NUTRIENT MANAGEMENT FOR CONSERVATION-TILLAGE COTTON IN THE SOUTHEAST

D. Wayne Reeves, Charles Mitchell, Greg Mullins and Joe Touchton[1]

INTRODUCTION

The basic principles of good plant nutrition and sound fertilizer management are the same, regardless of tillage system. When these principles are effectively applied and "fine-tuned" to the unique soil environment resulting from conservation-tillage, both economic and environmental sustainability of crop production are increased. The most important principles of soil fertility in cotton conservation-tillage systems deal with 1) soil pH and liming, 2) nutrient stratification, 3) nitrogen (N) management and 4) use of starter fertilizers.

SOIL pH AND LIMING

Since some conservation-tillage systems limit incorporation of fertilizers and lime, soil pH in the plow layer should be 6.0 to 7.0 in most soils prior to initiating a conservation-tillage system. Some growers use rotations, e.g. with small grains, that require some tillage. However, with continuous no-tillage there is no opportunity to quickly correct soil pH problems since lime must be incorporated into the soil in order to react and raise soil pH. Soil pH will stratify in soils under continuous no-tillage (Fig. 1).

Surface applications of ammonium-containing fertilizers [ammonium nitrate, urea, urea-ammonium nitrate solutions (UAN) and ammonium sulfate] and decomposition of plant residues can rapidly decrease soil pH at the soil surface compared to the entire plow layer in conservation-tillage systems. This affects the way that soil sampling for lime requirement should be done and interpreted in conservation-tillage systems.

When continuous no-tillage is used, a shallow (0- to 2-in.) soil sample should be taken at least every two years. If the lime recommendation is based on an 8-in. depth, the grower should apply to the soil surface only 1/4 the rate of lime recommended by the lab. Although lime must be thoroughly mixed with soil to react and correct soil acidity problems in the plow layer, research has shown that with proper sampling, surface applications of lime without incorporation are effective in reducing soil acidity in the surface of no-tillage systems (Blevins et al., 1978) (Fig. 1). Surface acidification can occur rapidly, and soil pH increases brought about by surface liming are not as quick as when lime is incorporated; therefore, it is imperative that growers keep on top of their liming program in conservation-tillage systems.

In addition to shallow sampling (0- to 2-in. depth), samples should also be taken from the entire depth of the plow layer (0 to 8 in.). If the bulk soil sample from the 0- to 8-in. depth calls for lime, then the entire rate recommended by the laboratory should be applied to the soil surface. If the plow layer was adequately limed prior to initiating conservation tillage, sampling the entire plow layer every three years is adequate. Thereafter, planned tillage rotations, e.g., chisel plowing or disking to plant a cover crop or small grain rotation, can be used to incorporate lime when needed.

Deep placement of lime occasionally receives much attention in the popular press, especially in conservation-tillage systems. Research on a number of crops, including cotton, indicates very little benefit from deep incorporation of lime, provided the surface soil is adequately limed (Doss et al., 1979; Hourigan et al., 1961; Mullins et al., 1992; Reeves et al., 1990). This is not surprising given that deeply placed lime is usually not incorporated and mixed with a sufficient subsoil volume to result in a zone of increased root growth sufficient to elicit a crop response. In a classic research study, cotton exhibited no tendency for roots to grow more profusely in a limed soil layer within an acid subsoil than within the acid subsoil itself, although total root growth was dependent on the volume of soil amended with lime (Pearson et al., 1973). Deep

[1]USDA-ARS National Soil Dynamics Laboratory and Agronomy and Soils Department, Auburn University.

placement of lime in conservation-tillage cotton is expensive as well as energy and labor intensive and is unjustified. Growers should maintain proper soil pH levels in both the surface 2 in. and the plow layer by timely surface applications of lime rather than by investing in expensive equipment for deep placement of lime.

NUTRIENT STRATIFICATION

As with soil pH, both phosphorus (P) and potassium (K) can become stratified with continuous no-tillage (Figs. 2 and 3). For this reason, growers should be certain that the entire plow layer has a "high" soil test rating for these nutrients, especially P, before practicing continuous conservation-tillage. With time, concentrations of these nutrients tend to accumulate near the soil surface, but research has shown that this is not a problem for plant uptake and crop response (Wells et al., 1987). This response is not surprising considering the proven effectiveness of banded fertilizers; surface applications of P and K in continuous no-tillage can be thought of as *horizontal banding*. Higher concentrations of P and K in a surface band coupled with greater root growth close to the soil surface promote efficient uptake of P and K at or near the soil surface in conservation-tillage systems.

Deep placement of K fertilizer has recently been suggested as a means of alleviating late-season K deficiency in cotton on soils testing adequate in surface-soil K but with a low level of K in the subsoil. Stratification of K between the subsoil and soil surface would be even greater in a continuous conservation-tillage system than in a conventional-tillage system. Results from deep placement of K fertilizer studies have been contradictory, and in many cases the effect of subsoiling has been confounded with K placement effects. Research on three soils types in Alabama, however, showed that deep placement of K was no more effective in increasing cotton yields than surface K application (Mullins et al., 1992). At higher rates of K (60 to 90 lb K_2O/acre), surface applications consistently produced higher yields compared to deep placement. On a Coastal Plain soil with a root-restricting hardpan, cotton leaf area, seedcotton yields, leaf K at early bloom and K uptake were greatest when K fertilizer was applied to the soil surface in conjunction with in-row subsoiling (Mullins et al., 1993; Reeves and Mullins, 1993) (Table 1). This research indicates that deep placement of K is not an effective practice and that surface applications of K are adequate, even in conservation-tillage cotton.

If the grower rotates cotton with crops such as small grains or cover crops, which may use some form of conventional tillage, then the recommended P and K that should be applied to cotton can be applied to the conventional-tillage rotation crop and incorporated. If cotton follows a cover crop or small grain, the rate of P and K applied should be increased to compensate for P and K removed in the rotation crop. For example, a 55-bu/acre wheat crop will remove approximately 19 lb K_2O/acre and 30 lb P_2O_5/acre in the grain. The recommended amount of P and K for the following cotton crop must be increased by this amount when the application is based on a soil test preceding the harvesting of the rotation crop. Likewise, if a cover crop is grazed or harvested for hay or silage, then the P and K removed in the crop must be considered when fertilizing the following conservation-tillage cotton crop. A winter legume or small grain cover crop that produces 4 tons/acre of forage (35% dry matter basis) will contain approximately 45 to 70 lb P_2O_5/acre and 80 to 240 lb K_2O/acre, depending on the forage species. If this crop is grazed or cut and removed, then the P and K removed in the crop must be accounted for in fertilizer applications made for the following cotton crop. A general recommendation in this situation would be to increase the P recommendation by 45 lb P_2O_5/acre; the K recommendation should be increased 70 lb K_2O/acre following small grains as forage and 140 lb K_2O/acre following winter legumes used as forage. Regardless of tillage system, there is no substitute for soil testing and plant analysis, as each soil and cropping situation is unique.

NITROGEN MANAGEMENT

Selection of N fertilizer rates, sources and application methods definitely requires management decisions in conservation-tillage systems that differ from those used in conventional-tillage systems. After crop emergence, surface applications of N fertilizer are the most practical method available for many conservation-tillage systems. Nitrogen sources commonly available are prilled ammonium nitrate, prilled urea, ammonium sulfate and various N solutions. Nitrogen solutions containing more than 19% N contain a considerable amount of urea N. The N in urea-containing fertilizers is subject to volatilization losses in conservation-tillage systems due to the increased contact of the fertilizer with plant residues. Therefore, urea sources of N should be applied in band applications rather than broadcast in order to reduce fertilizer-residue contact. Subsurface banding or injection with knives or disks will further reduce fertilizer residue contact and increase the effectiveness of urea-containing N fertilizers. Injection of anhydrous ammonia is also effective in conservation-tillage systems, and equipment is available for anhydrous application that results in minimal residue disturbance.

The total N requirement for any cotton production system is dependent upon yield potential. In non-irrigated cotton, yield potential is primarily a function of rainfall amount and distribution. If there are no other limiting factors, yield potential of conservation-tillage cotton is usually greater than that of conventional-tillage cotton under drought stress due to increased water conservation. Thus, cotton response to N may be greater in a conservation-tillage system in some years.

Cover crop choice is probably the single most important factor in developing a N-management program for conservation-tillage cotton. Small grain or grass cover crops, such as oat, wheat, cereal rye and annual ryegrass, are used more often than winter annual legumes. The N content of small grain cover crop residues varies but usually ranges from 25 to 50 lb/acre. This N is not readily available, however, because the carbon to nitrogen (C:N) ratio of grass cover crops is usually greater than 30:1. A C:N ratio of 20:1 is a "threshold" value determining whether N is released from residues to the soil (N mineralization) or whether N from any source, including crop residues, is tied up by the microbes that decompose the residue (N immobilization). Values less than 20:1 usually release N to the soil, while values greater than 20:1 usually immobilize N. Early killing of the cover crop results in a lower C:N ratio in the residue, but the total residue is reduced, and the residue decomposes more rapidly, reducing soil coverage. Reduced residue coverage increases the risk of soil erosion and decreases infiltration and storage of soil water. The potential for N losses by denitrification, volatilization and immobilization coupled with the wide C:N ratio of small grain cover crops means that the N fertilizer requirement of cotton following a small grain cover crop may be increased (Brown et al., 1985; Torbert and Reeves, 1991). As a general rule, the **total fertilizer N** applied to conservation-tilled cotton in small grain residue should be increased by 30 lb N/acre compared to recommended rates for conventional-tillage cotton. A starter fertilizer to supply 25 to 30 lb N/acre must be applied to conservation-tilled cotton in small grain residue.

The N content of legume cover crops also varies depending on the species, location and stage of growth of the cover when burned down. For cotton, the two most commonly used and researched winter annual legumes are crimson clover and hairy vetch. The average N content of above-ground residues from legume cover crops reported in research is 90 to 110 lb/acre. The C:N ratio of above-ground residues from legume cover crops is almost always less than 20:1, which means that the N in the residue is mineralized and becomes available to the succeeding crop. How much of this N is released and utilized by a cotton crop during the growing season is dependent on environmental factors, especially rainfall. Although conservation-tilled cotton following a winter legume may not respond to additions of N fertilizer (Touchton et al., 1984; Brown et al., 1985), in some years yield potential and N requirement increase as a result of increased soil water availability when these residues are left on the soil surface. A general recommendation for cotton following a good legume cover crop is to apply 25 to 30 lb N/acre as a starter fertilizer and then monitor the crop closely and apply additional N if needed.

Peak N demand by cotton (lb N/acre/day) occurs from early bloom to peak-bloom (Mullins and Burmester, 1990); two-thirds of the cotton plant's N is taken up after early bloom. Therefore, sidedress, split or multiple N applications usually result in more efficient N use by the plant, less potential loss to the environment and reduced risks of rank growth or N-deficient cotton, regardless of tillage system. Split N applications allow greater flexibility and control by the grower, which is especially critical in conservation-tillage cotton because the processes that control the availability of residual N, i.e., mineralization and immobilization, are even more subject to variations caused by environmental influences than in a conventional-tillage system. Planting cotton with conservation-tillage following winter cover crops can delay maturity (Stevens et al., 1992; Reeves et al., 1989); consequently, proper N management can reduce the risk of delayed maturity in heavy residue situations.

STARTER FERTILIZER APPLICATIONS

With the exception of N management, more research has probably been done on starter fertilizers than on any other fertility practice for cotton in recent years. Cotton is sensitive to reduced soil temperatures, and research on a number of crops has shown that starter fertilizers are especially effective under cool, wet soil conditions. Conservation tillage reduces soil temperatures and increases soil water due to the mulching effect from crop residues. In some conservation-tillage systems, surface soil compaction may also be increased compared to conventional-tillage practices. These conditions can restrict early-season root growth and can slow the chemical, physical and biological processes that control plant nutrient availability. Thus, starter fertilizers can be expected to be more beneficial to conservation-tilled cotton than to conventionally tilled cotton.

Yield increases with starter fertilizers are dependent on a number of variables. These include residual soil fertility, yield potential, nutrient combinations, accompanying tillage and type of crop residue. If some factor other than early-season nutrient availability limits the yield potential of the crop, then starter fertilizers will not result in a yield increase. This fact is based on a fundamental premise of plant nutrition called the "Law of the Minimum." Funderburg (1988) examined starter fertilizer applications in 18 on-farm studies and concluded that profitable responses to starter fertilizers increased when yield potential was 850 lb lint/acre or greater. On a sandy Coastal Plain soil subject to compaction, responses to starter fertilizer occurred only when cotton was planted with in-row subsoiling (Touchton et al., 1986). These examples illustrate that starter fertilizers are an integral component of a good management system; they cannot take the place of deep tillage in compacted soils, substitute for proper maintenance of soil P and timely N applications or compensate for insufficient rainfall in a drought year. Even when yield responses do not occur, starter fertilizers frequently result in increased early-season growth, which can more quickly close canopies, reducing weed competition and promoting earliness.

Research has consistently shown that both N and P are needed in starter fertilizers for cotton (Touchton et al., 1986; Funderburg, 1988; Howard and Hoskinson, 1990). Effective rates have been 15 to 30 lb of N/acre and 15 to 50 lb P_2O_5/acre. In conservation-tillage systems, the optimum N rate in the starter is in the upper end of the recommended range, i.e., 25 to 30 lb N/acre. Although cotton has consistently shown a response to P_2O_5 in starter fertilizers, the N component of the starter effects the greatest response. Ideally, the amount of P in a starter fertilizer for cotton should be on the lower end of the range presented above, so that the N to P_2O_5 ratio is around 1-1.5:1, with 25 to 30 lb N/acre applied.

If equipment is available, the starter should be applied in a 2 X 2 placement, i.e., 2 to 3 in. to the side and 2 to 3 in. below the seed, but banding the starter over the row or placing it in the subsoil slot if cotton is planted with an in-row subsoiler is also effective. Both fluid and solid materials can be used as starter fertilizers. Ammonium polyphosphate solutions such as 10-34-0 and 11-37-0 are frequently used in starter fertilizers. Ammonium phosphates such as monammonium phosphate (MAP) and diammonium phosphate (DAP) are granular products that can be used in starter fertilizers. Various N sources can be mixed with ammonium polyphosphates and ammonium phosphates to obtain the desired $N:P_2O_5$ ratio (1-1.5:1) for a starter fertilizer.

Cotton seedlings are very sensitive to ammonia toxicity, and care must be taken with ammonium N-containing starter fertilizers, especially DAP and urea-ammonium phosphate (UAP), to avoid placing them too close to the seed at planting. The free ammonia liberated from these sources of N and P can cause seedling injury if placed too close to the seed. On soils that may require applications of secondary nutrients, such as sulfur (S), or micronutrients, such as zinc (Zn), formulations of these nutrients can be included in the starter.

Farmers contemplating using conservation tillage should commit themselves to a high degree of management if they wish to make their chosen system work. Key soil fertility management practices for conservation-tillage cotton are 1) eliminating any inherent yield-limiting factors, e.g., in-row subsoil Coastal Plain soils subject to compaction; 2) properly liming and fertilizing the soil to a depth of 6 to 8 in. before beginning a conservation-tillage system; 3) using planned tillage that may be necessary for other crops used in rotations to incorporate lime and fertilizer; 4) sampling soil at appropriate depths and time intervals for the chosen tillage system to determine recommendations for lime, P, K, secondary nutrients and micronutrients; 5) being aware of the special considerations for managing N in conservation-tillage systems, especially in regard to cover crop choice; and 6) using starter fertilizers as an integral component of the management system.

LITERATURE CITED

1. Blevins, R.L., J.H. Grove and B.K. Kitur. 1986. Nutrient uptake of corn grown using moldboard plow or no-tillage soil management. Commun. in Soil Sci. Plant Anal. 17:401-417.
2. Blevins, R.L., L.W. Murdock and G.W. Thomas. 1978. Effect of lime application on no-tillage and conventionally tilled corn. Agron. J. 70:322-326.
3. Blevins, R.L., G.W. Thomas, M.S. Smith, W.W. Frye and P.L. Cornelius. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. Soil & Tillage Res. 3:135-146.
4. Brown, S.M., T. Whitwell, J.T. Touchton and C.H. Burmester. 1985. Conservation tillage systems for cotton production. Soil Sci. Soc. Am. J. 49:1256-1260.
5. Doss, B.D., W.T. Dumas and Z.F. Lund. 1979. Depth of lime incorporation for correction of subsoil acidity. Agron. J. 71:541-544.
6. Funderburg, E.R. 1988. Impact of starter fertilizers. pp. 25-27. *In* J.M. Brown and D.A. Richter (eds.). Proceedings Beltwide Cotton Conference, January 3-7, 1988, New Orleans, Louisiana. National Cotton Council, Memphis, Tennessee.
7. Hargrove, W.L. 1985. Influence of tillage on nutrient uptake and yield of corn. Agron. J. 77:763-768.
8. Hourigan, W.R., R.E. Franklin, Jr., E.O. McLean and D.R. Bhumbla. 1961. Growth and Ca uptake by plants as affected by rate and depth of liming. Soil Sci. Soc. Amer. Proc. 25:491-494.
9. Howard, D.D. and P.E. Hoskinson. 1990. Effect of starter nutrient combinations and N rate on no-tillage cotton. J. Fert. Issues 7:6-9.
10. Mullins, G.L. and C.H. Burmester. 1990. Dry matter, nitrogen, phosphorus, and potassium accumulation by four cotton varieties. Agron. J. 82:729-736.
11. Mullins, G.L., C.H. Burmester and D.W. Reeves. 1992. Cotton response to surface and deep placement of potassium fertilizer. pp. 77-79. *In* D.J. Herber and D.A. Richter (eds.). Proceedings Beltwide Cotton Conference, January 6-10, 1992, Nashville, Tennessee. National Cotton Council, Memphis, Tennessee.
12. Mullins, G.L., D.W. Reeves and C.H. Burmester. 1993. Potassium uptake by cotton and changes in soil chemical properties resulting from the deep placement of dry fertilizer. pp. 1319-1321. *In* D.J. Herber and D.A. Richter (eds.). Proceedings Beltwide Cotton Conference, January 10-14, 1993, New Orleans, Louisiana. National Cotton Council, Memphis, Tennessee.
13. Pearson, R.W., J. Childs and Z.F. Lund. 1973. Uniformity of limestone mixing in acid subsoil as a factor in cotton root penetration. Soil Sci. Soc. Amer. Proc. 37:727-732.
14. Reeves, D.W., J.H. Edwards, C.B. Elkins and J.T. Touchton. 1990. In-row tillage methods for subsoil amendment and starter fertilizer application to conservation-tilled grain sorghum. Soil & Tillage Res. 16:359-369.
15. Reeves, D.W., C.B. Elkins, H.H. Rogers, J.B. Powell and S.A. Prior. 1989. Controlled traffic research with a wide frame spanner for cotton double-cropped with wheat. pp. 519-522. *In* J.M. Brown and D.A. Richter (eds.). Beltwide Cotton Production Research Conference, January 2-7, 1989, Nashville, Tennessee. National Cotton Council, Memphis, Tenessee.
16. Reeves, D.W. and G.L. Mullins. 1993. Subsoiling and K placement: Effects on cotton water relations. pp. 1322-1325. *In* D.J. Herber and D.A. Richter (eds.). Proceedings Beltwide Cotton Conference, January 10-14, 1993, New Orleans, Louisiana. National Cotton Council, Memphis, Tennessee.
17. Stevens, W.E., J.R. Johnson, J.J. Varco and J. Parkman. 1992. Tillage and winter cover management effects on fruiting and yield of cotton. J. Prod. Agric. 5:570-575.
18. Torbert, H.A. and D.W. Reeves. 1991. Tillage and traffic effects on cotton yield and N requirement. pp. 931-935. *In* D.J. Herber and D.A. Richter (eds.). Proceedings Beltwide Cotton Conference, January 8-12, 1991, San Antonio, Texas. National Cotton Council, Memphis, Tennessee.
19. Touchton, J.T., D.H. Rickerl, C.H. Burmester and D.W. Reeves. 1986. Starter fertilizer combinations and placement for conventional and no-tillage cotton. J. Fert. Issues 3:91-98.
20. Touchton, J.T., D.H. Rickerl, R.H. Walker and C.E. Snipes. 1984. Winter legumes as a nitrogen source for no-tillage cotton. Soil & Tillage Res. 4:391-401.
21. Wells, K.L., G.W. Thomas and L.W. Murdock. 1987. Principles of fertilizing and liming no-till crops. Applied Agric. Res. 2:2-9.

Table 1. Effect of subsoiling and potassium (K) fertilizer placement (90 lb K_2O/acre) on leaf area, leaf K at early bloom, K uptake and seedcotton yield of cotton grown on a Coastal Plain soil with a hardpan in central Alabama in 1991.

Treatment	Leaf area	Leaf K at bloom	K uptake	Seedcotton
	cm^2/plant	%	g/plant	lb/acre
no K, not subsoiled	849	1.37	1.21	2589
no K, subsoiled	1298	1.30	1.47	2859
K surface applied, not subsoiled	937	1.68	1.36	3079
K surface applied, subsoiled	2011	1.90	2.48	3292
K deep placed, subsoiled	1281	1.83	1.76	2932
$LSD_{0.10}$	469	0.35	0.63	457

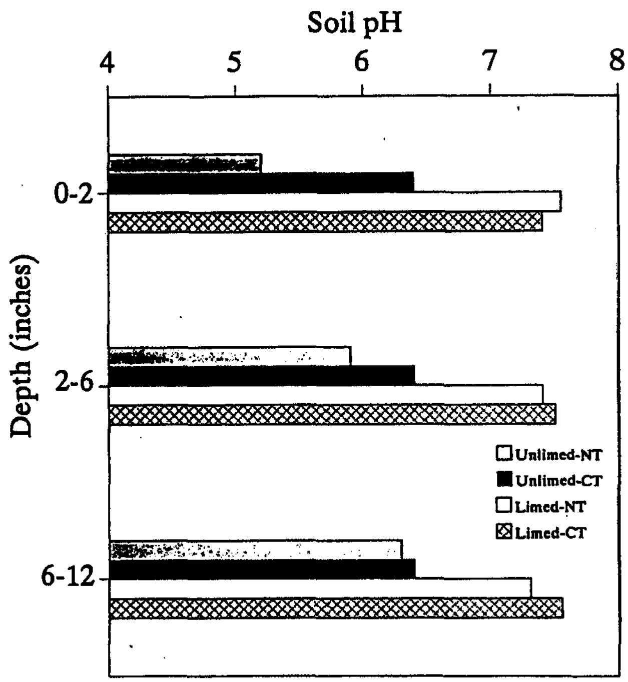

Fig. 1. Soil pH by depth after 10 years of corn production in Kentucky as affected by tillage and lime application. Corn was fertilized with 75 lb N/acre each year, and lime was applied to the soil surface during the third and fifth year of production. NT=continuous no-tillage, CT=conventional tillage (from Blevins et al., 1983).

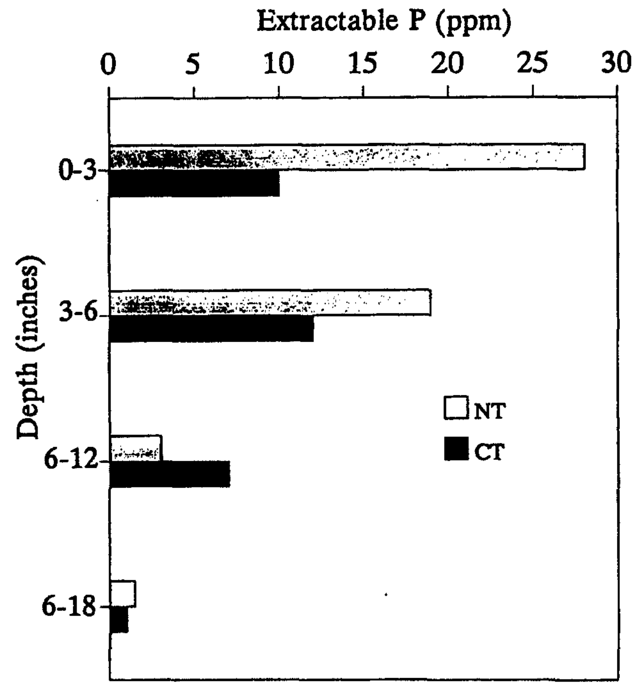

Fig. 2. Effect of tillage on distribution of P in the soil profile after three years of corn production in the Georgia Piedmont. Phosphorus as triple superphosphate was broadcast on the soil surface in all three years of the study. NT=continuous no-tillage, CT=conventional tillage (from Hargrove, 1985).

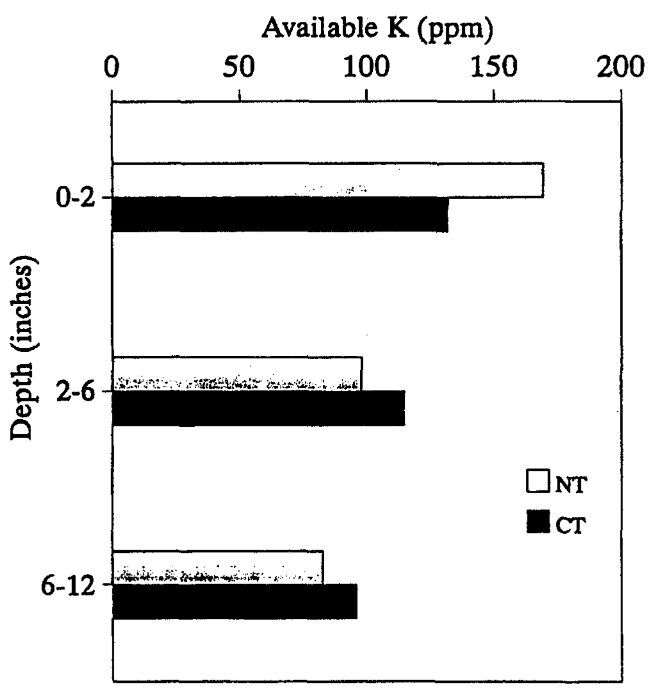

Fig. 3. Effect of tillage on distribution of K in the soil profile after 11 years of corn production in Kentucky. Potassium fertilizer as KCl was applied to the soil surface every year during the last five years of the study. NT=continuous no-tillage, CT=conventional tillage (from Blevins et al., 1986).