mg. The relationships are partly in agreement with the findings of Abaslou and Abtahi (2008) who found significant relationship between PBC^K and CEC, Ca and clay content of the soils. K-potential shows strong, negative relationships with pH, clay, Ca, Mg and ECEC but positive relationships with sand content and K. These relationships are transitive from the relations existing between these parameters and the components of K-potential (K_s and PBC^K) (Olk and Cassman, 1993) but it appears these relationships are influenced more by K_s than by PBC^K as can be seen from Table-4 that whether the relationship is positive or negative is likely to depend more on K_s . Finally, free energy shows a positive

relationship with only pH. Contrary to this, Talibudeen (1972) pointed out that free energy depends extensively on soil properties such as clay content and CEC. The finding in this study shows that less work needs to be done to remove of 1 mole of K^+ from solution as pH increases. No significant relationships were found among the rest of the soil properties and the Q/I parameters. Table-5 shows the cross-correlation among equilibrium solution parameters and Q/I parameters.

From Table-5, shows strong negative correlations with $[K^+]$, ${}^aK^+$, AR^K , and K_s . These relationships are expected since higher values of these equilibrium solution parameters contribute to high K-intensity which leads to lower PBC^K . However, no significant correlation exists between equilibrium activity ratio of K (AR_oK) and $\pm\Delta K$. K-potential shows a positive correlation with AR^K while K_s has positive relationship with AR_oK . Free energy has strong positive correlations with $[K^+]$, ${}^aK^+$, AR^K and K-potential but a negative correlation with PBC^K . This could suggest that lower concentrations of K in equilibrium solution are easily displaced than higher concentrations whereas much more work is required to release K from reserves as PBC^K decreases. Abaslou and Abtahi (2008) found a similar relationship between free energy and PBC^K . As expected, AR^K has strong positive correlations



with $[K^+]$ and ${}^aK^+$; and a highly significant, positive relation exist between $[K^+]$ and ${}^aK^+$. These relationships are significant and worthy of exploration to further

understand potassium dynamics in soils. Such an understanding can ease modeling and prediction of K behaviour in soils with given properties.

Table-5. Cross-correlation among equilibrium solution parameters and Q/I parameters.

	$[K^+]$	${}^aK^+$	AR^K	$\pm\Delta K$	AR_0K	K_s	PBC^K	K-potential	ΔGr°
$[K^+]$	1								
${}^aK^+$.999(**)	1							
AR^K	.716(*)	.725(*)	1						
$\pm\Delta K$	-.554	-.511	-.290	1					
AR_0K	.280	.253	-.197	-.471	1				
K_s	.332	.355	.629	.058	-.658(*)	1			
PBC^K	-.754(*)	-.768(**)	-.841(**)	.248	.175	-.770(**)	1		
K-potential	.578	.597	.752(*)	-.128	-.395	.921(**)	-.938(**)	1	
ΔGr°	.746(*)	.753(*)	.995(**)	-.342	-.172	.643(*)	-.869(**)	.782(**)	1

CONCLUSIONS

Quantity-Intensity (Q/I) isotherms provide a better overview of the dynamics of K in soils. The dynamics of K in Ghanaian soils has not received much research attention. In this paper, Q/I isotherms were used to evaluate the K dynamics in ten soil series representing the major agro-ecological zones of Ghana. The soils varied appreciably in their physico-chemical properties, particularly pH, organic carbon, particle size distribution and exchangeable acidity. Most of the soils were acidic to slightly acidic. Compared to the savannah soils, the forest soils had higher exchangeable acidity and organic carbon.

The forest soils had higher K intensity but lower K quantity as compared to the savannah soils (even though the K quantity values did not vary significantly). This shows that, unlike the forest soils, the savannah soils have a higher capacity to maintain or supply K for a longer period of time from the exchangeable pool. The practical implication is that the forest soils will have high K concentration in solution immediately after K fertilization. Nonetheless, this high K intensity can be rapidly depleted through leaching and/or plant uptake. Hence, split and frequent applications of K are essential soil management practices.

Further, the results confirm previous findings that higher K^+ intensity and activity lead to a lower PBC^K which is a better indicator of the ability of soil to maintain K intensity. Consequently, the forest soils which had higher K intensity had lower PBC^K as compared to the savannah soils, indicating that the forest soils will require frequent K fertilization. In all, considering the values of K-potential and the free energy of exchange, all the soils have a good capacity to supply K. However, the savannah soils have a higher capacity to replenish the solution K (Akuse series being the highest) and will therefore require less frequent but high K fertilization to simultaneously saturate the exchangeable pool and make K immediately available to plants in the right quantities.

Finally, significant correlations were found between soil physico-chemical properties and the Q/I parameters, as well as among equilibrating solution parameters and Q/I parameters. These relationships further illuminate the behaviour of K in soils and are worthy of exploration to aid modeling and prediction of K in soils with specific properties. Such an approach will ease the assessment of K dynamics in soils and make significant practical contribution to operational K management in agro-ecosystems.

REFERENCES

- Abaslou H. and Abtahi A. 2008. Potassium quantity-intensity parameters and its correlation with selected soil properties in some soils of Iran. *Journal of Applied Sciences*. 8(10): 1875-1882.
- Acquaye D.K. and Maclean A.J. 1966. Potassium potential of some selected soils. *Can. J. Soil Sci.* 46: 177-184.
- Acquaye D.K. 1973. Factors determining the K supplying power of soils in Ghana. In: *Proceedings of the 10th Colloq. of the Int. Potash Inst., Abidjan, Ivory Coast, Int. Potash Institute, Berne, Switzerland.* pp. 51-65.
- Adiscott T.M. and Talibudeen O. 1969. The buffering capacity of potassium reserves in soils. *Potash Rev.* 4: 45.
- Askegaard M., Eriksen J. and Olesen J.E. 2003. Exchangeable potassium and potassium balances in organic crop rotations on a coarse sand. *Soil Use Manage.* 19: 96-103.
- Barber S.A. 1985. Potassium availability at the soil-root interface and factors influencing potassium uptake. In: *Munson, R.D. (Ed): Potassium in agriculture, Madison, WI, USA: ASA-CSSA-SSSA.* pp. 309-324.



- Beckett P.H.T. 1964a. Studies on soil K: (a) Confirmation of the ratio law: measurement of K potential. *J. Soil Sci.* 15: 1-8.
- Beckett P.H.T. 1964b. Studies on soil K: (b) The Immediate Q/I relations of labile K in the soil. *J. Soil Sci.* 15: 9-23.
- Bouyoucos G.J. 1951. Recalibration of hydrometer method of mechanical analysis of soil. *Agron. J.* 43(2): 434-435.
- Diatta J. Z., Waclaw M. and Grezebisz W. 2006. Evaluation of potassium quantity-intensity parameters of selected Polish agricultural soils. *Agronomy.* 9: 4-15.
- Diest A.V. 1979. Factors affecting the availability of potassium in soils. *Potassium Research, Review and Trends.* pp. 29-32.
- Du Z., Zhou J., Wang H., Du C. and Chen X. 2006. Potassium movement and transformation in an acid soil as affected by phosphorus. *Soil Sci. Soc. Am. J.* 70: 2057-2064.
- Evangelou V.P. and Blevins R.L. 1998. Effect of long-term tillage systems and nitrogen addition on K quantity-intensity relationships. *Soil Sci. Soc. Am. J.* 52: 1047-1054.
- Fardeau J.C. 1996. Dynamics of phosphate in soils: an isotopic outlook. *Fertilizer Research.* 45(2): 91-100.
- Frissel M.J. 1978. Cycling of mineral nutrients in agricultural ecosystems. Elsevier B.V., Amsterdam, the Netherlands.
- Graham E.R. and Fox R.L. 1971. Tropical soil potassium as related to labile pool K and Ca exchange equilibria. *Soil Sci. III:* 318-322.
- Herlihy M. and Moss P. 1970. Availability of soil potassium to rye grass. *Ir. J. Agric. Res.* 9: 95-108.
- Lauchli A. and Pfluger R. 1979. Potassium transport through plant cell membranes and metabolic role of K in plants. *Potassium Research, Review and Trends*, Int. Potash Institute, Berne, Switzerland. p. 33.
- Munn D.A. and Mclean E.O. 1975. Soil potassium relationships as indicated by solution equilibration and plant uptake. *Soil Sci. Soc. Am. Proc.* 39(6): 1072-1076.
- Mustcher H. 1995. Measurement and assessment of soil potassium. *EPE Research Topics No. 4*, Int. Potash Institute, Switzerland. p. 102.
- Nash V.E. 1971. Potassium release characteristics of some soils of the Mississippi coastal plain as revealed by various extracting agents. *Soil Sci. III:* 313-317.
- Öborn I., Andrist-Rangel Y., Askegaard M., Grant C. A., Watson C. A., Edwards A.C. 2005. Critical aspects of potassium management in agricultural systems. *Soil Use Manage.* 21: 102-112.
- Olk D.C. and Cassman K.G. 1993. Reduction of potassium fixation by organic matter in vermiculitic soils. *Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture.* pp. 307-314.
- Pal Y., Wong M.T.F. and Gilkes R.J. 1999. The forms of potassium and potassium adsorption in some virgin soils from southwestern Australia. *Aust. J. Soil Res.* 37: 695-709.
- Romheld V. and Neumann G. 2006. The rhizosphere: contributions of the soil-root interface to sustainable soil systems. In: Swaminathan, M.S. (Ed.), *Biological approaches to sustainable soil systems*. Taylor and Francis, UK.
- Schneider A. 1997. Influence of soil solution Ca concentration on short term K release and fixation of a loamy soil. *Eur. J. Soil Sci.* 48(10): 513-522.
- Talibudeen O. 1972. Exchange of potassium in soils in relation to other cations. 9th Colloq. of the International Potash Institute, Berne, Switzerland. pp. 97-110.
- Timsina J. and Connor D. J. 2001. Productivity and management of rice-wheat cropping systems: issues and challenges. *Field Crops Res.* 69: 93-132.
- Tisdale S.L., Werner L., James D. B., Havlin L. J. 1993. *Soil Fertility and Fertilizers* (5th Ed.), Macmillan Publishing Co., NY. pp. 230-256.
- Walkley A. and Black I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.
- Zeng Q. and Brown P.H. 2000. Soil potassium mobility and uptake by corn under differential soil moisture regimes. *Plant Soil.* 221: 121-134.