



POTASSIUM QUANTITY INTENSITY RELATIONS AND UPTAKE BY *SORGHUM BICOLOR* (L) MOENCH, IN SOME SELECTED SOILS OF KWARA STATE, NIGERIA

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Received July 30 2005; accepted October 21 2006

ABSTRACT

The potassium (K) availability in some selected soils in Kwara State was studied by the use of parameters derived from the quantity/intensity relations and other K measurements. Exchangeable K in the soils ranged from 0.04 to 0.20 cmol/kg and difficultly exchangeable K from 0.13 to 0.32 cmol/kg. The Q/I isotherms determined in the soils before cropping were different from those obtained after cropping. Labile K (ΔK^0), Activity ratios (AR_K) and potential buffering capacity (PBC^K) all increased with the application of K, while Gapon coefficient (K_G) decreased. Exchangeable K and difficultly exchangeable K also increased in the soils after cropping. Potassium uptake by sorghum (*Sorghum bicolor*) was significantly correlated with exchangeable K, difficultly exchangeable K, labile K and Gapon coefficient as determined in the original soils before cropping. These parameters showed no relationship when they were calculated for the cropped soils. Conversely, activity ratio determined in the cropped soils was related to the total K uptake. Although both quantity and intensity factors were correlated with K uptake, the intensity factor was a better indicator of K availability than the quantity factors in these soils. The concentration of K in the plant tissues was a better K response parameter than the total uptake of K by the plant.

Key words: Potassium quantity/intensity relations; soil activity ratio of K; potential buffering capacity of K; Gapon coefficient; K uptake by sorghum in Kwara State soils.

INTRODUCTION

It is considered important to study potassium (K) to calcium plus magnesium (Ca+ Mg) equilibrium relationship for better understanding of the fertility status of agricultural soils. Although, several indices of K availability in soils have been proposed, the quantity and intensity factors have been widely studied and assessed. The activity ratio: $\frac{a_K}{\sqrt{aCa + aMg}}$ or AR_e^K in a solution in equilibrium with a soil, provides a

satisfactory measure of the availability, or the potential of potassium. AR_e^K is a measure of the intensity of labile K in the soil (Beckett, 1964b). The labile K is that fraction of the total soil K which takes part in exchange reaction over a short period of time. Different soils exhibiting the same value of AR_e^K may not possess the same capacity for maintaining AR_e^K while K is removed by plant roots. Therefore, to describe the K status of a soil, we must specify not only the current potential of K in the labile pool but also the form of the quantity – intensity relations (Q/I relations) or the way in which the potential depends upon the quantity of labile K present (Bansal et al, 2002).

A technique for studying the Q/I relations of K in the soil involves plotting AR_e^K for several K solution concentrations against change in exchangeable K (ΔK) with the resultant curve describing the K relations of the given soil (Barbayanis et.al, 1996). Udo and Olajide (1980) gave information on potassium quantity-intensity relations and uptake by sorghum plant in some ferruginous tropical soils. The soils studied were limited to the south west of Nigeria. Ekpote (1972b) predicted the uptake of potassium by millet and sorghum plants grown on selected soils of eastern Nigeria. Information on potassium in selected Kwara State soils is limited to their forms and release patterns (Odiase, 1988). It has been confirmed (Beckett, 1964b; Acquaye,

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1974, Bansal et al, 2002) that the availability of potassium in soil solution is more adequately determined by their quantity/intensity relations. There is no available data, of any form, on the quantity/intensity relations of agricultural soils of Kwara State, Nigeria.

The aims of this investigation were: to explore the forms of immediate Q/I relations for selected Kwara State soils, Nigeria; and to relate the uptake of K by sorghum plant to various K parameters including those determined from Q/I isotherms.

MATERIALS AND METHOD

Soils

The soils used were taken from four locations in Kwara State. The locations are Tsaragi in Edu Local Government area (LGA), Malete in Mooro LGA, Otteh in Asa LGA and Omu-Aran in Irepodun LGA (Fig 1). The soils from Malete in Mooro LGA, Otteh in Asa LGA and Omu-Aran in Irepodun LGA are derived from basement complex rocks which cover fourteen out of the sixteen local government areas of Kwara State. The soil from Tsaragi in Edu LGA represents the soils formed on Nupe sandstones found in two LGAs of the state.

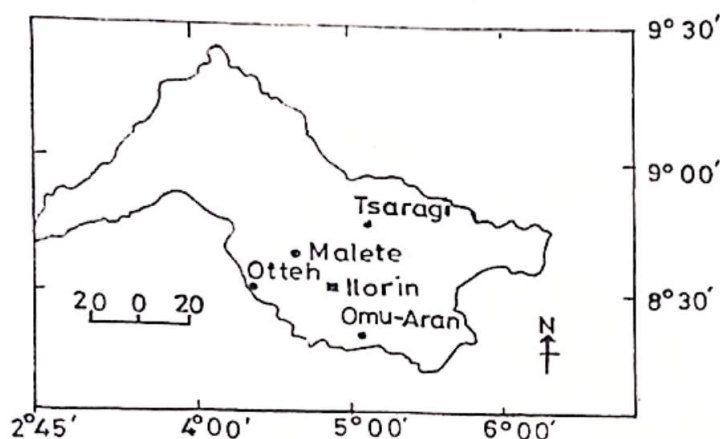


Figure 1: A map of Kwara State showing the sample locations

Omu-Aran and Otteh soils classify, each, as plinthic rhodustalf, Malete soil classifies as typic paleustalf while Tsaragi soil (Danggappe series) classifies as rhodic paleustult of the Soil Survey Staff (1994). The Danggappe soil series covers about 70 percent of the land areas of both Edu and Pategi LGAs (Ogunwale et al, 2002b).

The surface soils (0-15cm) were collected from twenty spots in each location and then bulked. The bulk samples were air-dried, ground and sieved to pass through 2mm sieve. Subsamples of the soils were analyzed for particle sizes by the hydrometer method (Buoyoucos, 1962); gravel content by wet sieving method; pH; organic carbon by wet oxidation method; total acidity and exchangeable cations (Udo and Ogunwale, 1986).

Greenhouse study

Soil samples weighing 0.75kg each were placed in 1000ml – capacity plastic bowls. Nutrient solutions containing 0.177g (NH₄)₂ HPO₄ were applied to the soil in each bowl at the rate of 100 and 110.7kg /ha of nitrogen (N) and phosphorus (P) respectively. The levels of K applied were 0, 15, 30, 45 and 60 kg/ha. These were applied a week after germination. Three replications were used for each soil. The contents of each bowl were watered to approximately field capacity daily. Five *Sorghum bicolor* seeds were sown in each bowl, but after germination thinned to two plants per bowl. The thinned plants were left inside each bowl. Harvesting of the sorghum tops were carried out after four weeks.

Analytical procedure

Two forms of K were determined in the soils. Exchangeable K was extracted with 1N NH₄OAc and difficultly exchangeable K with boiling HNO₃ (Udo and Ogunwale, 1978) both before and after the crop. The K potential was determined by equilibrating five gram samples, of the soil from each of the four locations studied, with 50ml aliquots of solutions of KCl (10⁻⁴ to 10⁻³) in CaCl₂ (2 to 7 x 10⁻³M) in 100ml shaking bottles. This gives the activity ratios: $\frac{aK}{\sqrt{aCa + aMg}}$ of these initial solutions

(Beckett, 1964b). In addition, 5g samples of soil were added to 50ml aliquots of solutions containing only CaCl₂ (2 to 7 x 10⁻³M). The bottles were allowed to stand overnight after shaking for one hour. The clear

supernatant was filtered through whatman No 42 filter paper. Samples of each filtrate (final solution) were analyzed for K (flame photometer) and Ca plus Mg (versenate titration).

For each suspension, the amount by which the soil had gained or lost K in achieving equilibrium with the final solution (ΔK_{ex} in cmol/kg of soil) was calculated from the difference between the concentration of the initial and final solutions. AR^k (the equilibrium activity ratio for each value of ΔK_{ex}) was calculated from the composition of the final solution

$$AR^k = \frac{aK}{(aC + aMg)^{1/2}} \quad (\text{Beckett, 1964b})$$

and the activity coefficient was derived from the second approximation of Debye-Hückel equation. In order to obtain Q/I isotherms, K values were plotted against those of AR^k .

The Gapon coefficients at $\Delta K = 0$ were calculated from the equation

$$K_G = \frac{K_{ex}(aC + aMg)^{1/2}}{aK(Ca + Mg)_{ex}} \quad (\text{Sposito, 1989})$$

and was used for estimating K availability.

The harvested sorghum tops and roots were dried in the oven at 60°C for 3 days, weighed and then milled into a fine powder. The ground plant tissues were wet digested with a mixture of HNO_3 and $HClO_4$ (Udo and Ogunwale, 1986) and K in the digests determined by flame photometry.

RESULTS AND DISCUSSION

Some properties of the soils used for the potted experiment are summarized in table 1. The soils are generally loamy sand to sandy loam in texture with Kaolinite being the dominant mineral (Ogunwale *et al.*, 2002). Their organic matter is low and this is partly attributed to annual burning, a phenomenon which reduces build up of organic matter.

Table 1: Some properties of the soils studied

Soil Variables	Ottech	Omu - Aran	Tsaragi	Malete
pH (1:1, H_2O)	6.30	4.0	6.30	5.7
Organic carbon (g/kg)	13.6	16.8	20.3	3.6
Gravel content (g/kg)	110.6	144.5	18.1	13.8
Clay (g/kg)	63.2	144.8	63.2	63.2
Silt (g/kg)	152.8	200.0	152.8	152.8
Sand (g/kg)	784.0	655.2	784.0	784.0
Total Acidity (cmol/Kg)	0.28	0.60	0.24	0.20
Exchangeable bases (cmol/Kg)				
Ca	4.00	2.00	2.40	4.00
Mg	2.00	2.40	5.20	3.20
K	0.47	0.14	0.04	0.04
Na	0.13	0.13	0.10	0.07
*ECEC	6.88	5.27	8.01	7.47

*Effective CEC = TEB + Total Acidity

The various forms of K content in the soils are shown in Table 2. Exchangeable K in the uncropped soils was high in two of the soils, and low in Tsaragi and Malete which had 0.04 cmol/kg each. The level of exchangeable K in Ottech and Omu-Aran soils would be regarded as being adequate for the immediate needs of plants (values being greater than 0.10 cmol/kg). The amount of K removed by boiling HNO_3 in the uncropped soils was also high, indicating the ability to extract an appreciable fraction of K in the difficultly exchangeable form. From this relatively high values of K obtained in this form, the soils will be regarded as having sufficient mobile K reserve for the needs of plants (Ekpette, 1972b). Both the exchangeable K levels and the K removed by hot HNO_3 were increased after cropping due to the addition of K fertilizer.

The divergent trend in respect of the non-exchangeable K distribution in different soils may be attributed to the variation in the fixation and release of K in soils as influenced by the cropping systems and fertilizer use pattern (Bansal *et al.*, 2002). Although the non-exchangeable K content variation in different soil groups and within a soil group maybe due to differences in clay content and amount of potassium bearing minerals like degraded-mica and vermiculites, soils dominated by kaolinitic clay mineral and iron oxides, like the red soil of Ottech are most likely to have less non-exchangeable K (Sekhon *et al.*, 1992). The fertilizer being used in Ottech soil has failed to build-up or maintain the reserve K status in it.

The activity ratios, AR_e^k , determined after cropping was appreciably greater than before cropping. Beckett (1964b) and Le Roux and Summer (1968) observed the same in their study of K quantity- intensity relationship

in soils. This was also the case in a study in Kano by Wild (1971) where the quantity and intensity parameters were found to increase with potassium fertilizers.

Table 2: Summary of soil potassium measurements

Location	Exchangeable K		HNO ₃ extractable K		Activity Ratio (AR _K)	
	Before crop	After crop	Before crop	After crop	Before crop	After crop
	cmol. kg ⁻¹		cmol. kg ⁻¹		(C/I) ^{1/2} × 10 ⁻⁵	
Otch	0.20	0.31	0.28	0.32	9.23	13.46
Omu-Aran	0.14	0.43	0.24	0.46	6.45	17.95
Tsaragi	0.04	0.33	0.15	0.33	6.54	12.31
Malete	0.04	0.32	0.13	0.33	5.19	17.44

Soil potassium properties derived from Q/I isotherms

The Q/I isotherms obtained through linear regression were used by Udo and Olajide (1980) to calculate labile K (-ΔK), potential buffering capacity and Gapon coefficient (K_G). These same properties for the four soils studies have been derived from linear regressions of potassium quantity against intensity factors (Table 3). The actual plot of potassium quantity against intensity factors gave isotherm that has a lower curved portion and a linear upper section (Fig 2) for each of the four uncropped soil samples. This asymptotic convergence of the Q/I relation to the Q-axis is one reason why determinations of exchangeable K are sometimes not precise. For the same reason, Beckett (1964b) suggested that it is convenient to measure changes in the amount of labile K in the soil, not against a zero state of the soil with no labile K, but relative to the amount held in the field soil.

TABLE 3: Potassium properties derived from Q/I isotherms

Location	Labile K (-ΔK ⁰)		Potential Buffering capacity (PBC ^K)		Gapon coefficient (K _G)	
	cmol Kg ⁻¹		cmol Kg ⁻¹ (C/I) ^{1/2}		(C/I) ^{1/2}	
	Before crop	After crop	Before crop	After crop	Before crop	After crop
Otch	0.09	0.09	392.20	642.90	11.99	2.11
Omu-Aran	0.07	0.19	652.32	1000.00	5.97	1.44
Tsaragi	0.05	0.13	875.53	962.96	7.17	1.11
Malete	0.05	0.19	73.60	1578.90	9.32	1.83

The partial regression between Potential Buffering Capacity (P.B.C.), percent clay and percent organic carbon is worth noting

$$P.B.C. = 14.2\% \text{ clay} - 413.0 \text{ organic C} + 1487.98$$

The partial regression coefficient between P.B.C. and % clay was positive ($r=0.20$), whereas that between P.B.C. and % organic carbon was negative ($r=-0.73$). This supports earlier evidence that organic matter retains K very weakly (Everlyn *et al* 2004).

The ratio P.B.C./% clay is a measure of the affinity of the clay for K. The average value of 0.30 found here is of the same order as values 0.41 and 0.51 for soil samples from Nigeria and Natal (Beckett, 1964b) and 0.32 for ferruginous tropical soils of Nigeria (Udo and Olajide, 1980). These values are lower than the average of 1.87 for eleven United Kingdom soils which probably contained hydrous mica. Moss (1967) found that kaolinitic soils in the West Indies retained K weakly. The evidence is therefore that the low buffer capacities for K_G are the results of low clay contents and of low affinities of the clays for K, probably because they are mainly kaolinitic. The low buffer capacity led to the important practical conclusion that the activity ratios, the concentrations of K in the soil solutions, and hence the availability of K to crops, will drop rapidly under cropping, except with the addition of fertilizers.

For the uncropped soils, AR_e^k , which represents the current K status of the soil were found to be significantly correlated with labile K ($r=0.93$) while the correlation coefficient with exchangeable K ($r=0.27$) was low. Bansal *et al.* (2002) reported that total labile K contents were generally higher than exchangeable K estimated by NH_4OAc , especially in black soils of India. However it followed the same trend as exchangeable

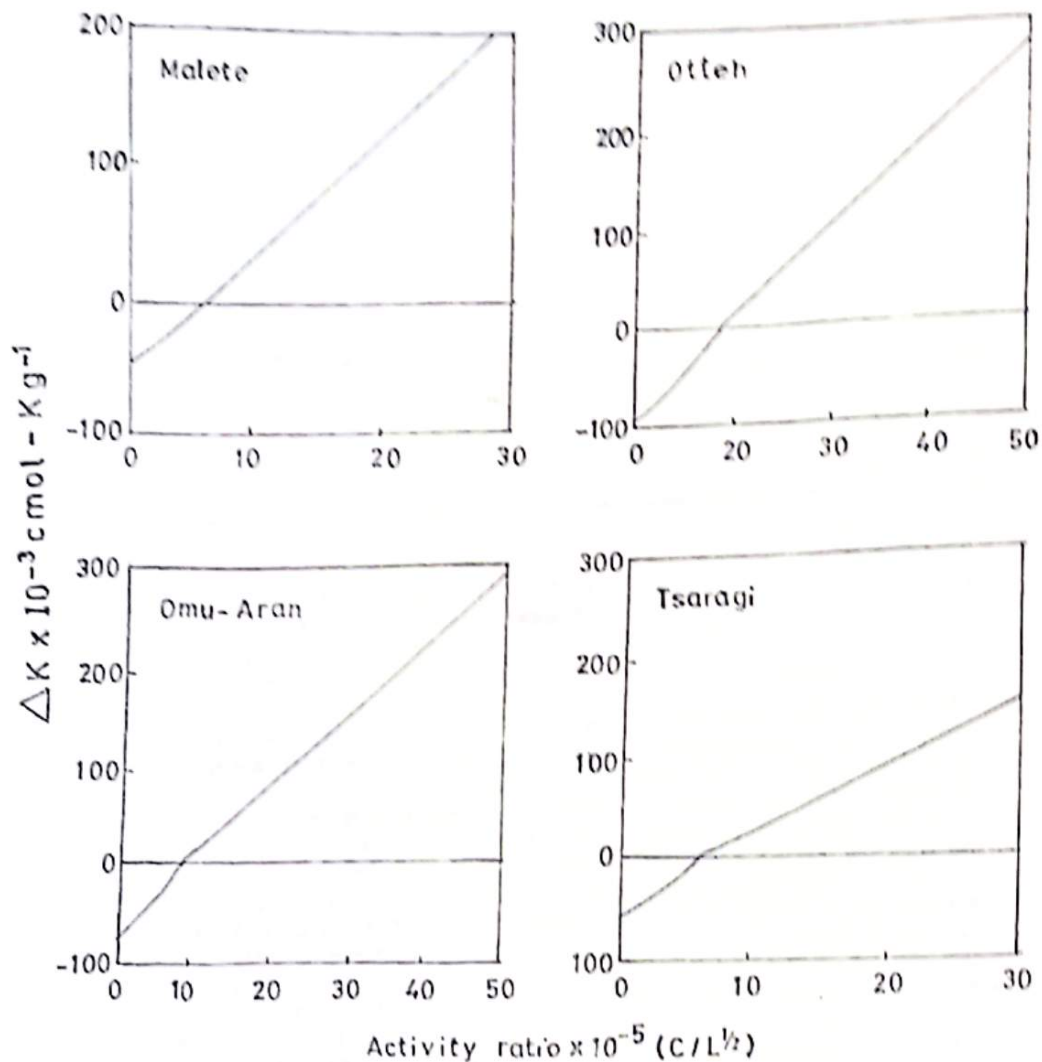


Figure 2: Potassium Q/I isotherms of the soils

K. Exchangeable K was found to be strongly related to labile K ($r=0.98$) which is enough measure of the potential of a soil to recharge available K from currently unavailable source.

The potential buffer capacity (PBC^k) which is a measure of the amount of labile K a soil can supply at a given energy level increased drastically after cropping while Gapon coefficient (K_G), and index of how tightly K is bound, decreased. This can be explained from the practical idea that K becomes smaller as K loading increases and then levels off. The high value of PBC^k is indicative of constant availability of K in the soil over a long period, probably as a result of continuous use of K supplying fertilizers (Bansal *et al.* 2002). It also indicates the ability of the soils to maintain the intensity of K in the soil solution, and is proportional to the CEC (Lee, 1973). Omu-Aran soil with a higher clay content of 144.8g/kg has the highest AR_e^k after cropping. This is because finer textured soil may release a greater portion of their total non-exchangeable K during the early period of K removal than coarse textured soils (Dhillon and Dhillon, 1990).

Relation of K measurements to plant uptake

Table 4 shows the mean of K in plant tissue (%) and total K uptake (g/pot). These values range from 0.16 to 0.24% and 2.52 to 6.42g/pot respectively.

Table 5 shows the correlation coefficients relating K response parameters of Sorghum tops in table 4 to the various soil K measurements taken before and after cropping. Out of the two parameters, the percent K gave better relationships than total uptake with the available K indices. The K uptake (% K in tissues) was strongly correlated with the quantity factors of exchangeable K, difficultly exchangeable K and labile K as well as with intensity factors of AR_e^k and K_G before cropping the soils.

Table 4: Potassium uptake by Sorghum tops

Location	Mean	Mean
	K in Plant tissue (%)	Total K uptake (g/pot)
Otch	0.24	6.15
Omu-Aran	0.18	2.52
Tsaragi	0.20	6.42
Malete	0.16	3.89

The soil K measurements gave no significant correlation except with difficultly exchangeable K ($r=0.90$). The PBC^k , whether computed before or after the crop, did not show any relationship with K uptake.

Table 5: Correlation Coefficients relating K uptake by Sorghum tops to various soils K measurements

K Measurement	%K	Before crop	%K	After crop
		Total uptake		Total uptake
Exchangeable K	0.72	-0.093	-0.38	-0.75
Difficulty ex. K	0.80	0.90	-0.23	-0.82
Labile K (ΔK^0)	0.84	0.19	-0.96	-0.88
AR_e^k	0.98	0.32	0.54	0.97
PBC^k	0.20	0.26	-0.36	-0.20
K_G	0.64	-	0.40	-

Most of the factors gave sensitive indications of K availability only in the original uncropped soil, but after the crop, only AR_e^k indicated some relationship with K uptake (Table 5). The failure of these parameters after crop to relate to K uptake is in accordance with the conclusion of Beckett (1964b) that the immediate Q/I relation will regulate the uptake of K only over a short period. Beckett (1964b) observed that the immediate Q/I will not indicate any simple relation when plants make use of the initially non-labile K released during the cropping period. The significant correlation with AR_e^k values obtained after cropping may therefore imply that the exchangeable K or mobile K reserve became a major source of K for the plants. This was affirmed from the correlation co-efficient between hot N HNO_3 and N NH_4OAc (pH 7.0) extractable K. This correlation coefficient value gave the K buffer power which is an index of the contribution of non-exchangeable K to plant availability (Nair, 1994). For the four soils, the correlation between hot N HNO_3 and N NH_4OAc (pH 7.0) gave a value with $r=0.86$ with the regression equation

$$Y = 0.0198 + 0.9256x.$$

The relative importance of the various factors can also be inferred from the correlation coefficients. Although the quantity factor, labile K and the K intensity represented by the activity ratio could both be used as an index of K availability, the latter showed a stronger relationship. The stronger indication of K availability of activity ratio to labile K can be explained by the findings of Beckett (1964b). In this finding, the ability of a soil to maintain the AR^k against depletion by plant roots is governed partly by the character of the pool of labile K and also by the rate of release of fixed K_s and by the diffusion and transport of K ions in the soil solution. Thus, in these soils where AR_e^k is a satisfactory measure of the intensity factor of soil K, the immediate Q/I relation adequately describes how the intensity of K in the soil depends upon the quantity of labile K present.

For diagnostic purposes, exchangeable K and AR_e^k are quick useful measurements for studying K availability in these soils and they seem to be superior to the corresponding factors derived from the Q/I measurements. For fertilizer recommendations, however, graded additions of K fertilizers are necessary to determine the appropriate levels of these factors for maximum yields.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. K.A. Adegbite of the Lower Niger River Basin Development Authority and staff in the Soil laboratory of the organization for permission to use the facilities in the laboratory.

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