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RELATIONSHIP BETWEEN MINIMUM EXCHANGEABLE POTASSIUM AND SOIL TAXONOMY [1]

KEYWORDS: Clay mineralogy, potassium recommendations, modeling.

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ABSTRACT

Potassium is an essential element for plant growth and its importance in agriculture has been well recognized. With continuous cropping of a soil, exchangeable K levels decrease to a minimum, steady-state level if no K is added. This minimum level is important to both modeling soil K cycling and fertilizer K recommendations, and it has been determined by field studies lasting from 2 to 10 years. Consequently, there is a need for estimation of minimum exchangeable K levels for a wide range of soil types from soil physical and chemical properties. A

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literature survey provided 19 studies where minimum exchangeable K had been measured and regression analysis was conducted on this data to determine predictive relationships. Minimum exchangeable K is closely related to soil clay content (r^2 from 0.66 to 0.99), however, regression constants varied from study to study. Improved correlations were obtained between minimum exchangeable K and clay content when all the soils (224, r^2=0.69) were divided into 3 groups according to the Fertility Capability Soil Classification (FCC) System and Soil Taxonomy (r^2 of 0.86, 0.82, and 0.68). Differences in regression constants between groups were consistent with changes in soil properties associated with K levels and exchangeability. This analysis provided relationships to estimate minimium exchangeable K level from soil clay content for a wide range of soil types, which should aid soil K modeling and fertilizer K recommendations.

INTRODUCTION

Potassium (K) is an essential element for plant growth and its importance in agriculture is well recognized [1-2]. Exchangeable K, as determined by NH_4OAc extraction, is generally used as a measure of plant available soil K, with several studies showing a close correlation between exchangeable K and plant uptake of K [3-8]. Other studies, however, have accounted for a greater amount of the variability in plant uptake of K when an estimate of nonexchangeable K was included with exchangeable K [9-14]

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In a study of K uptake by ryegrass by seven Ohio soils, Tabatabai and Hanway [14], observed that with no fertilizer or manure additions of K, the decrease in exchangable K after two years was equivalent to K uptake by ryegrass, for soils high in initial exchangeable K. For soils low in initial exchangeable K, however, plant uptake of K resulted in little or no change in exchangable K. Similarly, Williams and Jenny [15], found that when initial exchangeable soil K levels were low, plant uptake of K was greater than that initially exchangeable. Consequently, after exhaustion of the exchangeable K pool by plant uptake, a minimum steady-state level is established, if no K is added. At this level, plant uptake of K occurs by a shift of K from nonexchangeable to exchangeable pools, and the rate and amount of nonexchangeable soil K release will then be determined by crop uptake. Important in controlling this rate and amount of K release from the nonexchangeable form, is the type of K bearing mineral present in that soil. Soils that are high in kaolinite, quartz and other minerals contain little or no exchangeable K, while soils containing vermiculite feldspar and micas have large amounts of nonexchangeable K [16].

Knowledge of the minimum exchangeable K value is important from both soil K fertility and cycling standpoints, in terms of being able to estimate minimum K level which can supply a plant's needs without K stress and determining the point at which nonexchangeable K supplies exchangeable K for plant uptake.

Determination of the latter will be important in modeling the cycling of soil K.

Minimum exchangeable K has been determined in the past by exhaustive cropping of a soil [17-19]. This method can take several years, dependent upon exchangeable and nonexchangeable K levels in the soil. Consequently, a more rapid method of determining minimum exchangeable K for a given soil would benefit soil K fertility recommendations and modeling soil K cycling.

Our objective was to determine predictive relationships for minimum exchangeable K. Values of minimum exchangeable K, soil physical, and chemical properties were obtained from published studies and regression analyses conducted between values of soil properties and minimum exchangeable K.

RESULTS AND DISCUSSION

The published studies used in this analysis are shown in Table 1. Several studies have reported that minimum exchangeable K value is related to clay content of a soil [14, 19-22]. The regression equations for the relationship between minimum exchangeable K and clay content for these studies are presented in Table 1. Although minimum exchangeable K and clay content were closely related in all studies (r^2 from 0.66 to 0.99), the intercept value of the regression equation varied from study to study (-15.10 to 59.10). Slope values of the regression equation, however, were fairly similar (3.36 to 1.01, with a mean

Table 1. Relationship between minimum exchangeable K (mg kg^{-1}) and clay content (%).

Location	Soils	Land use	n	Regression Equation	r^2	Reference number
Puerto Rico	Inceptisols	Pangola grass	7	4.88 + 2.58 Clay	0.94	25
Puerto Rico	Ultisols & Oxisols	Pangola grass	15	6.67 + 1.10 Clay	0.85	27
Puerto Rico	Mollisols	Pangola grass	5	24.08 + 1.31 Clay	0.86	28
Ghana	Variable	Savanah & forest	14	59.10 + 0.75 Clay	0.66	29
New York	Variable	Clover	7	0.40 + 1.93 Clay	0.79	17
Alabama	Acidic kaolinitic	Cotton/vetch/corn	6	2.95 + 2.73 Clay	0.95	30
Delaware	Variable	Sudangrass & corn	29	-0.86 + 1.01 Clay	0.67	11
Arkansas	Low K saturation	Oats	7	-15.10 + 1.37 Clay	0.89	31
Ottowa	Variable	Oats & alfalfa	10	-10.93 + 3.01 Clay	0.92	21
Canada	Variable	Fallow & potatoes	11	-2.22 + 2.35 Clay	0.88	18
Ontario	Variable	Clover	3	1.15 + 3.36 Clay	0.99	19
Peru	Variable	Oats	16	14.87 + 1.51 Clay	0.89	7
Alabama	Variable	Sudangrass/turnips/ sunflowers/peanuts	8	2.92 + 1.16 Clay	0.87	32
Oregon	Variable	Clover	20	3.84 + 3.10 Clay	0.92	12
Iowa	Glacial till + Loess	Alfalfa	13	14.95 + 2.50 Clay	0.88	33
Scotland	Variable	Ryegrass	8	16.45 + 2.49 Clay	0.72	34
India	Alluvial	Maize/cowpea/wheat	10	16.25 + 2.41 Clay	0.88	35
Iowa	Variable	Ryegrass	7	-2.00 + 1.14 Clay	0.90	14
Nigeria	Sandy kaolinitic	Cashew plantation	17	-1.70 + 1.76 Clay	0.93	36

value of 1.98 ±0.81). When all these soils were combined, minimum exchangeable K was related to clay content, with an r^2 value of 0.69.

The soils in Table 1 were grouped according to the concept of the k modifier used in the Fertility Capability Soil Classification (FCC) System of Buol [23] and Sanchez et al. [24], using only the classification of the soils that could be made

from the data published by the authors. The FCC is a technical system for grouping soils according to the kinds of problems they present for agricultural management of soil physical and chemical properties, emphasizing quantifiable topsoil parameters as well as subsoil properties directly related to plant growth [24]. The system consists of three categorical levels; type (topsoil texture); substrata type (subsoil texture); and 15 modifiers, one of which is k. The k modifer (low soil K reserves) represents constraints on plant growth due to K stress when one of the following criteria is met: $<10\%$ weatherable minerals (ie. mica, feldspar, and ferromagnesium minerals) in the silt and sand fraction within 50 cm of the soil surface, (a property that is known if the soil has been properly classified in a siliceous family, Quartzi subgroup), exchangeable K <0.2 meq/100g or K $<2\%$ of the sum of the bases, if the bases <10 meq/100g (soil measurements often reported in fertility studies).

The soil groupings were;

Group 1 - Quartzipsamments; other sandy, siliceous, families (any soil order); and loamy, siliceous Arenic and Grossarenic Paleudults (S k, FCC group).

Group 2 - Other Paleudults; Paleustults; and Paleaquults (L k, SL k, LC k, and Ck, FCC groups).

Group 3 - other soils (those not receiving the FCC k modifier).

In general, Group 1 has a sandy particle size to a 50-cm depth or more and has 10% weatherable minerals, Group 2 has 10% weatherable minerals but has a finer texture in the surface 50 cm than Group 1, and Group 3 contains 10% weatherable minerals in most cases.

The mean, maximum and minimum values of clay content and minimum exchangeable K for each group of soils is presented in Table 2. Clay content of Group 3 was significantly greater (at the 1% level) than for Groups 1 and 2. Minimum exchangeable K of the soils in Groups 2 and 3 was significantly greater (at the 1% level) than Group 1 (Table 2). These differences are consistent with the criteria used above in obtaining these groups. Significant correlations (at the 0.1% level) were obtained between clay content and minimum exchangeable K for each soil group (Figs. 1, 2, and 3). 89%, 82%, and 68% of the variation in minimum exchangeable K was accounted for by clay content for Groups 1, 2 and 3, respectively, even though the data were obtained from several different studies. A greater variation in minimum exchangeable K was explained by clay content for each soil group except Group 3, which did not change, than for all the soils combined (r^2=0.69).

Although no consistent difference in regression slope value was apparent between soil groups, the intercept increased for Groups 1 (-1.297), 2 (4.432), and 3 (20.032). The regression intercept in Figures 1, 2 and 3 is the minimum exchangeable K

Table 2. Mean, maximum, and minimum clay content and minimum exchangeable K for the three soil groups.

Property		Soil group		
		1 (n=55)	2 (n=66)	3 (n=102)
Clay content, %	Mean +	11 a	18 a	28 b
	Maximum	27	50	70
	Minimum	5	4	5
Minimum exchangeable K, mg kg^{-1}	Mean +	18 a	51 b	58 b
	Maximum	49	119	138
	Minimum	5	10	21

+ Means across soil groups followed by the same letter are not significantly different at the 1% level, as determined by an unpaired t test.

value at zero clay content and is thus, an indication of the K supplying power of the non-clay components for each group of soils. The increase in intercept from Group 1 to 3 is consistent with the criteria used to group the soils. Such that in Group 1, the major proportion of exchangeable K is associated with the clay fraction. For Groups 2 and 3, there is apparently an increase in the amount of silt-sized particles containing weatherable minerals. This increase in intercept value and close correlation between clay and minimum exchangeable K (Figs. 1, 2, and 3), therefore, justifies the soil grouping and criteria

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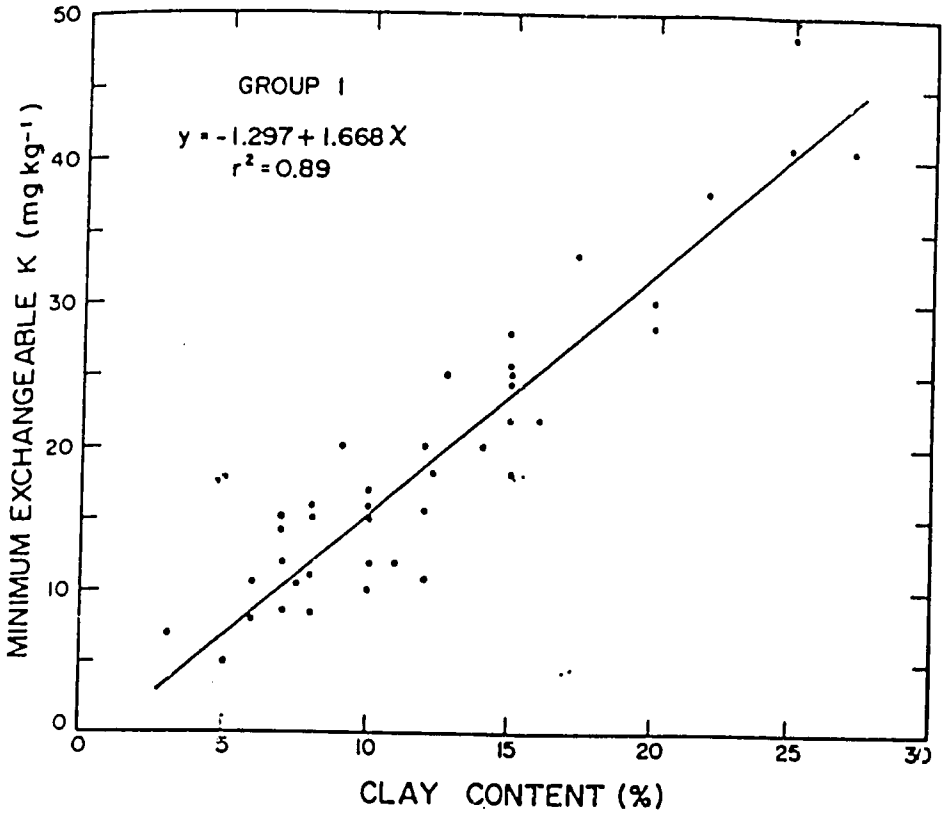

Figure 1. Relationship between clay content and minimum exchangeable K for the 55 Group 1 soils.

used above, especially considering the wide range of soil types and experimental studies used in the analysis.

It is apparent, therefore, that although different regression equations were obtained between clay and minimum exchangeable K for the different studies (Table 1), the relationship was similar for soils of similar taxonomy and soil

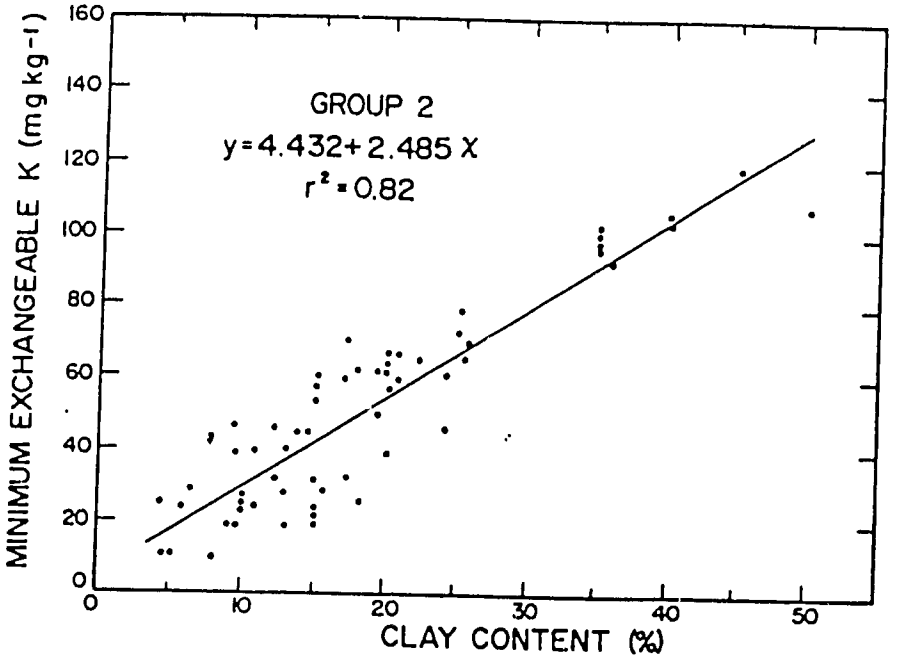

Figure 2. Relationship between clay content and minimum exchangeable K for the 66 Group 2 soils.

physical and chemical properties. Consequently, the FCC System can be used to better define the relationship between soil properties and fertility measurements which are a function of Soil Taxonomy [25]. As a result, the minimum exchangeable K value of a given soil can be estimated from clay content for properly classified soils of widely differing properties and geographic location. These relationships will have use in modeling the cycling of soil K, in determining the level at which the movement of K from nonexchangeable to exchangeable K pools occurs to supply plant available K. In addition, prediction of minimum

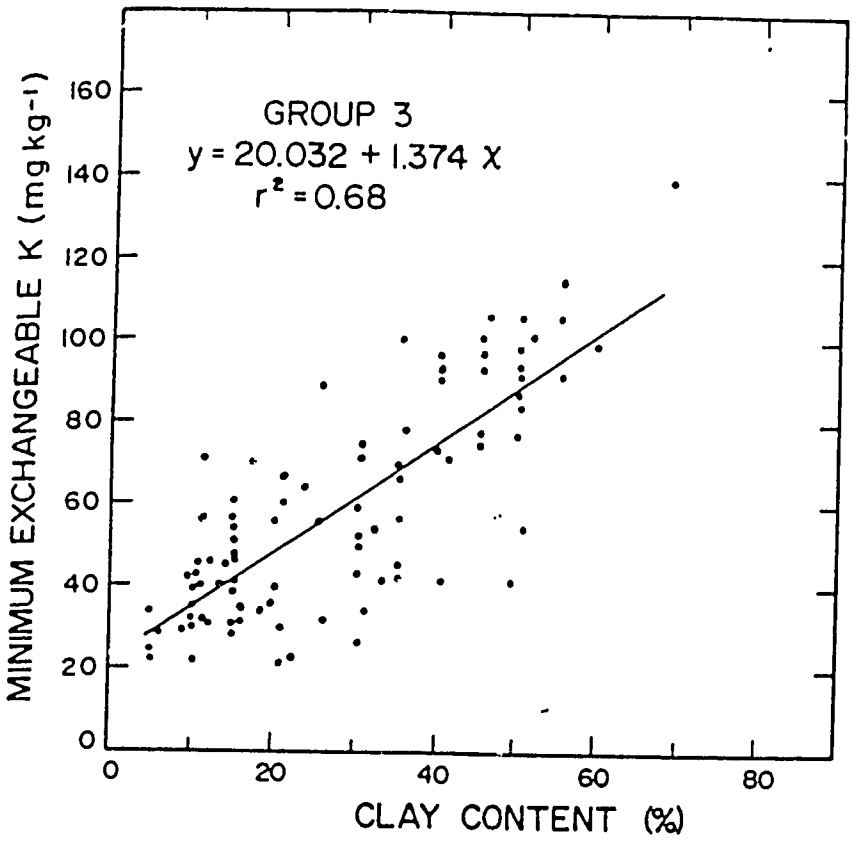

Figure 3. Relationship between clay content and minimum exchangeable K for the 102 Group 3 soils.

exchangeable K from simple soil properties will allow determination of critical soil K levels, in terms of plant availability, and thus, aid in fertilizer K recommendations.

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