UTILIZATION OF POTASSIUM BUFFERING CAPACITY TO PREDICT COTTON YIELD RESPONSE TO POTASSIUM FERTILIZER: 1992-1994

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Abstract

Potassium deficiency is widespread in cotton growing areas around the world. Many of the cotton producing states have initiated research programs to re-evaluate current K fertilizer recommendations, with conflicting results. It is, therefore, essential that the soil scientists across the Cotton Belt work together in a unified manner, seeking the principles which are true on all soil types, and using creative approaches to address this problem. The objectives of this study were: 1) to develop a method whereby we can predict cotton response to K fertilization across the U.S. Cotton Belt using the K buffering capacity, 2) to determine the relationship of commonly measured soil physical and chemical properties to KBC for a number of diverse cotton-producing soils, and 3) to compare soil extractants and K fertilizer recommendations used across the Cotton Belt. Locations were chosen to represent the major soil types across the Cotton Belt. Variations in soil texture and clay mineralogy are represented in this selection of 45 site-years. Each cooperator used varieties and management practices common to his/her state. Yield was measured by treatment in tests with a randomized complete block design with three application rates (0, 50, and 100 lb K_20/A) and four replicates. Soil samples were taken to 45 cm depth (in 15 cm depth increments) from each location prior to K fertilization. The following initial physical and chemical properties were determined: particle size analysis, clay mineralogy, organic matter content, CEC, soil pH, NH_4OAc-extractable K, Ca, and Mg, Mehlich-1 extractable K, Ca, and Mg, and Mehlich-3 extractable K, Ca, and Mg. Potassium fixation percentage was measured using a seven-day incubation in 10 mM KNO_3 and two sequential extractions. After clay mineralogy was determined by x-ray diffraction, the soils were grouped into seven mineralogical classes. All of the experimental sites which had yield responses to K fertilizer were in mineralogical classes with moderate to high amounts of kaolinite. When K fixation was < 100% there was a 44% probability of yield response to K across all experimental sites. When K fixation was between 100 and 110%, probability of yield response was 23%; and above 110%, probability of yield response was 0%. Potassium fixation was positively correlated with CEC, and was more highly correlated with Mehlich-3 and ammonium acetate extractable K than with Mehlich-1 extractable K. The use of K fixation percentage as a predictor of cotton yield response to K fertilization shows promise across the Cotton Belt and merits further research.

Introduction

Potassium (K) deficiency is widespread in cotton growing areas around the world, and in recent years, late-season K deficiency symptoms have been reported throughout the U.S. Cotton Belt. Many of the cotton producing states have initiated research programs to re-evaluate current K fertilizer recommendations, with conflicting results. Incongruous response to K fertilizer has led to confusion in the research and farming communities and waste of resources due to K application to insure against yield decline, whether there is sound, scientific basis for that application or not. It is, therefore, essential that the soil scientists across the Cotton Belt work together in a unified manner, seeking the principles which are true on all soil types, and using creative approaches to address this problem.

The nutrition of the cotton plant requires a sufficient amount of K for both fiber quality and yield to meet production goals. Newer cotton varieties that mature much faster and produce a heavier fruit set have made cotton even more sensitive to K nutrition. The demand for soil nutrients has been compressed to a shorter season creating a greater demand on the root system to supply K. This situation is further compounded by the lack of adequate K uptake by the root system during mid to late season as the root system declines in activity and boll demand is high.

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Although various causes of late-season K deficiency have been proposed, the fact that this problem exists on soils that may test high or very high in available K suggests that a more precise method of estimating soil supply of K is needed.

Our inability to predict optimum conditions for K fertilization is primarily due to the inability to predict K fertilizer requirement with present soil test methods (Cassman, 1986). Potassium exists in four main forms in soil systems: mineral, exchangeable, non-exchangeable, and solution K. Plant uptake occurs from the solution K pool only, but the solid K forms are in equilibrium with solution K. The exchangeable K is the quickest to be released into solution and the mineral K dissolution is the slowest. The complexities of the dynamic equilibria are what cause available soil K to be difficult to predict. Different chemical extractants have been found to predict plant uptake best in different regions of the U.S.

The soil supply of K depends on K concentrations or activity in soil solution, often referred to as K intensity, the total amount of diffusible K in the soil, referred to as K quantity, and the ability of diffusible K to maintain solution K concentration as roots remove K from solution, referred to as K buffer capacity or buffer power (Barber, 1984). A number of studies have shown that quantity/intensity (Q/I) measurements can be used to predict soil K status (Beckett, 1964a,b). The methodological difficulties and costs, however, have prevented widespread adoption of this approach for soil testing purposes.

Buffer power is related to clay type and amount. Sharpley (1990) recommended the use of the dominant clay mineralogy in prediction of fertilizer K disposition and in making fertilizer K recommendations due to the importance of clay mineralogy in K fixation and release. Beegle and Baker (1987) concluded that "K buffering behavior of individual soils should be included in K management decisions." Potassium buffering capacity is already in use for K fertilizer recommendations for a few crops in isolated countries around the world. For example, buffering capacity is used in K recommendations for tobacco in India (Krishnamurthy et al., 1984) and in apples and pears in South Africa (Woodridge, 1988). Scientists from Czechoslovakia (Vopenka, 1989), England (Johnston and Goulding, 1990), and the U.S. (Cervantes and Hanson, 1991) have recommended the utilization of K buffering capacity in the development of fertilizer recommendations.

The objectives of this study were**:**

1) to develop a method whereby we can predict cotton response to K fertilization across the U.S. Cotton Belt using the K buffering capacity,
2) to determine the relationship of commonly measured soil physical and chemical properties to KBC for a number of diverse cotton-producing soils, and
3) to compare soil extractants and K fertilizer recommendations used across the Cotton Belt.

Materials and Methods

Locations were chosen to represent the major soil types across the Cotton Belt. Variations in soil texture and clay mineralogy are represented in this selection.

Coastal Plain

The soils of the Coastal Plain are predominantly Ultisols, acidic soils which demonstrate increased clay content with depth. Soils of the Coastal Plain, particularly the sandy soils, have shown consistent responses to K fertilizer. The Kandiudults (soils dominated by low activity clays) are represented in this study by:
1) Tifton loamy sand (Tift County, Georgia), a Plinthic Kandiudult-1994
2) Norfolk loamy sand (Gadsden County, Florida), a Typic Kandiudult-1994
3) Norfolk sandy loam (Darlington County, South Carolina), a Typic Kandiudult-1993
4) Leefield sand (Colquitt County, Georgia), an Arenic Plinthaquic Kandiudult-1992
Paleudults and Hapludults are also common in the Coastal Plain and will be included in this test.
5) Suffolk loamy sand (Virginia), a Typic Hapludult-1993,1994
6) Greenville sandy clay loam (Sumter County, Georgia), a Rhodic Paleudult-1992,1993
7) Lucedale sandy clay loam (Autauga County, Alabama), a Rhodic Paleudult-1992,1993,1994
8) Benndale sandy loam (Escambia County, Alabama), a Typic Paleudult-1993,1994
One other soil was studied in the Coastal Plain region in order to include Entisols, young poorly developed soils.
9) Lakeland sand (Tift County, Georgia), a Typic Quartzipsamment-1993

Mississippi Delta

The Delta soils are silty soils due to their origin as alluvial flood plain soils. However, their classification is quite variable. Foliar K has resulted in increased yields in this region in spite of high soil K levels, in some cases.
10) Commerce silt loam (Pointe Coupee Parish, Louisiana), an Aeric Fluvaquent-1992
11) Calloway silt loam (Lee County, Arkansas), a Glossaquic Fragiudalf-1992

High Plains

The High Plains soils are characterized by their semi-arid environment and high pH levels. The soils vary in texture from sandy loams to clay loams and from Alfisols to Mollisols. These soils are generally high in K, and cotton response to K fertilizer is rare.
12) Amarillo fine sandy loam (Lubbock County, Texas), an Aridic Paleustalf-1992

13) Tipton loam (Tillman County, Oklahoma), a Pachic Argiustoll-1993,1994
14) Tillman-Hollister clay loam complex (Jackson County, Oklahoma), a Pachic Paleustoll-1993,1994

Arid, Alluvial Soils of the West

All of the soils in this group are loamy due to their alluvial parent material. Cotton yield responses to high K fertilizer rates have been reported in this region, especially on montmorillonitic soils depleted of K.
15) Glendale clay (Ana County, New Mexico), a Typic Torrifluvent-1993,1994
16) Bolfar clay loam (Merced County, California), a Cumulic Haplaquoll-1993,1994
17) Escano fine loam (Merced County, California), a Typic Haplaquoll-1993
18) Honcut silt loam (Merced County, California)-1993
19) Wasco sandy loam (Kings County, California), a Typic Torriorthent-1993
20) Kimberlina fine sandy loam (Kings County, California), a Typic Torriorthent-1993,1994
21) Nord fine sandy loam (Kings County, California), a Cumulic Haploxeroll-1993,1994
22) Grabe silt loam (Graham County, Arizona), a a Typic Torrifluvent-1993,1994

Other Cotton Soils

Limestone Valley: This region is in the limestone valleys and uplands of northern Alabama and is made up of predominantly silty, residual soils.
23) Decatur silt loam (Limestone County, Alabama), a Rhodic Paleudult-1992,1993,1994
24) Dewey silt loam (Limestone County, Alabama), a Typic Paleudult-1993
Deep Loess Soils: These soils cover a region of western tennessee upland from the Mississippi River.
25) Loring silt loam (Gibson County, Tennessee), a Typic Fragiudalf-1993
26) Lexington silt loam (Madison County, Tennessee), a Typic Paleudalf-1993
27) Memphis silt loam (Fayette County, Tennessee), a Typic Hapludalf-1993,1994
Piedmont: Cotton is also grown in the Piedmont region of the Southeast.
28) Helena sandy loam (Nottoway County, Virginia), an Aquic Hapludalf-1993,1994
Vertisols: The Blacklands region of Texas supports excellent cotton production on its calcareous Vertisols.
29) Burleson clay (Williamson County, Texas), an Udic Paleustert-1993

Each cooperator used varieties and management practices common to his/her state. Varying soil K application rates were applied in replicated tests, and yield was determined. A randomized complete block design was used with three application rates (0, 50, and 100 lb $K_2$0/A) and four replicates. Application rates may vary slightly by location. Soil samples were taken to 45 cm depth (in 15 cm depth increments) from each location prior to K fertilization. The following initial physical and chemical properties were determined: particle size analysis, clay mineralogy, organic matter content, CEC, soil pH, NH_4OAc-extractable K, Ca, and Mg, Mehlich-1 extractable K, Ca, and Mg, and Mehlich-3 extractable K, Ca, and Mg.

The method for determination of KBC which was utilized was developed by Cassman et al. (1990) and modified by Robert Miller. They used a solution-phase K^+ soil test to identify soils where a response to added K is likely and a K fixation isotherm method to estimate the fertilizer K requirement. The modified method requires a seven-day incubation in 10 mM KNO_3 and two sequential extractions to calculate K fixation percentage.

Results and Discussion

After clay mineralogy was determined by x-ray diffraction, the soils were grouped into seven mineralogical classes:
A) dominated by kaolinite and hydroxy-interlayered vermiculite--coastal plain, piedmont, limestone valley
B) dominated by mica--high plains
C) equal amounts of mica and vermiculite--arid west and high plains
D) moderate to high smectite and vermiculite--arid west and high plains
E) dominated by kaolinite with low to moderate amounts of smectite and hydroxy-interlayered vermiculite--coastal plain
F) dominated by smectite with moderate amounts of mica and kaolinite--Mississippi delta and deep loess soils
G) dominated by smectite with minor amounts of mica and kaolinite--arid west and vertisols

All of the experimental sites which had yield responses to K fertilizer were in mineralogical classes A, E, and F (Table 1). These three mineralogical classes also had the lowest mean K fixation percentages (ranging from 93-102) as compared to the other mineralogical classes (ranging from 104-163). Grouping soils by region rather than by mineralogical class showed similar results (Table 2). Regions which had positive yield responses to K fertilizer all had mean K fixation percentages $\leq$ 102 (Coastal Plain, Deep Loess, Piedmont, and Mississippi Delta). Regions without yield responses to K all had K fixation percentages > 102.

Using all 45 of the raw data points to determine critical level, the data would define the critical level between 100 and 110% K fixation (Figure 1). (In Figures 1-4 only significant yield increases were graphed with a positive lint yield increase. Those sites with no significant yield response are graphed with zero lint yield increase.) If the critical level was set at 110%, 36% of the soils below that level would be expected to respond to K fertilizer, and none of the soils above that level would respond. Lowering the critical level to 103% would increase the probability of yield response below the critical level to 41%, but would also increase probability of yield response above that level to 6%. A further reduction in critical level to 100% would increase probability of yield response to 44% below the critical level and to 14% above the critical level. Up to a K fixation of 100%, there is a high probability of yield response. From 100-110% K fixation, there is a low probability of yield response. Above 110%, the probability of cotton yield response to K fertilizer is nil.

Correlating K fixation with other soil properties showed that it was best correlated to CEC as opposed to clay content, organic matter content, or soil pH (Table 3). Evangelou and Karathanasis (1986) found that for six Kentucky soils, KBC was linearly related to soil CEC. In another study, Uribe and Cox (1988) found that KBC and CEC were linearly related for 17 soils from three major physiographic regions of North Carolina. However, in this study, K fixation was more highly correlated to extractable K content than to CEC. Mehlich-3 and ammonium acetate extractable K were correlated better than Mehlich-1 extractable K with K fixation.

Potassium fertilizer responses occurred on soils with Mehlich-1 soil K between 20 and 131 mg/kg (Figure 2). However, there was only one data point above 131 mg/kg in this study. Using this data, we could predict a K yield response would occur 32% of the time using a Mehlich-1 critical level of 131 mg/kg. Of all the sites studied, yield response occurred in 31% of the sites; therefore, Mehlich-1 was no better than no soil test at all for predictability of K yield response.

The Mehlich-3 extractant also has a critical level of 130 mg/kg, but prediction of yield response below that level was increased to 41% as compared to 32% with Mehlich-1 (Figure 3). The critical level for ammonium acetate could be set at about 154 mg/kg and improve predictability of yield response to 46% (Figure 4). Not only were Mehlich-3 and ammonium acetate extractable K better correlated to K fixation, they were also better indicators of K yield response. The ammonium acetate extractant was equally good (46%) for prediction of yield response as compared to K fixation percentage (44%).

The use of K fixation percentage as a predictor of cotton yield response to K fertilization shows promise across the Cotton Belt and merits further research. This research project will continue through 1996 and also includes relating plant analysis (leaf and blade) to soil K fixation and the inclusion of subsoil sampling in improvement of soil testing for K availability.

References

1. Barber, S.A. 1984. Soil nutrient bioavailability. John Wiley and Sons. Inc., New York.

2. Beckett, P.H.T. 1964a. Studies on soil potassium: I. Confirmation of the ratio law: Measurement of potassium potential. J. Soil Sci. 15:1-8.

3. Beckett, P.H.T. 1964b. Studies on soil potassium: II. The "immediate" Q/I relations of labile potassium in the soil. J. Soil Sci. 15:9-23.

4. Beegle, D.B., and D.E. Baker. 1987. Differential potassium buffer behavior of individual soils-related to potassium corrective treatments. Commun. Soil Sci. Plant Anal.18:371-385.

5. Cassman, K.G. 1986. Soil, crop management and plant factors which influence cotton potassium nutrition on vermiculitic soil of the San Joaquin Valley. J. Fert. Issues 3:38-45.

6. Cassman, K.G., D.C. Bryant, and B.A. Roberts. 1990. Comparison of soil test methods for predicting cotton response to soil and fertilizer potassium on potassium fixing soils. Commun. Soil Sci. Plant Anal. 21:1727-1743.

7. Cervantes, C.E., and R.G. Hanson. 1991. A potential method to incorporate quantity/intensity into routine soil test interpretations. Commun. Soil Sci. Plant Anal. 22:683-700.

8. Evangelou, V.P., and A.D. Karathanasis. 1986. Evaluation of potassium quantity-intensity relationships by a computer model employing the Gapon equation. Soil Sci. Soc. Am. J. 50:58-62.

9. Johnston, A.E., and K.W.T. Goulding. 1990. The use of plant and soil analyses to predict the potassium supplying capacity of soils pp. 153-180 In Development of K-fertilizer Recommendations. 22nd Colloquium of the International Potash Institute. Bern, Switzerland.

10. Krishnamurthy, V., B.V. Ramakrishnayya, and N.C. Gopalachari. 1984. Available potassium status of flue-cured tobacco in soils of Andhra Pradesh. Fertilizer News 29:36-39.

11. Sharpley, A.N. 1990. Reaction of fertilizer potassium in soils of differing mineralogy. Soil Sci. 149:44-51.

12. Uribe, E., and F.R. Cox. 1988. Soil properties affecting the availability of potassium in highly weathered soils. Soil Sci. Am. J. 52:148-152.

13. Vopenka, L. 1989. Detailed determination of potassium fertilization from data non-exchangeable potassium in soils. Rostlinna-Vyroba 35:595-602.

14. Woodridge, J. 1988. Potassium soil plant relations in apple and pear orchard soils. Deciduous Fruit Growers 38:154-160.

Table 1. Potassium fixation by mineralogical class.

Mineralogy	% K Fixation	CEC (cmoles/kg)	Yield Response[1]
A	93	8	4/16
E	98	5	3/5
F	102	8	6/10
G	104	20	0/3
D	104	21	0/7
B	155	30	0/2
C	163	13	0/7

[1] Yield response given as fraction of total sites which showed a positive yield response to applied K fertilizer.

Table 2. Potassium fixation by region within the Cotton Belt.

Region	% K Fixation	CEC (cmoles/kg)	Yield Response[1]
Coastal Plain	91	5	6/15
Deep Loess	99	8	5/8
Piedmont	99	21	1/2
MI Delta	102	6	1/2
Limestone Valley	103	8	0/4
Arid West	116	20	0/13
Vertisols	121	12	0/1
High Plains	172	16	0/5

[1] Yield response given as fraction of total sites which showed a positive yield response to applied K fertilizer.

Table 3. Correlation coefficients relating soil properties with K fixation.

Cation Exchange Capacity	0.14
Clay Content	0.10
Organic Matter Content	0.03
pH	0.03
Mehlich-1 Extractable K	0.24
Mehlich-3 Extractable K	0.34
Ammonium Acetate Extractable K	0.34

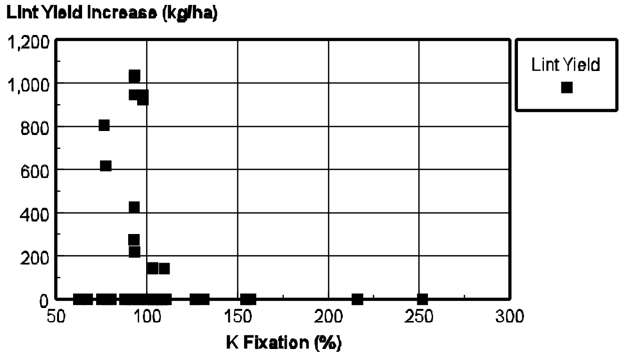

Figure 1. Yield increase as predicted by K fixation.

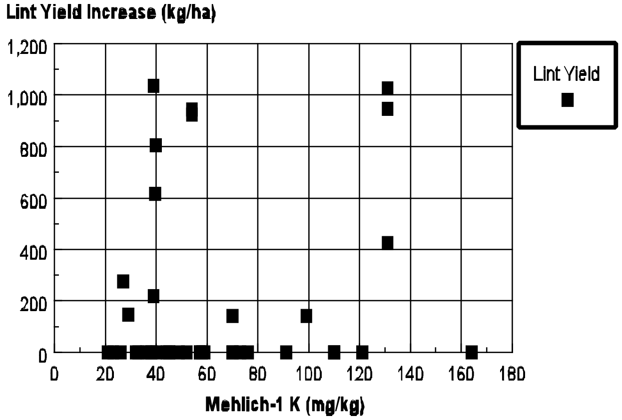

Figure 2. Yield increase as predicted by Mehlich-1.

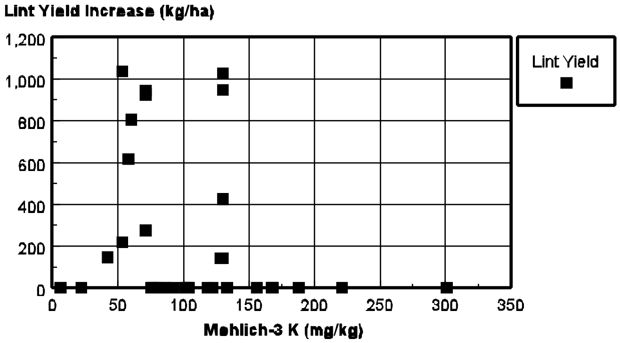

Figure 3. Yield increase as predicted by Mehlich-3.

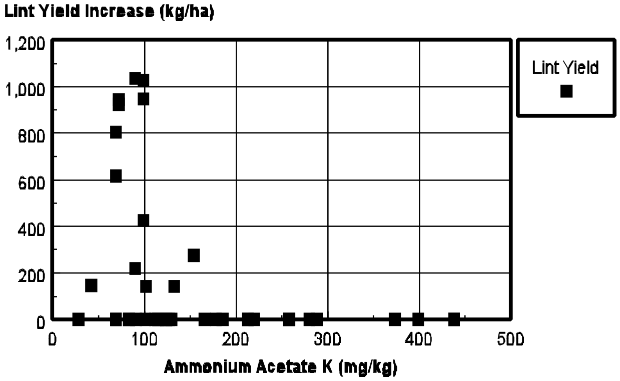

Figure 4. Yield increase as predicted by ammonium acetate.