IMPORTANCE OF SUBSOIL POTASSIUM

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Abstract

Recent information has emphasized the importance of nutrient distribution by depth in soils. Information from across the Cotton Belt in the U.S. has demonstrated that cotton yields have been affected by accumulation of potassium (K) near the soil surface with subsequent depletion of subsoil K. This condition combined with changes in K demand by new, high-yielding cotton varieties has led to a change in cotton K deficiency symptoms and delayed diagnosis of the actual problem. Recent studies have emphasized the importance of deep placement of K in increasing cotton yields. Other studies have demonstrated the effects of long-term soil fertility programs on nutrient distribution in soil profiles and the effects on following crops. The question of the importance of subsoil nutrient levels for optimum crop yields continues to represent an interesting area for research.

Introduction

The importance of K in cotton nutrition is nothing new (Cooper and Donald, 1949). Symptoms of K deficiency in cotton have been well defined and described as generally as "cotton rust". Those symptoms were described by various authors as yellowish-white mottling of the older foliage that changes the leaf color to light yellowish-green. Yellow spots begin to appear between the veins, then the centers of the spots die and numerous brown specks occur at the leaf tips, around margins and between veins. As the physiological breakdown progresses, the whole leaf becomes reddish-brown, dries and becomes necrotic. Many leaves are shed prematurely. Bolls fail to develop properly and many fail to open or open only partially. Potassium deficient fiber is of poor quality. All of these symptoms occur at the bottom of the plant on the lower, older leaves due to the general mobility of K.

Over the past several years, however, cotton plants have changed their appearance in response to the old problem of K deficiency. As far back as the early 1960's, research plots in Arkansas with Rex variety of cotton exhibited yellowing of leaves at the top of the plants (Maples, et al., 1989). Later in the 1980's, reports of K deficiency symptoms on young cotton leaves at the top of the plants were reported in Alabama. Potassium deficiency symptoms at the top of the cotton plant on new leaves were observed in Arkansas in 1985 in K fertilization studies and were confirmed by tissue analyses. Continuing studies confirmed through leaf petiole K analyses that deficiency symptoms occuring at the top of the cotton plants were indeed due to K and were similar in all other aspects to traditional symptoms except the position on heavily fruiting plants.

Cotton K deficiency in the San Joaquin Valley of California was noted as far back as the late 1950's (Stromberg, 1960) and was estimated to reduce cotton yield on 15 to 20 percent of approximately 1.2 million acres of cotton. During the 40 years from the late 1950's until the early 1990s, the scientific community debated whether symptoms similar to cotton deficiency were actually a disease or a nutritional problem (Cline, 1991; Mikkelsen, et al., 1988). Like the situation in Arkansas, deficiency symptoms in California cotton included bronze leaves with a metallic sheen, leaves with folded misshaped edges and marginal necrosis usually occuring in the upper one-third of the plant in late season (Munier, 1991). In the controversy over cause of the problem, verticillium wilt or K, the malaise of the crop was termed "cotton decline".

The situation was complicated by the fact that soil testing and recommendations did not reliably identify soil on which a response to applied K was likely (Cassman, 1986) and similarly did not provide an accurate estimate of fertilizer-K requirements.

The combination of apparant changes in cotton K deficiency symptoms and problems of identification of K-deficient soils through soil testing led to some interesting conclusions and an impressive array of continuing research on K fertilization of several crops.

California

Soils where cotton K-deficiency occurs in the San Joaquin Valley are mostly derived from granitic alluvium and contain significant amounts of biotite mica at various stages of weathering plus vermiculite (Shaviv, et al., 1985). Cassman, et al. (1990) point out that fertilizer-K has rarely been applied to soils in cotton-based rotations in California while crop rotations with alfalfa for hay or corn for silage are extremely K-extractive. Cassman, et al. (1989) have shown that where exhaustive K removal from cropping had occured on vermiculitic soil, very heavy fertilizer-K applications (over 500 lb K_2O/A/yr) were required to obtain maximum seed cotton yield (Figure 1).

Cassman, et al. (1990) surveyed the relationship between seed cotton yield and four soil test methods for K at 38 on-farm sites over two years. They found that intensity parameters obtained from two soil tests measuring solution-phase K^+ concentration in soil-solution suspensions were the best predictors of cotton yield across soils, sites, and years. Quantity parameters based on 1 M ammonium NH_4-extractable K or K extracted by 5 N H_2SO_4 were significantly less precise in yield predictions. They estimated that the improved diagnostic capability of the solution-phase test likely resulted from the large K buffering capacity provided by nonreplaceable K reserves in these vermiculitic soils.

Interestingly, Cassman and co-workers noted that the conclusions on soil test K measurements were more correlated to the surface 0.2 meters (8 inches). Deviations from regression with two solution-phase tests decreased significantly when the mean solution-phase K^+ concentration from 0 to 0.4 meters (16 inches) was used to predict seed cotton yield.

The improved relationship of plant yield with soil sampling to greater depth was consistent with findings of Gulick, et al. (1989). Gulick, et al., showed that for both cotton and barley, plant dry matter and K uptake increased linearly with increased topsoil depth but barley K uptake with increasing topsoil depth was 3.6 to 6.5 times greater compared to cotton with frequent and infrequent irrigation, respectively (Figure 2). Increased K uptake per unit increase in topsoil depth reflected coincident root and K distribution. Poor exploitation of topsoil layers by the cotton root system was attributed to greater sensitivity at a low soil water potential.

Gulick and co-workers concluded that a root system with little compensatory root development in the surface soil when subsoil is low in nutrients may limit K uptake and crop productivity on layered soils such as in the San Joaquin Valley and might require management systems designed to promote more congruent root and nutrient distribution. They also concluded that under rainfed conditions, crop residue management and tillage systems which conserve moisture at the soil surface might promote root distribution coinciding with surface-soil nutrient availability. However, furrow-irrigated systems might require maintenance of nutrient supply in subsoil zones by deep fertilizer placement to enhance nutrient uptake by crops which tended to poorly exploit the surface layer when subsoil nutrient availability is low. Gulick and co-workers also concluded that the poor K nutrition of cotton grown in the layered, vermiculitic soils of the San Joaquin Valley may reflect the low K supply in subsoil and poor root exploitation of the surface layer where K availability is highest.

Woodruff and Parks (1980) pointed out that an adequate K supply in surface soil can mask K depletion in deeper layers, which may impact K nutrition of crops with deep, low density rooting patterns like soybean and cotton more than crops which have high root density concentrations in surface soil zones.

Gulick, et al., and Woodruff and Parks' conclusions are supported by the reports of Khasawneh and Copeland (1973) and Barber (1984) who emphasized that since K primarily moves to the root surface by diffusion, the density, diameter, and distribution of roots are the most important determinates of crop K uptake.

Concentrations of specific ions such as ammonium (NH_4^+), nitrate (NO_3), and phosphate ($H_2PO_4^-$) stimulate root proliferation, particularly when supplied to a localized zone in the root system (Stryker, et al., 1974; Drew, 1975; Barber, 1984). Gulick, et al. noted that although K appears to have little effect on root development, the profile distribution of available K often follows that of ammonium, nitrate, and phosphate and speculate that the apparent sensitivity of cotton to a limited soil K supply may result in part from a relatively non-plastic root system which does not concentrate root development in surface soil zones where K availability is highest.

Roberts (1992) reviewed the pros and cons of surface applications of potassium on the K-fixing soils of the San Joaquin Valley. Noting the difficulty of soil test procedures to predict K needs, Roberts emphasized plant tissue anaysis as an excellent indicator of soil-plant-K interactions and supported its use to guage the effectively utilization of soil K applications.

The general disadvantages of surface applications of K could be offset somewhat by either fall or early spring applications which would allow incorporation through various tillage operations. The variety of options and methods of surface application emphasize this as a versatile and manageable means of addressing K problems. Expanding the definition of surface application to include the top 8 to 12 inches of soil draws attention to two additional methods of K application that are gaining interest in California, namely early season sidedressing and K application in irrigation water.

Munier (1991) reported excellent cotton responses to K sidedressed early (3 to 5 inches tall) 8 to 10 inches on both sides of the row at depths of 5 to 6 inches. Roberts pointed out that the major disadvantages of surface applications of K including high rates of fixation can be turned around with time, patience and large amounts of applied K. Data in Table 1 show changes in extractable K that occurred from three annual K applications. Note that soil K to a depth of 16 inches was improved by these heavy, repeated applications.

In the discussion of the importance of nutrient distribution with depth, Brouder and Cassman (1990) emphasized the distinct differences between cotton varieties' abilities to utilize soil K. They demonstrated a significant genotypic difference in K uptake and sensitivity to late-season K deficiency associated with differences in the determinacy of root growth after peak bloom. More K-efficient varieties had a larger mean root diameter and an increased rate of root extension after peak bloom that resulted in 58 percent more total root surface area by mid-August then the sensitive variety. Selection of a variety that is more efficient at foraging for soil K is an important decision and can greatly impact the overall utilization of K inputs and the distribution of K with depth.

Mississippi Delta

Potassium problems with cotton in the Mississippi Delta (Arkansas and Mississippi) have been reported for over 30 years (Maples, et al., 1989). Following Maples' work in Arkansas, Tupper at Mississippi State University began investigation of K problems on cotton and efficiency of methods of application to overcome the deficiencies. Samples from over 500 center-pivot irrigated cotton fields in the Mississippi Delta between 1985 and 1986 (Table 2) indicated a high percentage of the samples tested low in available K at a depth of 12 to 18 inches.

Consequently, Tupper embarked on a series of studies to evaluate deep-banding of K for cotton with interesting results. Placement of K in a continuous band from a depth of 6 inches to 15 inches beneath the seed row effectively increased cotton yields (Tupper, 1988). The study compared controls with 80 lb/A K_2O surface-applied and 80 lb/A K_2O deep banded. Soil from the experimental site tested low to very low from a depth of 6 inches to 24 inches. Surface soils' K values were medium. Both deep and surface applications of K significantly increased lint yields (Table 3). Total yields from two harvests were somewhat higher with the 6 to 15 inch band.

In a series of continuing studies, Tupper (1992), Tupper and Ebelhar (1992) and Tupper et al. (1992) reported on the desirability of correcting low soil test K values in the subsoil with a low concentration, deep band placement of K, directly under the planted row. Tupper and Ebelhar (1992) reported that soil test K levels in the 10 to 15 inch depth were raised 1 lb/A with each 3 lb K_2O/A applied in a deep band over a five year period. Cotton lint yields were increased with a combination of subsoil tillage at a 45 degree angle to the row and deep banding of K. During that five year study, deep banding of K significantly increased lint yield over both ripped and non-ripped treatments without K (Table 4). Ripping alone did not signficantly increase lint yield. Deep banding of K produced longer tap roots than either ripped or non-ripped treatments without added K (Table 5).

Tupper (1992) concluded that subsoil analyses (6 inches to 12 inches or preferably 6 inches to 15 inches deep) should be undertaken to assess problems before considering deep banding. A subsoil pH of 5.7 or higher is desirable or correction with a deep placement of lime and potassium may be required. Tupper noted that subsoil K deficiencies can be corrected more rapidly with deep banding than by surface K applications.

On the other hand, studies by Varco, et al. (1992) failed to show any lint yield advantage for deep banding of K. Broadcast application of K resulted in increased K uptake with increasing rates, while a consistent trend was not apparent for banding or combined applications of band and broadcast. In the final analysis, however, combined broadcast and deep banded treatments resulted in the greatest lint yield increases.

Arkansas studies have shown good responses to broadcast K applications with essentially no advantage for deep-banding (Keisling, 1991).

Alabama

A survey of 108 cotton fields in Alabama during 1990 showed that 81 percent of the subsoil samples had a medium or lower soil test K rating (Mitchell, et al., 1990; Michell, et al., 1991). Many of those subsoils had been biologically depleted of K through many years of continuous cropping. Mullins, et al. (1992a) studied cotton response to surface and deep placement of K under Alabama conditions. To evaluate methods of K application and the effects of K placement in the subsoil, K was either broadcast on the surface or placed in a continuous band from 6 to 15 inches deep behind a subsoiler shank. Only one of three sites responded to deep banding of K and then only at the lowest application rate. Higher rates of surface broadcast K consistently produced highest yields compared to the deep placed treatments.

Mullins and co-workers concluded that four factors may have affected a consistent response to deep placed K. First, acid subsoil pH at two sites could have inhibited root growth limiting the ability of the plants to fully access the deep placed K. Secondly, cotton in these studies was not planted on beds and the seed may not have been centered over the subsoil channels. Third, the volume of soil affected by the deep placement of K may have been too small reducing the portion of the cotton root system that was affected by increased subsoil K levels. Fourth, the variety of cotton used in this study (Deltapine 50) may not be as responsive to deep placement of K as other varieties. Tupper, et al. (1991) showed that cotton varieties differ in their response to deep placement of K. Over a three year period, variety DES 119 responded better to deep placement of K than varieties Deltapine 50, Stoneville 453, and Coker 130. Surface and subsoil samples were classified low in exchanageable K in that study.

Other studies by Mullin, et al. (1992b) evaluated the effects of subsoiling, broadcast K without subsoiling, broadcast K with subsoiling, and deep placement of K. The Norfolk fine sandy loam of the experimental site had a medium soil test K rating for the top 6 inches and a low soil test K rating at greater depths and exhibited a well developed traffic pan at depths of 6 to 15 inches. Soil water and root density measurements showed that water uptake and root growth at depths greater than 8 inches were improved by subsoiling and the application of fertilizer K. However, the application of K on the surface in combination within-row subsoiling resulted in the highest whole plant weight, leaf surface area and seed cotton yield. Higher yields of the surface application of K with in-row subsoiling probably resulted from the surface applied K being exposed to a larger proportion of the cotton root system as compared to the in-row, deep placed K.

Netshivhumbe (1992) studied soil profile K distribution on selected K variable plots from long-term fertility studies summarized by Cope (1981, 1984). Netshivhumbe noted that long-term fertilization increased the concentration of exchangeable K in surface horizons of soils at three experimental sites. Subsoil K contributed to total dry matter production of pearl millet on three soils increasing K uptake as much as 20 percent. He concluded that subsoil K testing on soils where K accumulates in the subsurface horizons might lead to the economic utilization of those plant nutrients. Conversely, one might conclude from those same studies that depletion of subsoil K could be a factor in reduced plant growth.

Other Areas

An interesting report by Schmitt, et al. (1991) documented the residual effects of alfalfa extraction of K in an alfalfa-corn rotation. The initial study was conducted to investigate the interactive effects of K fertilization, alfalfa cutting management schedules, and alfalfa varieties differing in winter hardiness ratings. Potassium fertilization included rates of 0, 125, 250, and 500 lb K_2O/A/year. Initial plowdown K applications were repeated as topdressed treatments in two following years.

Bulk corn in the plot area representing the sixth crop after initiation of the study showed severe K deficiency symptoms (Figure 3) related to K fertilizer rates in the original main plots. Corn grain yields reflected the K effects and ranged from 6 to 180 bu/A (Figure 4). An interesting aspect of this study is that available K in the plow layer only ranged from 53 to 87 ppm K, hardly reflective of the tremendous differences in yields. Despite some possibility for leaching (Waukegan silt loam) on the site, it is interesting to speculate as to the effects of alfalfa on K removal from lower soil horizons. Consideration of subsoil values might have been part of a more predictive set of soil test recommendations from such an area.

Kansas high-yield alfalfa studies reported by Ball and Teneyck (1980) suggest the same heavy subsoil use of nutrients, particularly K, that probably occurred in the Minnesota study. Alfalfa yields averaging over 11 T/A removed more then 500 lb of K_2O equivalent per acre per year. Even though initial soil test results indicated that alfalfa should respond to K fertilization, there was no response to K applications of 160 lb/A K_2O annually. Surface soil tests on plots where no K was applied declined from an initial 259 lb K/A to about 90 lb/A. Possibly the mineralology of the sandy soil of the test site released enough K to supply the high yielding alfalfa but the possibility also exists that heavy subsoil K depletion had occurred. Unfortunately, no subsoil samples were taken which would have clarified the situation.

Recent research in western Missouri (Sanders, et al., 1992) has shown that alfalfa can significantly lower K levels in the subsoil. On a Marshall silt loam, a 6-year corn-soybean rotation was compared to an alfalfa-corn rotation in side-by-side studies. Soil test K was rated high to very high based on a 0 to 6-inch sample. The total amount of K_2O applied on the alfalfa-corn rotation was 530 lb/A over 6 years versus 290 lb/A for the corn-soybean rotation.

Soil profile samples in 3-inch increments in the seventh year of the study determined differences in profile K extraction patterns between the two cropping systems (Figure 5). The alfalfa-corn rotation produced much lower available soil K levels throughout the profile, even though it received almost twice as much K fertilization.

Depending upon the following crop and possibly upon rooting pattern differences between varieties of other crops, the effects of such subsoil K depletion could have significant effects upon future crop production. Such a situation would pose an excellent opportunity to compare variable rate responses to applied K (and other nutrients).

Kentucky scientists (Vaught, et al., 1977) studied fertilizer recommendations for alfalfa on deep red soils of the Western Pennyroyal area. Soil samples were taken to a 36-inch depth in 6-inch increments before and after the experiment. Those samples indicated little influence of K rates on subsoil K content. A rate of 200 lb K_2O/A/year supplied only 1200 lb K_2O during the six years while total removal was 2290 lb K_2O/A during that time. During the same period, surface soil test levels increased from 240 to 363 lb/A. Without the application of K, however, plant removal of about 1900 lb K_2O/A over a six year period decreased the surface soil test level from 240 to 145 lb K/A.

Subsoil sampling did not really show a change in soil test K with depth but surface soil test K accumulation combined with much larger amounts of K removed than applied strongly suggest that lower soil horizons provided tremendous amounts of available K.

Summary

Taproot crops such as cotton and alfalfa extract nutrients and moisture deep into the subsoil. This characteristic can have significant effects on the ability of crops to withstand stress but also may place higher emphasis on the availability of subsoil nutrient levels for optimum crop growth. Heavy, late-season demand for K by high yielding cotton varieties has emphasized the importance of subsoil K for optimum crop yields and high fiber quality. It is interesting to speculate on the effects of subsoil nutrient levels on nutrient uptake and yield of other crops which may follow in rotation. Rehm (1990) reported excellent responses to K knifed into the ridge for ridge-till corn even when the surface soil test K levels were adequate. Differences in response between corn hybrids has led to studies of soil, tillage, and fertilizer K effects on root distribution in corn. Allan, et al. (1992) reported that soil properties affected by tillage as well as hybrid differences appear to be involved in observed early season K deficiency in ridge-till corn. They speculated that less soil K may be available in the ridge-till system compared to a chisel plow system and suggest that some effects of the tillage system on root and/or soil properties seem likely since ridge tillage reduces K uptake for many hybrids.

The importance of K placed deeper in the soil profile under such conditions is still being investigated. Corn hybrids more prone to K defiency under ridge-till systems may exhibit greater early shoot growth at the expense of roots or greater proliferation of surface roots at the expense of deeper root development.

In the final analysis, more remains to be determined about the importance of subsoil nutrient levels, how those nutrient levels interact with newer, higher-yielding varieties and hybrids and whether fertilizer management systems should pay greater attention to modifying nutrient availability in these soil regions.

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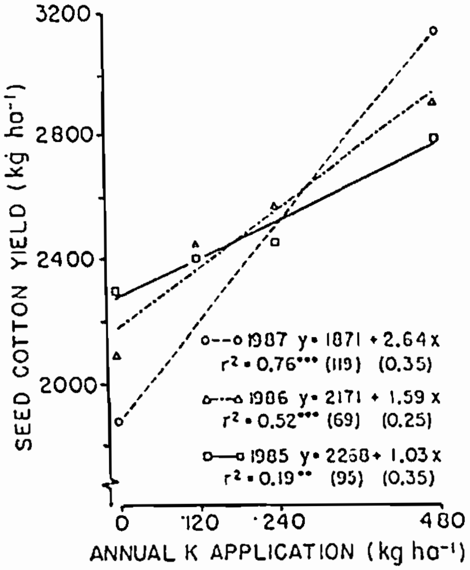

Figure 1. Very high annual broadcast K applications have been required to overcome K deficiencies and maximize cotton yields on soils of California's San Joaquin Valley (Cassman, et al., 1989).

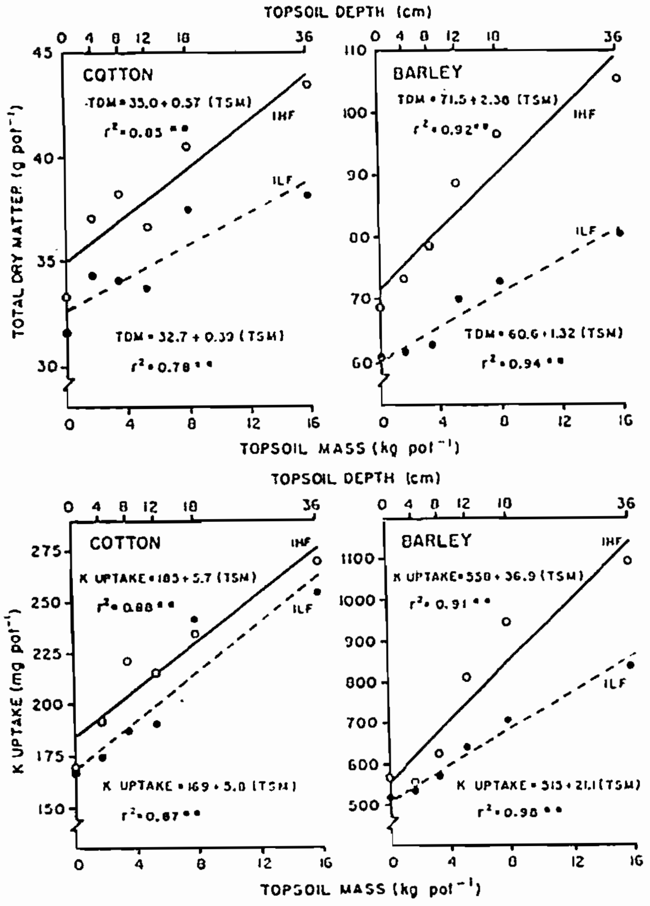

Figure 2. Cotton and barley dry matter and K uptake increased linearly with increased topsoil depth (Gulick, et al., 1989).

Figure 3. Depletion of soil K by alfalfa led to tremendous differences in corn growth and severe K deficiencies (Schmitt, et al., 1991).

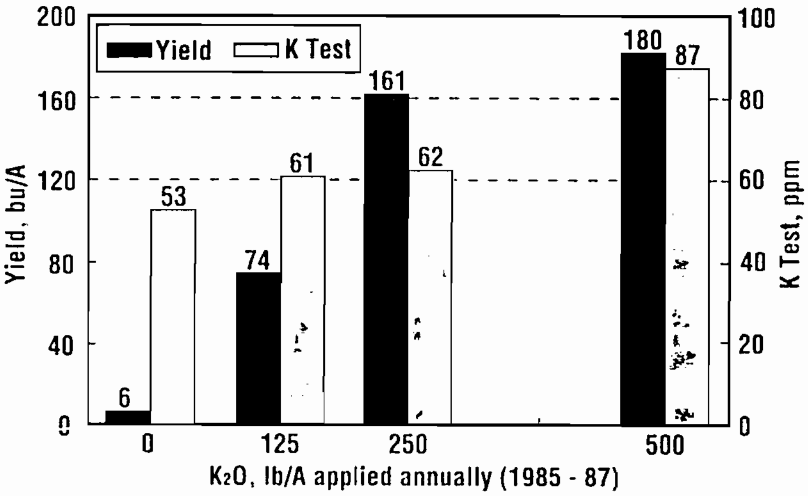

Figure 4. Variable degrees of soil K depletion by alfalfa, depending on rate of K application, produced a tremendous range in corn yields but relatively little difference in surface soil K test values (Schmitt, et al., 1991).

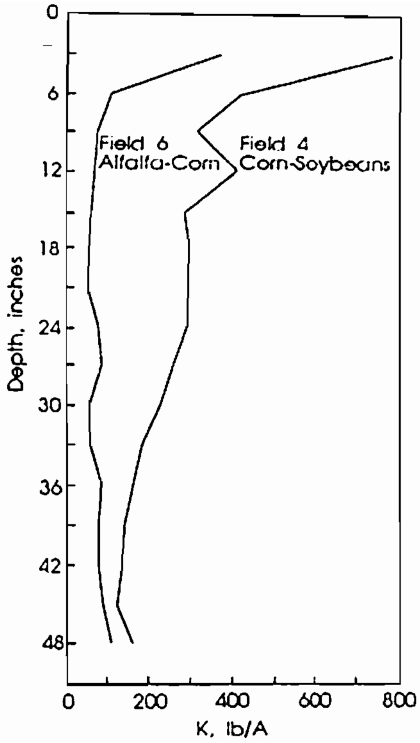

Figure 5. An alfalfa-corn system substantially lowered subsoil K levels compared to a corn-soybean rotation in this Missouri study (Sanders, et al., 1992).

Table 1. Change in extractable K from three annual K applications on a Grangeville sandy loam soil (California).

Cumulative K_2O input	Depth		Extractable K (ppm)
(lb/A)	(in.)	1985	
0	0-8		85.8
	8-16		66.3
		1987	
0	0-8		70.2
	8-16		62.4
1500	0-8		117.0
	8-16		81.9

Cassman, et al., 1989.

Table 2. Soil test values for exchangeable K from Mississippi on-farm center-pivot irrigation studies.

Soil sample depth	High	Exch. K^+ level Medium	Low
(Inches)	--------------------------	% of samples	------------------------
0-6	45.4	24.9	29.7
6-12	10.4	13.7	75.9
12-18	4.3	6.3	89.4

Tupper, et al., 1990.

Table 3. Effect of K on irrigated 2 x 2 skip-row cotton

K_2O lb/A	Placement	1st Harvest lb/A	2nd Harvest (%)	2nd Harvest lb/A	Total Lint lb/A
0	--	1,330	(91)	127	1,457
80	Deep (6-15 in.)	1,619	(94)	104	1,723
80	Surface	1,573	(95)	75	1,648
					5% LSD = 90

Tupper, 1988

DES 119 variety.
K soil test = 0-6, M; 6-12, L; 12-24, VL.

Table 4. Effects of deep tillage and K on lint yield on non-irrigated cotton.

	Deep		Lint yield		
	Ripped	K_2O (6-15 in.)	Not subsoiled	Subsoiled	Treatment mean
		(lb/A)	-----------------(lb/A)---------------------		
5 year Mean	No	0	883	982	932 C
	Yes	0	931	982	956 CB
	Yes	80	992	1024	1008 AB
	Yes	120	987	1098	1042 A
	Yes	160	1008	1088	1048 A

Variety: DES 119. Tupper and Ebelhar, 1992.

Table 5. Effects of deep tillage and K on tap root length of non-irrigated cotton.

	Deep		Tap root length		
	Ripped	K_2O (6-15 in.)	Not subsoiled	Subsoiled	Treatment mean
		(lb/A)	----------------(lb/A)----------------------		
5 year Mean	No	0	11.1	11.6	11.4 D
	Yes	0	12.0	12.5	12.2 C
	Yes	80	12.8	12.7	12.7 BC
	Yes	120	12.8	13.8	13.3 AB
	Yes	160	12.8	14.1	13.5 A

Variety: DES 119. Tupper and Ebelhar, 1992.

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