

# Plant Uptake and Leaching of Applied and Indigenous Potassium in Dothan Soils<sup>1</sup>

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## ABSTRACT

The K fertilization requirement for corn (*Zea mays* L.) frequently is overestimated by soil test procedures for Atlantic Coastal Plain soils having sandy Ap horizons and high K concentrations in clayey subsoil. It seemed probable that the lack of response could reflect availability of subsoil K. This field and laboratory research was conducted to evaluate the availability and origin of subsoil K and the downward movement of K in two Dothan soils (Plinthic Paleudults). These soils had low CEC in the Ap, A2, and B21t horizons; fine sandy loam Ap horizons; higher clay contents in the B21t horizons than in the Ap horizons; and very acidic B21t horizons. Mineral suites in the clay-sized fraction of the two soils were predominantly 14 A intergrade minerals, kaolinite, and quartz. The three horizons in these two soils contained high levels of total K ranging from 6.5 to 12.0 meq/100 g. Over 90% of the total K in the A2 and B21t horizons of the two soils was in feldspar and mica forms indicating that parent material, rather than leaching of applied K, was the main origin of K in these horizons. Decreases in exchangeable K occurred during the first growing season in the A2 and B21t horizons of control plots in field experiments on the two soils. These decreases in exchangeable K indicated K uptake by corn plants from the subsoil horizons. With time, two-annual broadcast applications of 83 and 249 kg K/ha as KCl increased the exchangeable K in the A2 and B21t horizons of the two soils. These increases were ascribed to leaching of K into the subsoil horizons. This leaching of K suggests that downward movement of applied K could result in an accumulation of K in clayey subsoil. The K in subsoil, either from leaching of applied K or from genetic origin, would be available to plants unless root growth into the subsoil was restricted by adverse chemical and physical properties.

*Additional index words:* K deficiency, K fertilization, and K mobility.

POTASSIUM fertilization has failed to increase corn (*Zea mays* L.) yields on certain soils of the Atlantic Coastal Plain region. These soils characteristically have sandy surface horizons and high K concentrations in clayey subsoil. Normally, K fertilization recommendations are based on samples collected from the surface 18 to 20 cm. Often these samples contain low levels of extractable K and, yet, there is no yield response to K fertilization. This lack of response could reflect availability of subsoil K.

Crops grown on many Atlantic Coastal Plain soils with sandy surface horizons have not responded to K fertilization (Hutton and Robertson, 1961; Black, 1963<sup>3</sup>; Liebhardt et al., 1976; Yuan et al., 1976). Black (1963)<sup>3</sup> reported high corn yields on two Coastal Plain soils in Virginia to which no K fertilizer had been applied for 7 years. Yuan et al. (1976) investigated the lack of corn, soybean [*Glycine max* (L.) Merr.], and small grain yield responses to K fertilization on some Ultisols in the lower Coastal Plain. A reserve of 1,500 to 2,800 kg K/ha was found in samples from each 15-cm increment of these soil profiles. A large portion of this K reserve occurred in the feldspar and micaceous mineral forms and little in the exchangeable and fixed forms. Corn yield was

not increased by application of K fertilizer over a 4-year period on sandy soils in Delaware (Liebhardt et al., 1976). This lack of K response was attributed to release of K from fixed and mineral forms.

Investigations have been conducted to determine the relationship between plant uptake and leaching of applied K. Jackson and Thomas (1960) found that changes in exchangeable K in surface soil plus K in sweet potato (*Ipomoea batatas* L.) tissue exceeded applied K at rates of 131 and 262 kg K/ha in Norfolk sandy loam. However, at the 524 kg K/ha rate, 38 kg K/ha was unaccounted for by the sum of exchangeable K in the surface horizon and K in plant tissue. This deficit was attributed to leaching of K into lower soil horizons. Lutrick (1963) found that leaching of K occurred in unlimed areas, but not in limed areas, where 112 to 224 kg K/ha were applied on a Eustis loamy fine sand. Leaching from application of 56 to 90 kg K/ha increased quantities of K in the 20 to 41 and 41 to 61-cm depths of some South Carolina soils (Craddock, 1958)<sup>4</sup>. Hutton and Robertson (1961) studied the residual effect of K fertilization in two sandy Ultisols and observed an accumulation of K in subsoil from leaching.

The objectives of this research were to evaluate the plant availability of subsoil K in two Dothan fine sandy loams and to determine if the subsoil K was derived from leaching of applied K or from genetic origin. The plant availability and movement of K was evaluated during two growing seasons. Selection of the two soils was based on differences in total K in their Ap, A2, and B21t horizons.

## MATERIALS AND METHODS

Studies were conducted on two Dothan soils (fine-loamy, siliceous, thermic Plinthic Paleudults) in Greensville and Nottoway Counties, Virginia. The Greensville County soil was cultivated for over a century, whereas the Nottoway County soil supported forest for three decades prior to this study. Bulk samples were obtained from the Ap, A2, and B21t horizons of the two soils. These samples were air-dried and crushed to pass a 2-mm sieve in preparation for laboratory characterization analyses.

### Soil Characterization Analyses

Particle size analyses were determined by the pipette method (Kilmer and Alexander, 1949). The samples were prepared for soil mineral particle size fractionation by treatment with

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<sup>3</sup>Black, W. R. 1963. Phosphorus and K fertility in two Coastal Plain soils. Unpublished M. S. thesis. Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061.

<sup>4</sup>Craddock, G. R. 1958. Soils may store K for plant use. South Carolina Agric. Exp. Stn. Annual Report. Dep. of Agron. and Soils, Clemson Univ., Clemson, SC 29631.

30%  $H_2O_2$  to remove organic matter (Kunze, 1965) and then with Na-dithionite-citrate-bicarbonate to remove Fe-oxides (Mehra and Jackson, 1960). Sand was separated from silt and clay by wet sieving and clay was separated from silt by repeated centrifugation and decantation. X-ray diffraction and differential thermal analyses were performed on the clay fraction of the soils. X-ray diffractograms were obtained from oriented clay slides (Rich and Barnhisel, 1977) with a Diano XRD 8300 AD instrument employing a  $CuK\alpha$  radiation source and a graphite monochromator. Differential thermograms of Mg-saturated samples were obtained with a DuPont 990 differential scanning calorimeter.

Soil pH was determined from a 1:1 soil-to-water mixture after a 1-hour equilibration period, organic matter by a wet-oxidation procedure (Walkley and Black, 1934), and CEC by  $MgCl_2$  saturation and subsequent  $CaCl_2$  displacement (Rich, 1962; Okazaki et al., 1963). Dilute  $HCl-H_2SO_4$  extractable K was determined from a 5-g soil sample shaken for 5 minutes with 20 ml of a solution consisting of 0.05 N HCl and 0.025 N  $H_2SO_4$ . Exchangeable Ca, K, Mg, and Na were extracted from soil with N  $NH_4OAc$ . Nonexchangeable K was calculated as the difference between K extracted with hot N  $HNO_3$  (Pratt, 1965) and exchangeable K. Samples were digested with HF for total K determinations (Bernas, 1968). Potassium present in feldspar was extracted by the Na-pyrosulfate fusion method of Jackson (1979). The K present in micas was assumed to be the difference between total K and the sum of feldspar K, nonexchangeable K, and exchangeable K. Calcium, K, Mg, and Na in these extracts were analyzed by atomic absorption spectrophotometry.

### Crop Response Studies

Field studies were initiated on the two Dothan soils in 1977 and continued in 1978. Treatments applied on the same plots in March of both years were: 0, 83, and 249 kg K/ha in the Greenville County site; and 0 and 83 kg K/ha in the Nottoway County site. The K as KCl was broadcast on the soil surface and disked-in to a depth of approximately 10 cm. The treatments were applied in quadruplicate to  $5.5 \times 9.1$ -m plots that were arranged in a randomized, complete-block design. Corn 'DeKalb XL78' was grown at a population of 53,400 plants/ha on the Greenville County site in 1977, and 'Pioneer 3369A' was grown on the Nottoway County site at a population of 51,200 plants/ha in 1977 and 59,100 plants/ha in 1978. It was not possible to grow corn on the former site in 1978 due to a change in land proprietorship. Peanuts (*Arachis hypogea* L.) were grown on this site in 1978. Amendments in addition to treatments applied to the Greenville County site in 1977 and to the Nottoway County site in both 1977 and 1978 were 48 kg P/ha as triple superphosphate, 5.6 kg Cu and 17 kg of both Mn and Zn/ha as sulfates, and 1.1 kg B/ha as Na-borate. A level of 202 kg N/ha as  $NH_4NO_3$  was applied to both soils in 1977 and 314 kg N/ha as  $NH_4NO_3$  was applied to the Nottoway County site in 1978. Heavy rainfall following the initial N application necessitated the high level of N application in 1978. Weed control was achieved with herbicides at both locations.

Grain and stalk yields were determined from 6.1-m sections of two interior corn rows from each plot of the field experiments. These yields were adjusted to 15.5% moisture. The remaining plant tissue was removed from the experimental areas each fall. Potassium concentrations were determined in composite samples from each plot consisting of 12 ear leaves sampled at the early silk growth stage and of both 12 stalks and grain from 10 ears sampled at corn maturity. This plant tissue was dried to constant weight at 70 C and ground to pass a 20-mesh screen. One-g subsamples of the tissue were dry ashed at 450 C and leached with dilute  $HNO_3$ . Potassium in the acidic solution was determined by atomic absorption spectrophotometry.

### Leaching Studies

Six soil cores were taken periodically from each plot of the two field experiments. Each core of 1.9-cm diam was taken to a depth of 41 cm with a sampling tube and was separated into the Ap, A2, and B21t horizons. These samples were obtained in June, August, and November 1977 and in March, June, September, and December 1978 from the Nottoway County site. The same sampling times were used on the Greenville

County site, except samples were not taken in either June or September 1978 to avoid disturbance of peanut growth. The March samples were taken prior to K application. Exchangeable K in these samples was determined by the N  $NH_4OAc$  procedure.

### Statistical Analyses

Yield, nutrient concentration, and K movement data were evaluated by analyses of variance and by Duncan's Multiple Range Tests. These analyses were performed on an IBM 370 computer utilizing the SAS program (Barr et al., 1976).

## RESULTS AND DISCUSSION

Selected physical, chemical, and mineralogical properties of the Dothan soils from Greenville and Nottoway Counties are given in Table 1. Soil pH levels in the Ap horizons of both soils were within the range where corn yield responses would not be expected from limestone application (Adams, 1969). The soil pH levels in the A2 horizon of the Nottoway County soil and in the B21t horizons of both soils were in the pH range where Al toxicity of plants has occurred on some soils (Foy and Fleming, 1978). Organic matter content and CEC were relatively low in both soils as is normally the case in well-drained Atlantic Coastal Plain soils. Calcium was the predominant exchangeable base in the three horizons of both soils as expected for most soils in the humid region. The mineral suite, as determined by X-ray diffraction, was very similar in both soils. Chloritized vermiculite was the most abundant mineral in the Ap, A2, and B21t horizons of both soils. The A2 horizons of the Nottoway County location contained some vermiculite and mica. These minerals were absent from the A2 horizon of the Greenville County location. The B21t horizon from both soils contained detectable amounts of mica.

### Forms of Soil K

The K status of the two soils was evaluated by the dilute  $HCl-H_2SO_4$  extractable K and exchangeable K availability indexes (Table 2). Dilute  $HCl-H_2SO_4$  extractable K is used in Virginia and many other southeastern states to assess K fertilization requirements. The Ap horizon contained a medium level of dilute  $HCl-H_2SO_4$  extractable K in the Greenville County soil and a low level in the Nottoway County soil according to calibration data for the procedure (Rich, 1955). The sum of either dilute  $HCl-H_2SO_4$  extractable K or exchangeable K was higher in the three horizons for the Greenville County soil than for the Nottoway County soil. This may reflect K fertilization during the many years of crop production in the former soil. An increase in both dilute  $HCl-H_2SO_4$  extractable K and exchangeable K was evident from the A2 to B21t horizons for both soils.

The three horizons of the two soils contained relatively high amounts of total K ranging from 6.5 to 12.0 meq/100g (Table 2). Greater than 90% of the total K in each horizon of the two soils was in feldspar and mica forms. The high portion of total K in these primary mineral forms suggests that parent material was the origin of most of the K in each horizon of the two soils. Relatively large portions of the total K were present in the silt fraction of both soils and

even in the sand fraction of the Nottoway County soil. The presence of K in primary minerals in the sand and silt-sized fractions supports the conclusion that much of the total K in the two soils was genetic in origin (Barshad, 1964). Amounts of the nonexchangeable K forms were relatively low in the three horizons of the two soils (Yuan et al., 1976), which would be expected where much of the total soil K was in feldspar and mica forms.

**Effect of K Application on Tissue K Levels and Corn Yield**

Applications of K generally increased the K concentrations of the corn plant ear leaves during the early silk growth stage on both soils (Table 3). Jones (1967) reported that a K concentration in ear leaves at this growth stage of <1.25% indicates inadequate K for normal corn plant growth and of 1.71 to 2.25% indicates adequate K for maximum corn yields. Relationships between K application and corn yield were consistent with these critical levels. That is, K application increased the total grain and stalk yields where the ear leaves from plants on control plots contained 1.0 and 0.7% K on the Nottoway County Soil in 1977 and 1978, respectively; whereas K application did not increase total yields on the Greenville County soil where the ear leaves of plants on control plots contained 2.0% K. The yields were much higher on the Nottoway County soil in 1978 than in 1977. The lower yield in 1977 reflects the severe drought that was only partially overcome by irrigation. Corn grain yield was exceedingly low on the Greenville County soil in 1977 due to a severe lack of rainfall during the grain filling stage. The amount of rainfall at this site was 3.5 cm in June and 6.9 cm in July.

**Table 3. Effect of K application on yield, K concentration, and K removal of corn on Dothan soils from Greenville County for 1977 and from Nottoway County for 1977 and 1978.**

Treat- ment†	Yield			K in ear leaf %	K removal		
	Grain	Stalk	Total		Grain	Stalk	Total
kg K/ha	kg/ha				kg K/ha		
Greenville County, 1977							
0	330a**	5,300a	5,630a	2.0b	1a	70b	71b
83	340a	5,240a	5,580a	2.1b	1a	85ab	86ab
249	230a	4,590a	4,820a	2.5a	1a	113a	114a
Nottoway County, 1977							
0	4,940a	4,890b	9,830b	1.0b	12a	46a	58a
83	5,110a	6,060a	11,170a	1.5a	13a	54a	67a
Nottoway County, 1978							
0	6,430b	7,330a	13,760b	0.7b	11b	19b	30b
83	8,380a	9,220a	17,600a	1.2a	14a	66a	80a

\*\* Column means for each treatment are significantly different at the 0.10 probability level if followed by different letters for a given year.  
† The K was applied annually.

The sum of either dilute HCl-H<sub>2</sub>SO<sub>4</sub> extractable K or exchangeable K in the Ap, A2, and B21t horizons was higher in the Greenville County soil, than in the Nottoway County soil (Table 2). These data suggest a higher level of plant available K in the surface three horizons of the former soil. Accordingly, K concentration in ear leaves and total K uptake was higher in corn plants grown in 1977 on the Greenville County soil (Table 3). More K was present in corn stalks, than in grain. This was most evident on the Greenville County soil in 1977 where grain yield was exceedingly low due to lack of rainfall, but also was evident on the Nottoway County soil in 1978 where rainfall was nearly adequate. Overall, these data indicate much greater K removal from soil when corn

**Table 1. Selected physical, chemical, and mineralogical properties of Dothan soils from Greenville and Nottoway Counties.**

Horizon	Depth cm	Soil separates			Organic matter	Soil pH	CEC	Exchangeable bases			Clay mineral suite†
		Sand	Silt	Clay				Ca	Mg	Na	
		%						meq/100 g			
Greenville County											
Ap	0-20	66.6	24.4	9.0	0.5	6.1	4.2	0.74	0.12	0.04	VC <sub>1,†</sub> GI <sub>2</sub> , QZ <sub>3</sub> , KK <sub>4</sub>
A2	20-31	77.0	16.0	7.0	0.3	5.8	4.0	1.03	0.21	0.03	VC <sub>1</sub> , KK <sub>2</sub> , QZ <sub>3</sub> , GI <sub>4</sub>
B21t	31-41	65.9	23.8	10.3	0.3	4.8	4.8	0.85	0.27	0.02	VC <sub>1</sub> , KK <sub>2</sub> , GI <sub>3</sub> , MI <sub>4</sub>
Nottoway County											
Ap	0-15	81.6	15.0	3.4	1.2	5.8	5.8	1.72	0.85	0.01	VC <sub>1</sub> , KK <sub>2</sub> , QZ <sub>3</sub> , GI <sub>4</sub>
A2	15-33	70.8	20.1	9.1	0.2	5.2	3.4	0.24	0.13	0.03	VC <sub>1</sub> , VR <sub>2</sub> , KK <sub>3</sub> , MI <sub>4</sub>
B21t	33-58	69.1	19.1	11.9	0.2	4.7	4.0	0.26	0.06	0.03	VC <sub>1</sub> , KK <sub>2</sub> , GI <sub>3</sub> , MI <sub>4</sub>

† GI = gibbsite; KK = kaolinite; MI = mica; QZ = quartz; VC = chloritized vermiculite; VR = vermiculite.  
‡ Subscript 1 = most abundant, 4 = least abundant.

**Table 2. Forms of K in Dothan soils from Greenville and Nottoway Counties.**

Horizon	Depth cm	Dilute HCl-H <sub>2</sub> SO <sub>4</sub> Ext. K	Exchange- able K	Non- exchange- able K	Primary mineral K		Total K	Total K			
					Feldspar	Mica		Sand	Silt	Clay	
								meq/100 g			
Greenville 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	0.06	0.11	0.19	5.7	0.9	6.9	0.4	3.4	3.1	
B21t	31-41	0.10	0.22	0.38	5.1	3.6	9.3	0.2	1.4	7.7	
Nottoway County											
Ap	0-15	0.07	0.10	0.22	11.3	0.4	12.0	2.5	4.1	5.4	
A2	15-33	0.03	0.09	0.19	8.2	2.3	10.8	2.0	5.5	3.3	
B21t	33-58	0.08	0.13	0.24	5.4	5.6	11.4	1.8	4.7	4.9	

**Table 4. Effect of K application and sampling time on exchangeable K in three horizons of the Greenville and Nottoway County soils.**

Treatment†	Horizon	Sampling date						
		6/77	8/77	11/77	3/78	6/78	9/78	12/78
kg K/ha		meq exchangeable K/100 g						
Greenville County								
0	Ap	0.09cA**	0.07cBC	0.08cAB	0.07bBC	-§	-	0.06cC
83	Ap	0.12bA	0.09bBC	0.09bBC	0.11abAB	-	-	0.08bC
249	Ap	0.19aA	0.13aB	0.12aB	0.12aB	-	-	0.11aB
0	A2	0.12aA	0.09bB	0.10bAB	0.10bAB	-	-	0.08bB
83	A2	0.13aA	0.10bB	0.10bB	0.12abAB	-	-	0.12bAB
249	A2	0.13aB	0.13aB	0.13aB	0.15aB	-	-	0.19aA
0	B21t	0.20aA	0.16aB	0.16aB	0.18aAB	-	-	0.13bC
83	B21t	0.20aAB	0.16aBC	0.19aABC	0.15aC	-	-	0.23aA
249	B21t	0.19aB	0.16aB	0.18aB	0.18aB	-	-	0.24aA
Nottoway County								
0	Ap	0.11bA	0.07bB	0.08bB	0.07bB	0.07bB	0.05bC	0.05bC
83	Ap	0.13aA	0.09aCD	0.10aBC	0.10aBC	0.11aB	0.08aD	0.09aCD
0	A2	0.08aA	0.06aBC	0.07aAB	0.07aAB	0.06bBC	0.06bBC	0.05bC
83	A2	0.07aBC	0.06aC	0.07aBC	0.06aC	0.09aA	0.08aAB	0.08aAB
0	B21t	0.12aA	0.10aBC	0.12aA	0.10aBC	0.11aAB	0.11aAB	0.09aC
83	B21t	0.10aBC	0.09bC	0.10aBC	0.10aBC	0.11aB	0.13aA	0.10aBC

\*\* Column means for each horizon are significantly different at the 0.10 level of probability if followed by different lower case letters. Row means are significantly different at the 0.10 level of probability if followed by different higher case letters.

† The K treatment was applied after soil sampling in 3/77 and in 3/78.

§ Soil samples were not obtained.

was harvested for silage than for only grain. Total uptake data show that application of 83 kg K/ha would not always be adequate to replenish the soil K removed when plants were used for silage.

#### Uptake of Subsoil K

As expected, K application increased the exchangeable K in the Ap horizons of both soils (Table 4). Decreases in exchangeable K occurred in the Ap horizons of both soils during the June to August 1977 and the June 1977 to December 1978 samplings in control and K-treated plots. These decreases in exchangeable K are attributable mainly to crop uptake and leaching of K, and possibly to some K fixation. Decreases in exchangeable K occurred in the A2 and B21t horizons of control plots on both soils during the June 1977 to August 1977 samplings. These decreases indicate that corn roots, which were visibly detected in these horizons, were able to extract K from the subsoil even though the pH levels in the B21t horizons of both soils were below 5.0 (Table 1). Plants would not absorb K from B horizons where root growth was inhibited by Al and Mn toxicities. Likewise, plant sorption of K would not occur from B horizons where roots did not grow into this horizon due either to lack of O<sub>2</sub> or to pan development.

#### Leaching of K

Although corn plants could not be grown on the Greenville County soil in 1978, the study was continued to determine the effect of a high level of K application combined with relatively low K removal (Table 3) on leaching of K. Application of the 249 kg K/ha level increased exchangeable K in the A2 horizon of the soil on the August 1977 through December 1978 samplings (Table 4). Exchangeable K was increased in the B21t horizon of the soil in the December 1978 sampling from application of both 83 and 249 kg K/ha. These increases in exchangeable K indicate

downward movement of K into the soil, assuming a similar amount of K release in the A2 and B21t horizons of control and K-treated plots. This conclusion for leaching of K would not be altered either if K release would be higher in the A2 and B21t horizons of K-treated plots due to greater crop uptake of K or if crop uptake of leached K was greater from the A2 and B21t horizons of the K-treated plots.

Downward movement of K into the A2 horizon of the Nottoway County soil was indicated by increases in exchangeable K from application of the 83 kg K/ha level in this horizon during the June 1978 to December 1978 samplings (Table 4). An effort was made to select very uniform experimental areas for this study, nevertheless, slight variation in exchangeable K occurred in the B21t horizon between the control and K-treated plots. For example, exchangeable K was higher in the B21t horizon in the control plots than in the K treated plots for the August 1977 sampling. The higher exchangeable K concentrations in this soil on June 1978 and September 1978 sampling dates, than on the August 1977 sampling suggest downward movement of K into the B21t horizon of the soil.

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