Paper No. 991058
An ASAE Meeting Presentation

SUBSOILING CONSIDERATIONS FOR SITE-SPECIFIC TILLAGE

by

R. L. Raper
Agricultural Engineer
USDA, ARS, National Soil Dynamics Laboratory
411 S. Donahue Drive, Auburn, AL 36832 USA

Written for Presentation at the
1999 ASAE Annual International Meeting
Sponsored by ASAE

Sheraton Toronto Center
Toronto, Ontario Canada
July 18-22, 1999

Summary:

Shanks designed to operate at a particular depth to disrupt compacted soil profiles may have excessive draft requirements when operated at depths other than their originally intended depth. The use of site-specific technology may require that shanks operate at multiple depths based on the localized soil's needs. Comparisons between an angled and a curved shank in two soil bins showed that reduced draft requirements were found for the angled shank in one soil bin. Similar amounts of soil disruption were found for both shanks with a trend indicating greater disruption for the curved shank.

Keywords:

Subsoil, soil compaction, shank, cone index, draft

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9059 USA
Voice: 616.429.0300 FAX: 619429.3852 E-Mail:<hq@asae.org>

SUBSOILING CONSIDERATIONS FOR SITE-SPECIFIC TILLAGE

R. L. Raper[1]

ABSTRACT

Shanks designed to operate at a particular depth to disrupt compacted soil profiles may have excessive draft requirements when operated at depths other than their originally intended depth. The use of site-specific technology may require that shanks operate at multiple depths based on the localized soil's needs. Comparisons between an angled and a curved shank in two soil bins showed that reduced draft requirements were found for the angled shank in one soil bin. Similar amounts of soil disruption were found for both shanks with a trend indicating greater disruption for the curved shank.

INTRODUCTION

Soil compaction has long been noted to cause root restrictions and yield reductions in many crops in the Southeastern United States (Cooper et al., 1969). Much energy is expended in this region to disrupt these compacted soil profiles to enhance root growth and increase drought tolerance. However, the emergence of site-specific technologies affords us an opportunity to determine whether significant savings in energy could be achieved by targeting the tillage to the appropriate depth of compaction.

A soil cone penetrometer (ASAE, 1999) has been used to determine the variation in depth of this hardpan profile in many Southeastern soils. In many soils, a multiple-probe soil cone penetrometer was used that was developed at the USDA-ARS National Soil Dynamics Laboratory (Raper et al., 1999). In other soils, a manual probe, the Rimik[2] recording penetrometer, was used to determine cone index values. These measurement devices have been used in conjunction with Global Positioning Systems to determine the spatial position of cone index measurements.

Most fields that have been examined show a great amount of variability in depth of hardpan (Fig. 1). This variability leads us to believe that significant savings in tillage energy could be achieved by adjusting tillage depth on-the-go. However, the design of tillage tools, in particular subsoilers, may have to be optimized in order to take advantage of these potential savings.

The shape of a subsoiler has been shown to have an effect on it's required draft. Nichols and Reaves (1958) measured the draft of several subsoilers ranging in shape from a normal straight configuration to a deeply curved configuration. Measurements of draft indicated that the subsoiler with the most curve required the least amount of energy. It was also reported that the resultant soil breakup was approximately the same for all tool shapes. The reduction in draft associated with increased curvature

---

[1] Agricultural Engineer, USDA-ARS National Soil Dynamics Laboratory, Auburn, AL

[2] The use of company names or trade names does not imply endorsement by USDA-ARS.

may not always be true, however. Upadhyaya et al. (1964) found a straight shank mounted at an inclination to the vertical gave reduced draft measurements compared to a curved subsoiler in sandy loam soils.

A consideration that exists concerning the shape of a subsoiler is how the draft will vary depending upon the depth of operation. Gill and Vanden Berg (1966) state that: "Improper operation can defeat the advantage of decreased draft with a curved subsoiler. Unless the curved tool is operated at its intended depth, all advantages of the curve may be lost. Presumably, the curved subsoiler gains its advantage from the direction in which it applies forces to the soil and the direction in which these forces cause the soil to move. The advantage of the proper use of the design is lost if operation is too deep; the curved subsoiler operates as though it were straight."

Therefore, the objectives of this research effort were to:

(1) Determine if any significant differences in force requirements existed at different depths of operation between an straight shank mounted at an angle to the vertical and a curved shank commonly used for subsoiling in the Southeastern U.S.

(2) Determine if any differences existed between the soil disruption caused by the use of an angled and a curved shank.

METHODS AND MATERIALS

An experiment was conducted in the soil bins at the USDA-ARS National Soil Dynamics Laboratory in Auburn, Alabama to investigate the effect of depth of tillage and shank shape on draft, vertical, and side forces and soil disturbance. Soils chosen for the study were a Norfolk sandy loam soil (Typic Paleudults) and a Decatur clay loam soil (Rhodic Paleudults) (Table 1). Both soils were from the Southeastern United States and they contained a wide range of particle size distributions. These soils were selected because they were located indoors which facilitated the maintenance of a constant moisture content for an extended period of time.

A hardpan condition was formed in the soil bins to simulate a condition that is commonly found in the Southeastern United States. This naturally-occurring and sometimes traffic-induced hardpan was found approximately 0.1 to 0.3 m below the soil surface and was quite impervious to root growth, particularly at low moisture levels. The hardpan condition was created in the soil bins by using a moldboard plow to laterally move the soil and then using a rigid wheel to pack the soil left exposed in the plow furrow. A small amount of soil was packed-at a time and the entire procedure repeated until the entire bin had been traversed. The surface soil was then bladed and leveled. Variations can occur between bins, but within a bin the same depth of the hardpan can usually be achieved with little error.

The shanks used for the experiment was an angled shank manufactured by KMC Corp. (Fig. 2) and a curved shank manufactured by Powell Corp. (Fig. 3). Each shank was of slightly different construction with the angled shank being made of 3.2-cm (I.25 in) thick material and the curved shank being made of 2.5-cm (l-in) thick material. Slight differences in wear tips were also used by the different manufacturers with the angled shank having a 4.4-cm (1.75, in) width and the curved shank having a 5.1 -cm (2-

in) width. OEM wear plates (shown in the photos but not in the accompanying drawings) were used with the shanks to simulate conditions of actual use.

These shanks were mounted on the dynamometer car to a 3-dimensional dynamometer, which has an overall draft load capacity of 44 kN (10,000 lbs). Draft, vertical force, side force, speed, and depth of operation were recorded continuously for each shank test. The speed of tillage for all tests was held constant at 0.45 m/s (1 mi/hr). Three depths of operation were conducted for each shank 22.9 cm (9 in), 30.5 cm (12 in), and 38.1 cm (15 in).

Each soil bin was treated as a randomized complete block design with two shank types, three tillage depths, and four replications. Three subsoiling runs were conducted side-by-side across the width of the bin with eight separate lanes being constructed along the length of the bin. This arrangement allowed all 24 runs to be conducted. The approximate size of each plot was therefore 2-m wide by 5-m long. The spacing across the bin was sufficient to ensure that disturbed soil resulting from a previous tillage operation would not affect a current test. Each set of force values obtained from each plot was averaged to create one specific value per plot of draft, vertical force, and side force. Each of the soil bins was considered as a separate experiment and each ANOVA handled separately. A probability level of 0.10 was assumed to test the null hypothesis that no differences existed between the shanks operating at each of the three depths.

Before the shank tests were conducted in each plot, a set of five cone index measurements were acquired with a Rimik recording penetrometer. This set of measurements was taken with all five cone index measurements being equally spaced at a 20 cm (7.5 in) distance across the soil with the middle measurement being directly in the path of the shank. As soon as the shank had been tested in each plot, another set of five cone index measurements was also taken in the disturbed soil in close proximity to the original cone index measurements.

Measurements of bulk density and moisture content were also taken in undisturbed regions of each replication for analysis. Values of moisture contents were taken at depths of O-l5 cm (O-6 in) and 15-30 cm (6-l2 in) immediately after the experiment was completed. Bulk density values were taken at depths of 5-10 cm (2-4 in), 20-25 cm (8-10 in), and 30-35 cm (12-14 in).

RESULTS AND DISCUSSION

The moisture content of the Norfolk sandy loam soil was 9.4 % at the O-15 cm (O-6 in) depth and at 10.0% at the 15-30 cm (6-12 in) depth (Table 1). The moisture content of the Decatur clay loam soil was slightly higher with it being at 12.3 % at the O-15 cm (O-6 in) depth and 14.8 % at the 15-30 cm (6-12 in) depth.

The bulk density values obtained for both soils showed the approximate location of the hard pan that was installed in the soil bins. In the Norfolk sandy loam soil, the surface bulk density was found to be 1.24 Mg/m^3 while the soil within the hard pan had a bulk density of 1.60 Mg/m^3 and the soil below the hardpan had a density of 1.95 Mg/m^3 (Table 1). In the Decatur clay loam soil, the surface bulk density was 1.08

Mg/m^3 while the soil within the hard pan was 1.24 Mg/m^3 and the soil below the hardpan had a density of 1.74 Mg/m^3.

The draft measurements indicated that the variation in draft caused by the soil tended to overshadow the differences in draft measured between the two shanks, particularly in the Decatur soil (Figs. 4 and 5 and Table 2). However, in the Norfolk sandy loam soil, the angled shank had significantly smaller draft values than the curved shank at all depths of operation (Fig. 4). At the 23-cm depth, the angled shank required 10% less draft than the curved shank ($P \leq 0.075$); at the 30.5-cm depth, the angled shank required 16% less draft than the curved shank ($P \leq O.032$); and at the 38-cm depth, the angled shank required 7% less energy than the curved shank ($P \leq O.098$). In the Decatur clay loam soil, the variation in draft data was extremely large and masked any statistical differences in shank draft force even though a trend existed (Fig 5).

Differences in vertical force and side force were very similar for all tests with the exception of the shallow runs in both soil types (Table 2). In the Norfolk sandy loam soil, the angled shank required 5% less vertical force than the curved shank ($P \leq O.037$). In the Decatur clay loam soil, the angled shank required 22% less vertical force than the curved shank ($P \leq O.063$).

The draft measurements, particularly in the Norfolk sandy loam soil, tended to indicate that the use of the angled shank was the most efficient shape at all depths of operation. Due to the extreme variation experienced in the Decatur clay loam soil, statistically significant differences in draft were not measured. Overall, the results in both soils were somewhat surprising because it was thought that at some depth, the“ curved shank would be the most efficient shape. This was also expected because the width of this shank was slightly narrower than the angled shank. However, the tip of the angled shank was slightly wider than the tip of the curved shank so the overall effect of shank width was somewhat negated. Also, it may be important to consider that both shanks were used with wear plates supplied by the manufacturers which may slightly alter their draft requirements and the resulting soil disturbance.

Measurements of cone index indicated that the top of the hardpan was at 10 cm (4 in) in the Norfolk sandy loam soil and 14 cm (5.5 in) in the Decatur clay loam soil (Fig. 6). The cone index measurements were highly variable but enabled broad differences in soil disruption caused by the different shanks and the various depths of tillage to be seen. In the Norfolk soil, tillage at the 23-cm (9-in) depth showed only a small reduction in cone index down to an approximate depth of 25 cm (9.8 in). Larger effects of tillage were seen, however, at the two deeper depths of tillage in this same soil. At a tillage depth of 30.5 cm (12 in) in the Norfolk soil, the curved shank showed reductions in cone index down to this depth, while the angled shank only showed reductions down to a depth of 25 cm (9.8 in). At the deepest tillage depth of 38 cm (15 in) in the Norfolk soil, both shanks behaved similarly by disrupting the soil down to 30 cm (12 in).

In the Decatur soil, differences in soil disruption caused by the two shanks seemed to be more evident. At a tillage depth of 23 cm (9 in), the angled shank only showed soil strength reductions down to a depth of IO cm (4 in) while the curved shank showed differences down to 30 cm (12 in). Increasing the tillage depth to 30.5 cm (12 in) seemed to change little, with both shanks tending to show cone index reductions down to the same values as previously mentioned for the 23-1 (9-in) tillage depth. At the deepest tillage depth of 38 cm (15 in), the curved shank showed soil strength reductions all the way down to this approximate depth while the angled shank again showed no benefit below 12 cm (4.7 in).

A statistical comparison of the cone index values obtained in the centerline of the shank at each depth showed few differences occurred between the use of the two shanks in the Norfolk sandy loam soil (Table 3). With only one exception, the use of the curved shank was beneficial only between the depths of 27 and 34.5 cm when compared to the angled shank. In the Decatur clay loam soil, however, differences were more drastic and occurred much shallower. At the 23-cm depth of tillage, the curved shank showed improved cone index values from 7.5 cm to 21 cm. An interesting anomaly occurred between the depths of 34.5 cm and 40.5 cm where the angled shank showed reduced cone index. This anomaly occurred well below the tillage depth of 23 cm, however, and must be due to random variation in data. Cone index data obtained after tillage with the curved shank was much lower than that obtained after tillage with the angled shank at the 30.5 cm and 38 cm depths in the Decatur clay loam soil. These benefits occurred between depths of 7.5 cm and 19.5 cm when the soil was tilled down to 30.5 cm and between the depths of 16.5 cm and 24 cm when the soil was tilled down to 38 cm.

The measurements of cone index seemed to show that the reduced draft requirements for the angled shank come at a price of reduced soil disruption. In both soil types, at most depths of operation, the angled shank did not show the reduced cone index measurements that the curved shank produced. This reduced soil disruption may be perceived in a negative manner if complete disturbance of the growing profile was desired or it may be perceived in a positive manner if you are simply trying to reduce force requirements. However, before complete conclusions are drawn on this issue, more data must be obtained to reduce the overall variability and allow a more thorough analysis. It may even be desirable to grow plants in both subsoiled conditions to determine their response.

CONCLUSIONS

The conclusions that can be drawn from this experiment were:

1) The angled shank was found to have reduced draft requirements from the curved shank in the Norfolk sandy loam soil but only exhibited a trend in the Decatur clay loam soil.

2) Differences in cone index were found with the soil strength being reduced by a greater amount with the curved shank than with the angled shank. These differences were found to be statistically significant in the Decatur clay loam soil at approximate depths of 12-21 cm.

REFERENCES

ASAE Standards. 1999. ASAE S313.3: Soil cone penetrometer. St. Joseph, MI.

Cooper, A.W., A.C. Trouse, and W.T. Dumas. 1969. Controlled traffic in row crop production. Proc., 7th International Congress of Agricultural Engineering, Baden-Baden, W. Germany, Theme 1, pp. I-6.

Gill, W.R., and G.E. Vanden Berg. (Eds.) 1966. Soil dynamics in Tillage and Traction. Agricultural Handbook ed. Vol. 316. USDA, pp. 230-231.

Nichols, M.L., and C.A. Reaves. 1958. Soil Reaction: to subsoiling equipment. Ag. Eng. (June), pp. 340-343.

Raper, R.L., B.H. Washington, J.D. Jarrell. 1999. A tractor-mounted multiple-probe soil cone penetrometer. Applied Engineering in Agriculture (In Press).

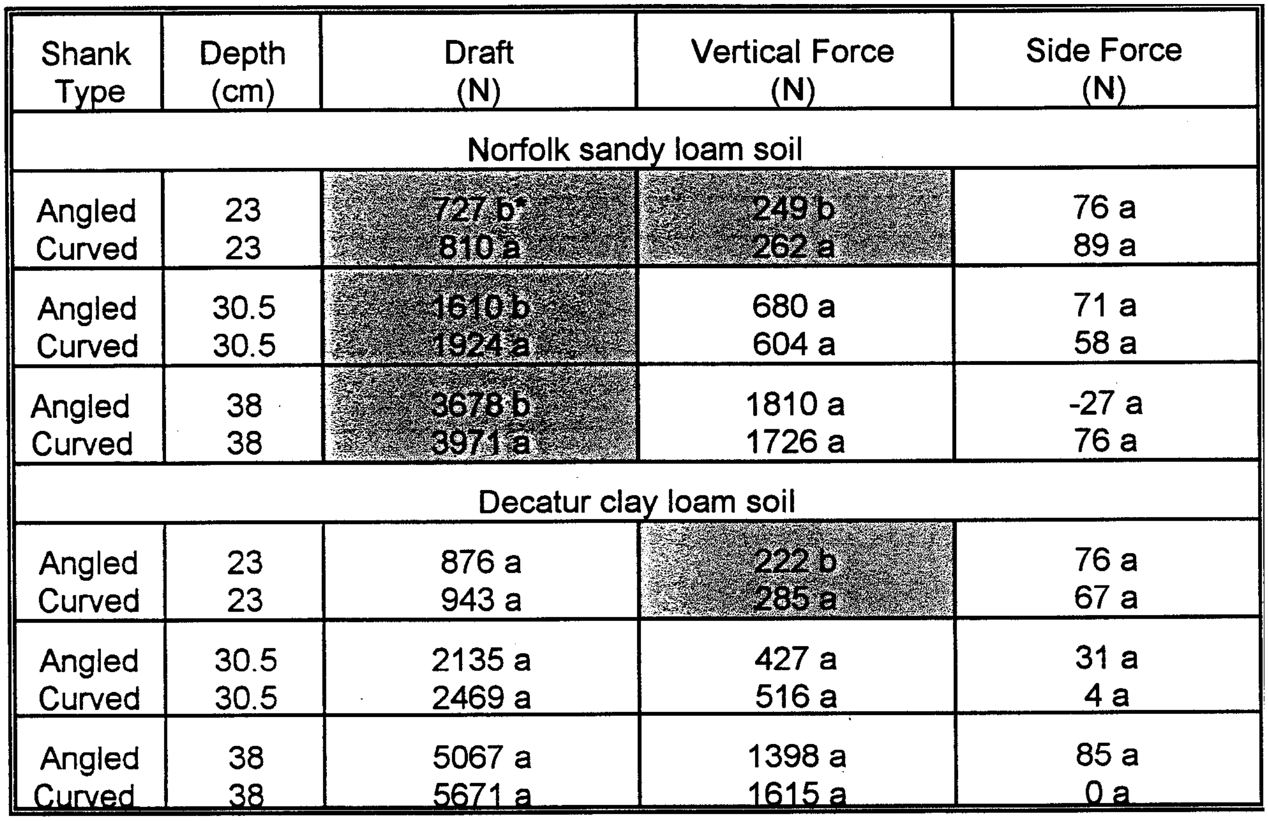
Taylor, H.M., and H.R. Gardner. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Sci. 96(3):153-I56.

Upadhyaya, S.K., T.H. Williams, L.J. Kemble, and N.E. Collins. 1984. Energy requirements for chiseling in coastal plain soils. Trans. ASAE 27(6): 1643-l649.

Table 1. Soil measurements showing the initial soil condition of the two indoor soil bins at the NSDL used for this experiment

Depth (cm)	Bulk Density (Mg/m^3)	Moisture Content (%db)	Cone Index (MPa)
Norfolk sandy loam soil (Sand 72%, Silt 17%, Clay 11%)			
0-15 15-30		9.4 10.0	
5-10 20-25 30-35	1.24 1.60 1.95		0.15 1.96 1.94
Decatur clay loam soil (Sand 27%, Silt 43%, Clay 30%)			
0-15 15-30		12.3 13.8	
5-10 20-25 30-35	1.08 1.24 1.74		0.30 2.45 2.15

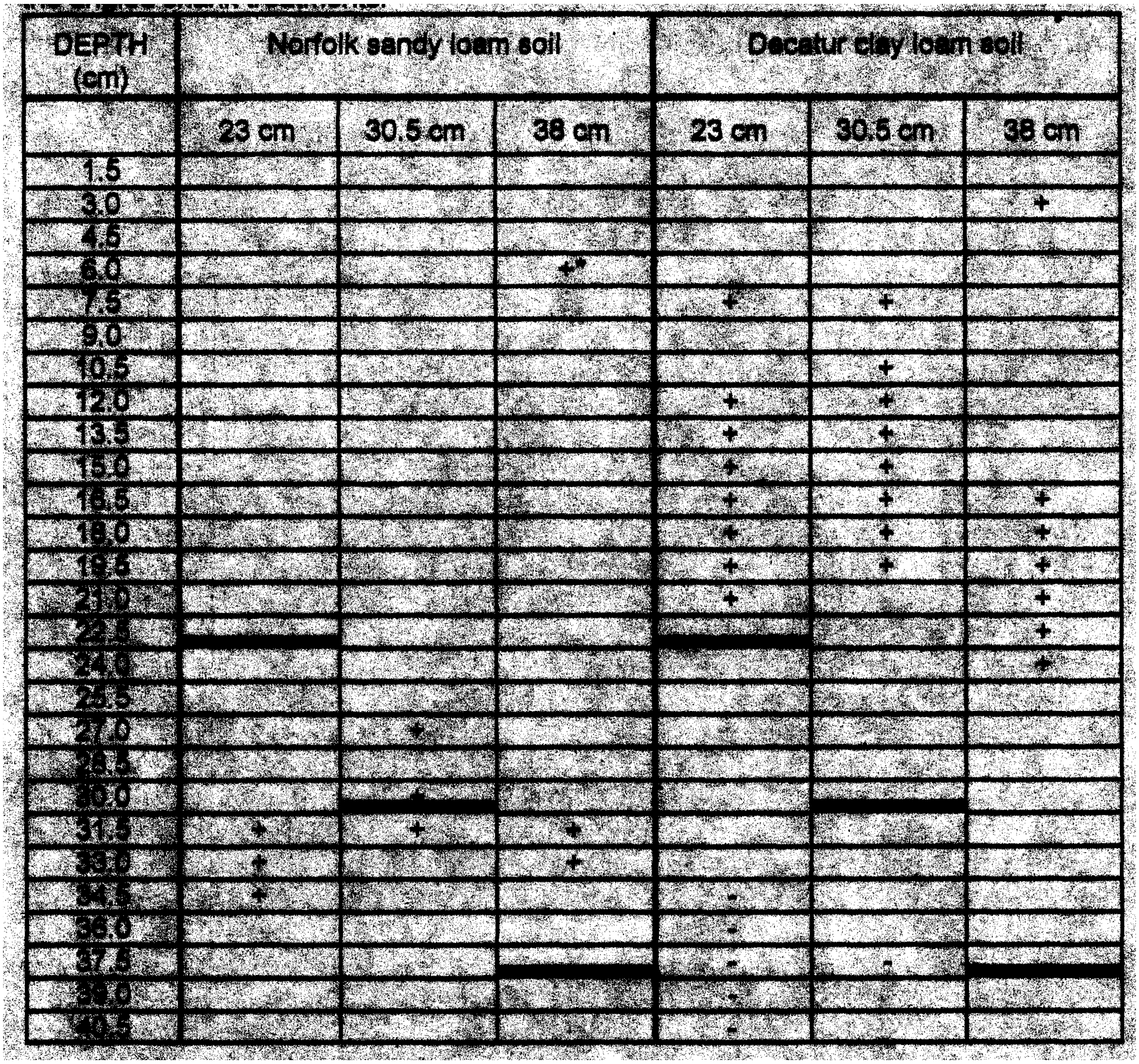
Table 2. Measurements in force obtained from the shank tests in the soil bins at the NSDL



Shank Type	Depth (cm)	Draft (N)	Vertical Force (N)	Side Force (N)
Norfolk sandy loam soil				
Angled Curved	23 23	727 b* 810 a	249 b 262 a	76 a 89 a
Angled Curved	30.5 30.5	1610 b 1924 a	680 a 604 a	71 a 58 a
Angled Curved	38 38	3678 b 3971 a	1810 a 1726 a	-27 a 76 a
Decatur clay loam soil				
Angled Curved	23 23	876 a 943 a	222 b 285 a	76 a 67 a
Angled Curved	30.5 30.5	2135 a 2469 a	427 a 516 a	31 a 4 a
Angled Curved	38 38	5067 a 5671 a	1398 a 1615 a	85 a 0 a

* Letters indicate statistical differences at the 0.1 level for each soil type at each depth.

Table 3. Statistical significance (0.1 level) of cone index in the path of the shank immediately after tillage. Cone index values were compared between the curved and the angled shank treatments.



DEPTH (cm)	Norfolk sandy loam soil			Decatur clay loam soil		
	23 cm	30.5 cm	38 cm	23 cm	30.5 cm	38 cm
1.5						
3.0						+
4.5						
6.0			+*			
7.5				+	+	
9.0						
10.5					+	
12.0				+	+	
13.5				+	+	
15.0				+	+	
16.5				+	+	+
18.0				+	+	+
19.5				+	+	+
21.0				+		+
22.5						+
24.0						+
25.5						
27.0		+				
28.5						
30.0		+				
31.5	+	+	+			
33.0	+		+			
34.5	+			-		
36.0				-		
37.5				-	-	
39.0				-		
40.5				-		

*+ indicates curved shank cone index < angled shank cone index at 0.1 level

*- indicates curved shank cone index > angled shank cone index at 0.1 level

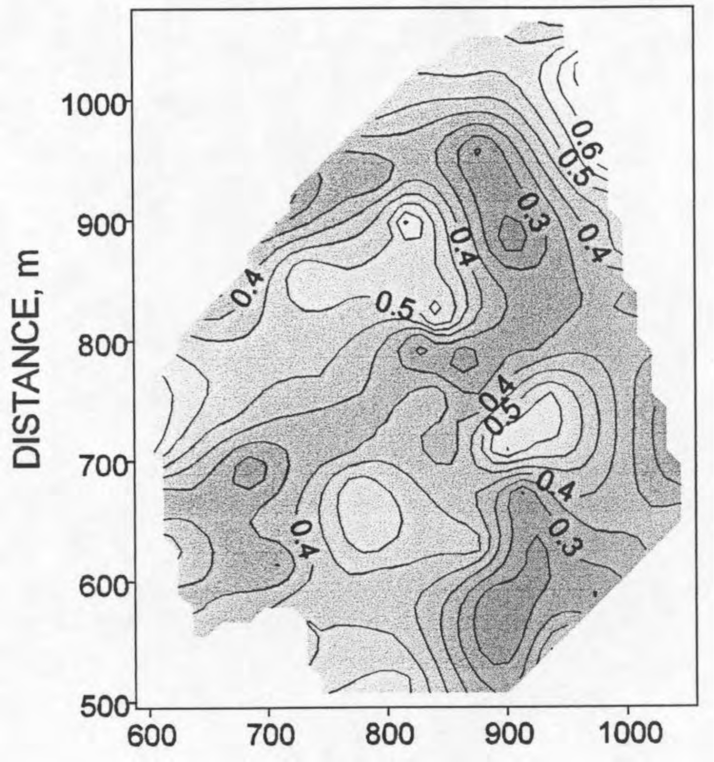


Figure 1. Depth to hardpan layer (m) contours across a field in the silty uplands of Northern Mississippi. The hardpan depth was defined at the depth of the occurrence of the 2 MPa level of cone index (Taylor and Gardner, 1963).

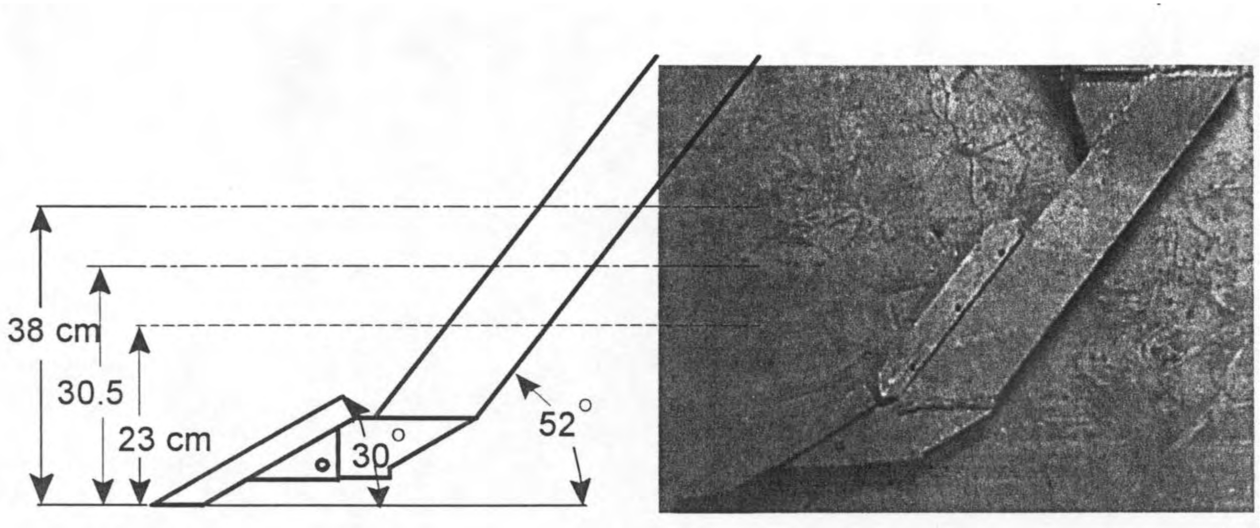


Figure 2. Photo and schematic drawing of angled shank showing different depths of operation.

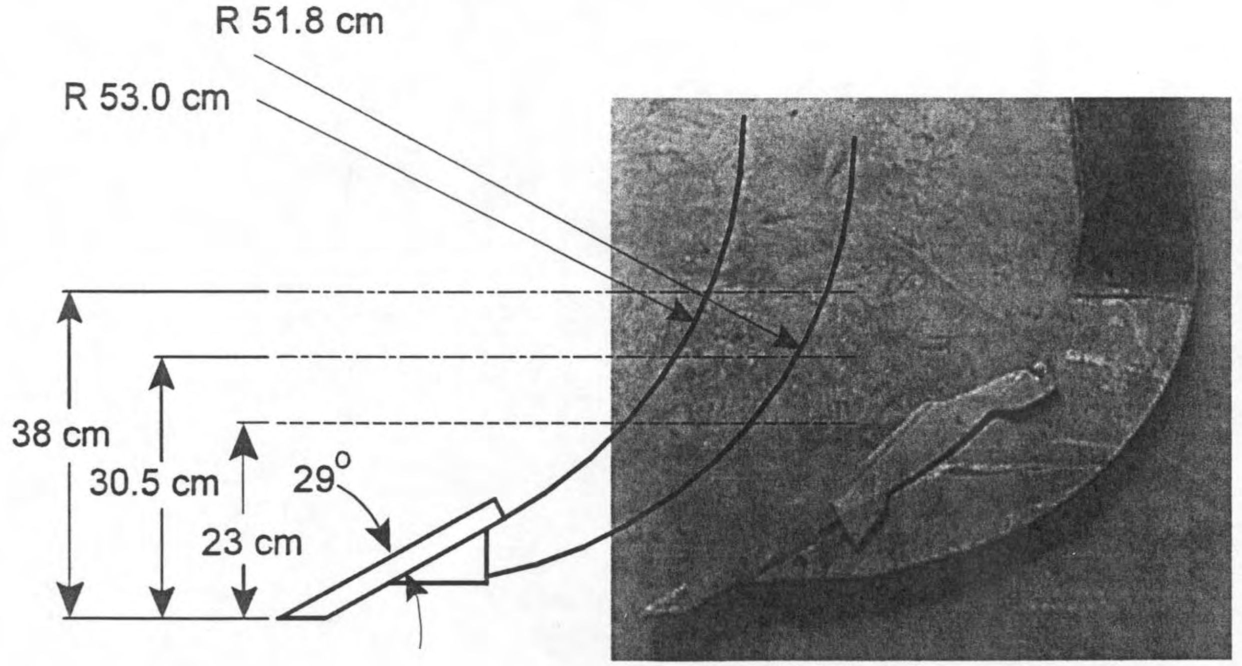


Figure 3. Photo and schematic drawing of curved shank showing different depths of operation.

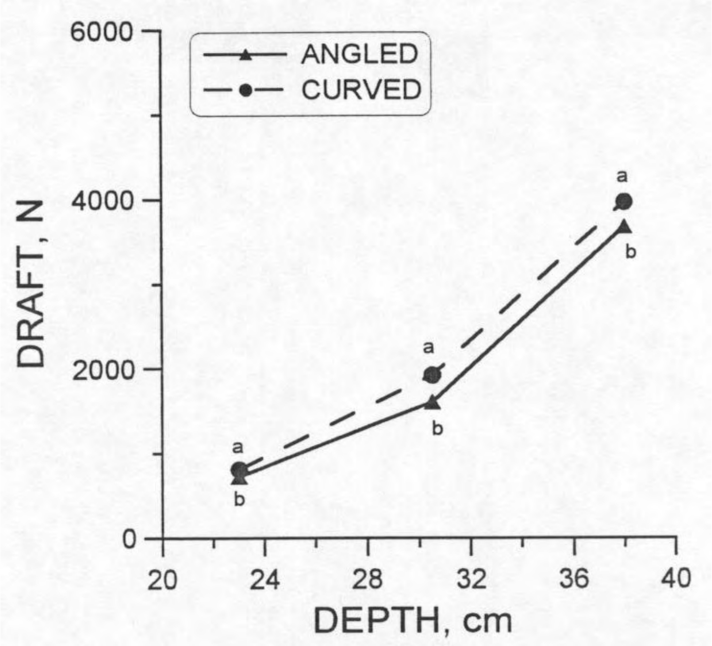


Figure 4. Draft (N) of shanks operating at three different depths in Norfolk sandy loam soil. The letters indicate statistical differences at all three depths at the 0.1 level.

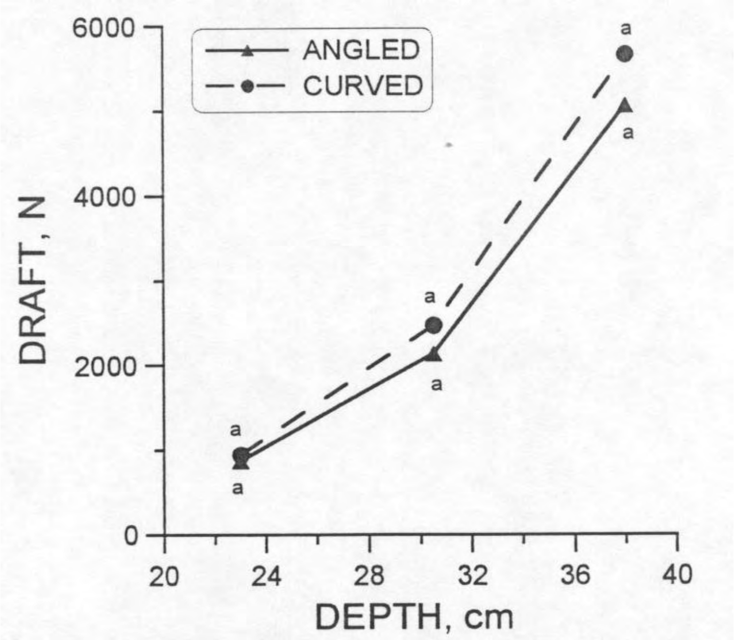


Figure 5. Draft (N) of shanks operating at three different depths in Decatur clay loam soil. The letters indicate no statistical differences at all three depths at the 0.1 level.

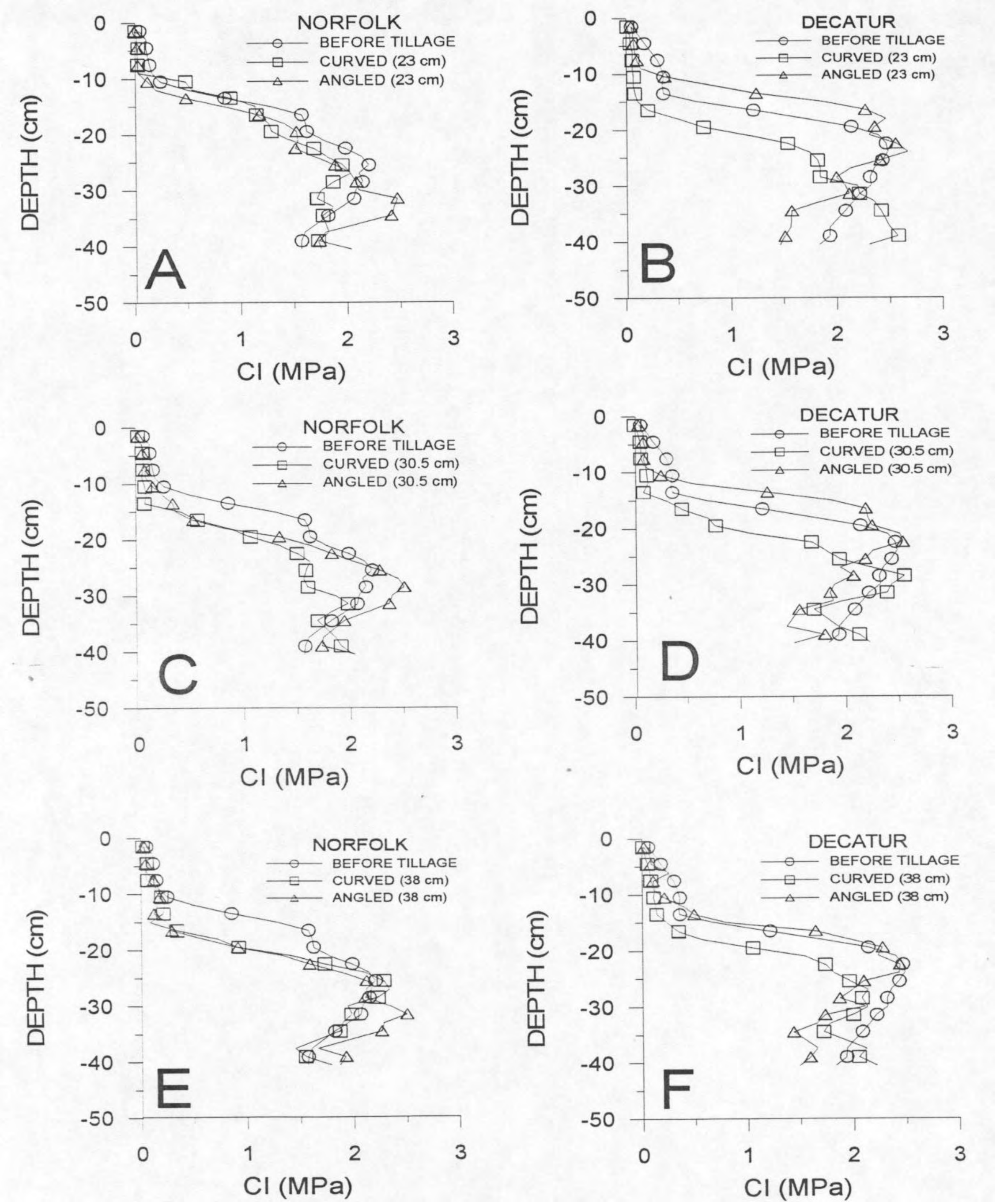


Figure 6. Cone index measurements before and after tillage directly in the path of the shank.