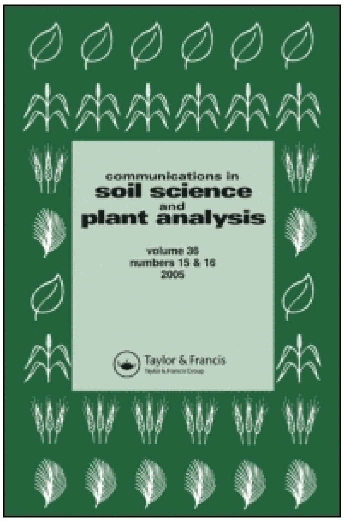

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

Chemistry of soil potassium in Atlantic coastal plain soils: A review

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Online Publication Date: 01 January 1980

To cite this Article Sparks, D. L.(1980)'Chemistry of soil potassium in Atlantic coastal plain soils: A review',Communications in Soil Science and Plant Analysis,11:5,435 — 449

To link to this Article: DOI: 10.1080/00103628009367051

URL: http://dx.doi.org/10.1080/00103628009367051

COMMUN. IN SOIL SCIENCE AND PLANT ANALYSIS, 11(5), 435-449 (1980)

CHEMISTRY OF SOIL POTASSIUM IN ATLANTIC COASTAL PLAIN SOILS: A REVIEW[1]

KEY WORDS: K kinetics, forms of soil K, crop response, leaching of K

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ABSTRACT

Literature dealing with general properties of soil K and with K relationships in Atlantic Coastal Plain Soils was discussed. Potassium, among major and secondary nutrient elements, is the most abundant in soils. It, among mineral cations required by plants, is largest in non-hydrated size. Potassium has a polarizability equal to .88 $\mathring{A}^3$ and a low hydration energy of 34 kcal g^{-1} ion^{-1}. The major K forms in soils are water soluble, exchangeable, nonexchangeable, and mineral. Various dynamic interrelationships exist between these forms with the reaction kinetics between the various phases determining the fate of applied K.

Many Atlantic Coastal Plain soils contain high levels of total K. Most of the total K in these soils is contained in mineral forms such as micas and K-feldspars. These K forms are slowly released to solution and exchangeable forms that are available to plants. Many researchers have noted a lack of crop response to K fertilization on Atlantic Coastal Plain soils. This lack of response has been ascribed to the high indigenous levels

of mineral and non-exchangeable K in the soils which would become available to crops. Some researchers have also attributed the lack of response to K accumulations in subsoil from leaching of applied K. If the physical and chemical conditions were favorable in the subsoil horizons, e. g., no pan formation and no severe Al toxicity, plant roots could absorb K from the subsoil horizons.

INTRODUCTION

The role of K in soils is prodigious. Its complex behavior in soils and plants has been epitomized by Albrecht (3): "Because of the prevalence of its minerals in the lithosphere, of its readily soluble nature, of its readiness to become insoluble and inexchangeable from the colloid, of its movement from vegetation to the soil through leaching from the tops or exchange from the roots, and of its reserve in the silt and sand minerals to buffer the clay; K is so nomadic that its performances in any particular situation are difficult to interpret." Many reports have appeared in the literature concerning the K status and crop response to K fertilization on Atlantic Coastal Plain soils. Before discussing the latter reports, some general characteristics of soil K will be given.

General Characteristics of K

Of the major and secondary nutrient elements, K is usually the most abundant in soils. The lithosphere contains an average of 2.8% K while soil contains 1.7% K (4). Some chemical characteristics of K are given in Table 1. Potassium, among mineral cations required by plants, is the largest in nonhydrated size ($r = 1.33$ Å) and the number of oxygen ions surrounding it in mineral structures is high (8 or 14) which suggests that the strength of each K-O bond is relatively weak. Potassium has a polarizability equal to 0.88 Å^3 which is higher than for Ca^{++}, Li^{+}, Mg^{++}, and Na^{+} ions but lower than for Ba^{++}, Cs^{+}, NH_4^{+}, and Rb^{+} (5). Ions with higher polarizability would be preferred in

TABLE 1.

Chemical Characteristics of Potassium

Crystalline radii (Å)[6,7]		Hydrated radii (Å)	Polarizability $(Å)^3$	Debye-Huckle parameter (Å)[8]	Coordination number[9]	Hydration energy[10]
						kcal/g ion
1.33	1.33	3.31	0.88	3.63	8-12	34

ion exchange reactions. Potassium has a hydration energy of 34 kcal g^{-1} ion^{-1} which would indicate little ability to cause soil swelling (11).

Forms of Soil K

Most researchers concur that soil K exists in water soluble, exchangeable, non-exchangeable and mineral phases. These forms can be analytically determined using extraction methods given in Table 2. Water soluble K is found in low concentrations and is very mobile. Anderson et al, (12) found that H_2O-soluble K

TABLE 2

Methods for Extracting Forms of Soil K.

Form	Location	Extractant
Water Soluble	Soil Solution	H_2O
Exchangeable	Exchange Phase	NH_4OAc and H_2SO_4
Nonexchangeable	Vermiculites and 2:1 intergrade clay minerals	Hot HNO_3
Mineral	Micas and feldspars	Selective dissolution using Na-pyrosulfate fusion
Total	----------------	H F digestion

ranged from 0.83 to 83 ppm of K on a soil basis in some humid soils. When water content was increased to a soil: water ratio of 1:10, extracted K increased by 3- to 27-fold. They attributed the increase in solution K to hydrolysis of exchangeable K by divalent ions, or to dissolution of K-bearing minerals. Exchangeable K, that held by the negative charges of soil organic matter and clay, is easily exchanged with other cations such as Ca^{++} and Mg^{++}, and is readily available to plants (15). Non-exchangeable K is moderately available to plants (5, 13, 14, 15) and, like NH_4^+, is held between the platelets of clay particles of soil mica and vermiculite (4, 5, 13, 16, 17, 18, 19, 20). Potassium in primary minerals, such as micas and feldspars, is very slowly available to plants (5, 13, 15).

Interrelationships exist between the various forms of soil K as shown in Fig. 1. Fixation of soil-solution and exchangeable K occurs between the platelets of 'illite' or of hydrated mica and vermiculite, and between frayed edges of mica platelets particularly in environments with high concentrations of these two readily available K forms (21). This fixation occurs in clayey surface soils when K levels are increased from leaching following fertilization (13, 14, 21). Release of fixed K to exchangeable and water soluble forms increases the levels of these readily available forms (21). Doll and Lucas (22) found that nonexchangeable K in soil mica, vermiculite, and chlorite was released as soluble or exchangeable K when levels of the latter were decreased. Levels of exchangeable and soil solution K are commonly decreased by crop removal and by leaching (13, 14, 23). A relatively small amount of mineral K is released by weathering during a growing season (13, 14).

The rate kinetics between the various forms of soil K determine the magnitude of leaching, release, and fixation in soils. The kinetic reactions between the exchangeable and nonexchangeable phases of K are slow (15, 16, 24). Cooke and Hutcheson (21) investigated the rate of transformation and release of K from biotite and "illite". Potassium release from these minerals was extremely slow as compared with reactions between soluble and exchangeable forms.

The rate of reaction between the soil-solution and exchangeable phases of K is generally proposed to be almost instantaneous (16, 25, 26, 27, 28, 29). However, the kinetics of K exchange in soils depend on the type of clay minerals present. Barshad (30) reported a low rate of K exchange in vermiculite. Sparks et al,

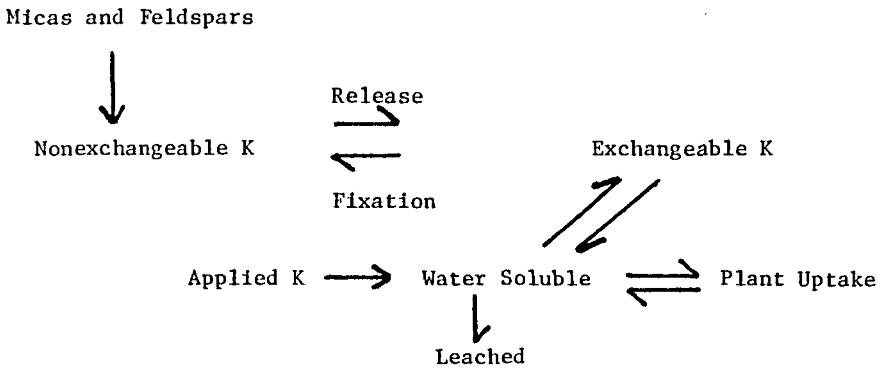

FIG. 1

Chemical Relationships Between Phases of Soil Potassium[13].

(31) found that the kinetics of K exchange in two Dothan soils from the Coastal Plain of Virginia and high in chloritized vermiculite and vermiculite had low reaction kinetics (Fig. 2). Equilibrium was reached in these soils in two hours when the soils were equilibrated with a 5-25 µg/ml K solution but in 1 to 2 days with a 100 µg/ml K solution. These low rate kinetics would suggest that K should remain in solution for an extended period where it could be leached or absorbed by plants. Selim et al (15) found K exchange to be fairly rapid in some Florida Coastal Plain soils where the mineralogy was dominated by kaolinite. Kaolinite has been shown to exhibit a rapid rate of K exchange (29).

Distribution of Forms of K in Soils

The major portion of total K in most soils is nonexchangeable. An average of 99.6% of the total K in samples of 20 soils of New Jersey was nonexchangeable. The remaining 0.4% included both the exchangeable and water soluble forms (32). Yuan et al (33) found that some Florida Coastal Plain soils had significant portions of K in feldspar forms. Sparks et al (23) found that most of the

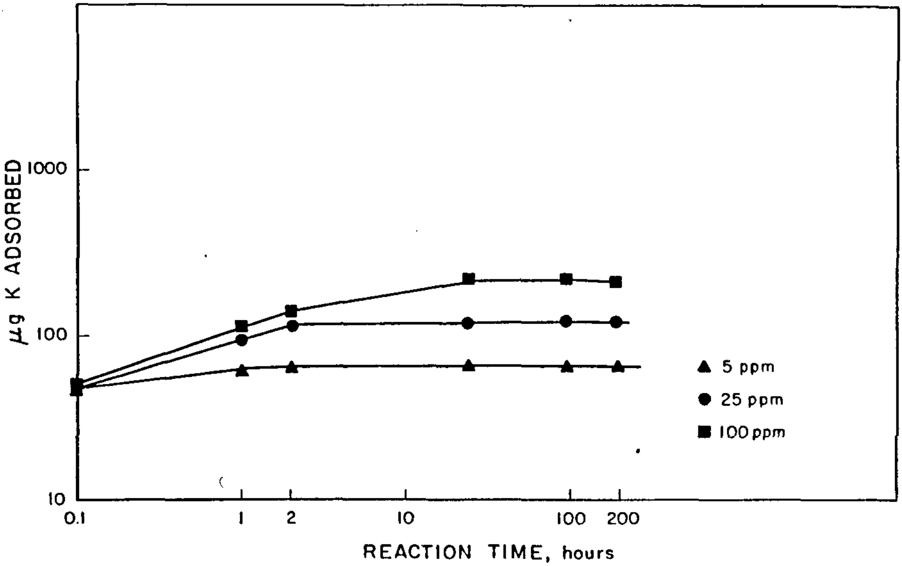

FIG. 2

Potassium adsorption at 250 by Nottoway county Ap soil horizon (Al-saturated) as a function of time.

total K in two Virginia Coastal Plain soils was in the nonexchangeable and mineral forms (Table 3). The exchangeable K comprised only a small percentage of the total soil K and was always <0.2 meq/100g. Most of the total K in both soils occurred in the feldspar and mica forms. Feldspar K comprised approximately 94% of the total K in the Ap horizon of the Nottoway County soil. Potassium from the nonexchangeable and mineral forms could be released with time to the exchangeable and solution phases that would be available to plants. Significant portions of the total K in both these soils were present in the silt fraction of both soils and even in the sand fraction from the Nottoway site. Other researchers have observed the contributions made by the sand and silt fractions to total K release (34, 35). Munn et al (35), found that K released from sand and silt fractions could reach a maximum of 56 and 21% of the total K released, respectively.

TABLE 3

Forms of K in Dothan soil sites examined from Greensville and Nottoway Counties.

Horizon	Depth	NH_4OAc Ext.	Acid Ext. K		K-Minerals		Total Soil K	Total K		
			H_2SO_4	HNO_3	Feldspar	Mica		Sand	Silt	Clay
	cm	meq/100g								
					Greensville County					
Ap	0-20	0.11	0.11	0.17	5.4	0.8	6.5	0.3	3.7	2.5
A2	20-31	0.11	0.10	0.19	5.7	0.9	6.9	0.4	3.4	3.1
B21t	31-41	0.22	0.21	0.38	5.1	3.4	9.3	0.2	1.4	7.7
					Nottoway County					
Ap	0-15	0.11	0.11	0.22	11.3	0.3	12.0	2.5	4.1	5.4
A2	15-33	0.09	0.11	0.19	8.2	2.3	10.8	2.0	5.5	3.3
B21t	33-58	0.13	0.14	0.24	5.4	5.5	11.4	1.8	4.7	4.9

Leaching of K in Coastal Plain Soils

Soil solution K is either leached or sorbed by plants or soils (15). The leaching of K is of considerable magnitude in many sandy Atlantic Coastal Plain soils (36). Three main factors that influence the magnitude of K leaching are K absorption by plants, the reduction in the volume of soil water by transpiration, and the composition of fertilizer materials and soils (37).

Crops reduce K leaching by assimilating K into their tissue as well as by reducing water percolation through soil (38). Volk and Bell (37) suggested that greater K leaching in fallow versus cropped soil was due to movement of more gravitational water.

Rainfall duration and intensity affects K movement in soil. Gammon (39) noted that downward water movement occurs in soil during a rain and that upward movement occurs when water is lost at the surface through evapotranspiration. Upward movement of K salts may accompany this upward movement of water.

Retention of K can be enhanced in Coastal Plain soils after application of lime and P (37, 38, 40). Nolan and Pritchett (38) found that liming to pH 6 to 6.5 caused maximum retentivity of added K in a Lakeland fine sand. Potassium was replaced by Ca on the exchange complex at higher levels of limestone application. Less leaching of K occurred at pH 6.0 to 6.5 due to enhanced substitution of K for Ca than for Al which is more abundant at low pH. Leaching of soil K was observed to vary inversely with quantities of organic matter and clay (36).

Several investigations have been conducted to determine the relationship of crop uptake and rate of K application to leaching of K in Coastal Plain soils. Jackson and Thomas (41) applied up to 524 kgK/ha prior to planting sweet potatoes (Ipomoea batatas L.) on a Norfolk sandy loam. At harvest time, soil and plant K exceeded applied K at the 131 and 262 kg K/ha rates. However, at the 524 kg K/ha rate, 38 kg of K was unaccounted for by soil and plant K. This deficiency of K was attributed to leaching below sampling depths. During a two year study with corn (Zea mays L.)

on two Dothan soils of Virginia, Sparks et al (23) found that 83 and 249 kg K/ha of applied K increased the exchangeable K in the A2 and B21t horizons of the two soils. These increases were ascribed to leaching of applied K. The magnitude of leaching varied directly with rate of K application. No accumulation of K was found in the top 76 cm of a Leon sand after 40 years of heavy K fertilization (52). Lutrick (43) found that K leaching occurred on unlimed areas, but not on limed areas, when 112 to 224 kg K/ha was applied on a Eustis loamy fine sand.

Crop Response to Applied K on Coastal Plain Soils

On many sandy soils of the Atlantic Coastal Plain region K fertilization has failed to increase corn (*Zea mays* L.) yield (23, 33, 44, 45, 46). These soils characteristically have sandy surface horizons and accumulations of K in clayey subsoil horizons. Normally, K fertilization recommendations for these soils are based on samples from the surface 18 to 20 cm. Often these samples contain low levels of extractable K and yet, there is no response to K fertilization. Black (45) reported high corn yields on two Coastal Plain soils in Virginia to which no K fertilizer had been applied for 7 years. He pointed out that when one considers the K content in the soil depths to which corn roots may penetrate, it is necessary that subsurface horizons as well as the plow layer need consideration when evaluating K availability from soils. Hutton and Robertson (44), in a study of the residual effect of K fertilizer in two Ultisols on crop production, showed some K accumulation in subsoil. Yuan et al (33) investigated the lack of crop response to K fertilization for corn, soybeans, and small grain on some Ultisols in the Lower Coastal Plain. Profile samples were analyzed for exchangeable, nonexchangeable, mineral, and total soil K. A K reserve of 1,500 to 2,800 kg/ha was found in 15 cm increments of these soil profiles. A large portion of this K reserve occurred in the K-feldspar form and was found in micaceous mineral forms while very little of this K reserve was in the exchangeable and fixed forms. Sparks et al (13) attributed the lack of response of corn to K fertilization on two Dothan soils from the Virginia Coastal Plain to large quantities of K feldspars found in the soils which with time supplied the soil with available K. In Delaware, corn yield was not significantly increased by application of K fertilizer over a 4-year period on sandy soils (46). This lack of K response was attributed to release of K from nonexchangeable and mineral forms.

SUMMARY

Many sandy Atlantic Coastal Plain soils contain large quantities of total K. Much of this total K is found in mineral and nonexchangeable forms which can slowly be released with time to plant available forms.

The lack of crop response to applied K on many of these soils has been ascribed to the presence of these K forms. In addition, there is evidence that this lack of crop response could be due to leaching of applied K into clayey subsoil horizons. This subsoil K is available for absorption by plant roots unless adverse physical and chemical soil properties e. g., pan formation, and high Al, exist in these horizons.

The rate of K release from the exchangeable, nonexchangeable, and mineral forms in these soils needs to be further investigated. With kinetic data, predictive models could be developed for these soils which would aid in making sound fertilizer recommendations.

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