SUBSOILER SHAPES FOR SITE−SPECIFIC TILLAGE

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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 originally intended. This may be particularly true for curved shanks, which are designed to operate at a specific depth where draft is minimized. The use of site−specific technology may require that shanks operate at varying depths based on localized soil 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 a sandy loam soil with a trend toward reduced draft for the angled shank in the clay loam soil. Similar amounts of soil disruption were found for both shanks with a trend indicating greater disruption for the curved shank. Producers who conduct subsoiling at varying depths throughout their field may want to minimize draft force by using an angled shank, but should recognize that their soil may not be maximally disrupted throughout the soil profile.*

Keywords. *Draft, Tillage, Subsoil, Compaction.*

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; McConnell et al., 1989; Mullins et al., 1992). Much energy is expended in this region to disrupt compacted soil profiles to enhance root growth and increase drought tolerance. However, the emergence of site−specific technologies presents 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 Standards*, 1999a; 1999b) has been used to determine variation in depth of hardpan profiles in many Southeastern soils. In many soils, a multiple−probe soil cone penetrometer, developed at the USDA−ARS National Soil Dynamics Laboratory (Raper et al., 1999), has been used. In other soils, a manual probe (e.g., the Rimik recording penetrometer; Toowomba, Australia) was used to determine cone index values. These measurement devices have been used in conjunction with Global Positioning System receivers to determine the spatial position of cone index measurements.

Most fields examined show a great amount of variability in depth of hardpan (fig. 1). This variability suggests 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 need to be optimized to take advantage of these potential savings.

The shape of a subsoiler has been shown to have an effect on its 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 subsoilers with the most curvature required the least amount of energy. It was also reported that the resultant soil breakup was approximately the same for all tool shapes. Smith and Williford (1988) reported that a parabolic subsoiler required reduced draft as compared to a conventional subsoiler and a triplex subsoiler. The reduction in draft associated with increased curvature may not always be true. Upadhyaya et al. (1984) found a straight shank mounted at an inclination to the vertical gave reduced draft measurements compared to a curved subsoiler in sandy loam soils.

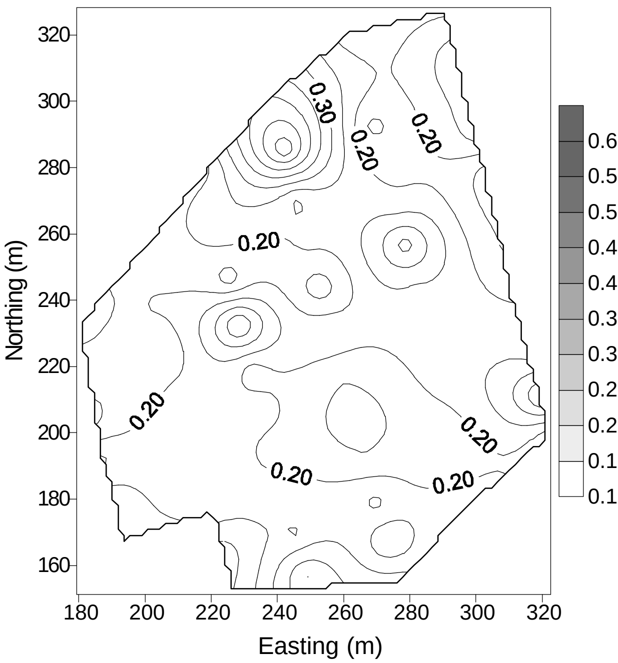

Figure 1. Depth to hardpan layer (m) contours across a field in the silty uplands of Northern Mississippi. The hardpan depth was defined at the depth of the occurrence of the 2−MPa (300−psi) level of cone index (Taylor and Gardner, 1963).

Article was submitted for review in August 2003; approved for publication by the Power & Machinery Division of ASAE in June 2004. Presented at the 1999 ASAE Annual Meeting as Paper No. 991058.

The use of trade names or company names does not imply endorsement by USDA−ARS.

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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:

- Determine if any significant differences in force requirements existed at different depths of operation between a straight shank mounted at an angle to the vertical and a curved shank commonly used for subsoiling in the Southeastern United States.
- Determine if any differences existed between 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. The Laboratory maintains nine outdoor and two indoor soil bins that contain surface soils for conducting full−scale studies of tillage and traction systems. Each bin is of uniform width [6.1 m (20 ft)], which allows specialized machinery to be used for soil preparation on all bins. 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 were composed of a wide range of particle sizes. These soils were selected because they were located indoors, which facilitated the maintenance of a constant moisture content for an extended period of time. The indoor bins were 57.9 m (190 ft) long.

A hardpan 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 can be found approximately 0.1 to 0.5 m below the soil surface and can be 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 followed by 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 was 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 hardpan depth can usually be achieved with little error.

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

Depth (cm)	Bulk Density (Mg/m^3)	Moisture Content (% d.b.)	Cone Index (MPa)
Norfolk sandy loam soil (Sand 72%, Silt 17%, Clay 11%)			
0−15		9.4 (0.4)	
15−30		10.0 (0.4)	
5−10	1.24 (0.08)		0.15 (0.05)
20−25	1.60 (0.21)		1.96 (0.35)
30−35	1.95 (0.13)		1.94 (0.56)
Decatur clay loam soil (Sand 27%, Silt 43%, Clay 30%)			
0−15		12.3 (0.5)	
15−30		13.8 (1.2)	
5−10	1.08 (0.05)		0.30 (0.13)
20−25	1.24 (0.19)		2.45 (0.65
30−35	1.74 (0.17)		2.15 (0.50)

[a] Numbers in parentheses indicate standard deviations of the values.

The shanks used for the experiment were: 1) an angled shank manufactured by KMC Corp. (Tifton, Ga.; fig. 2), and 2) a curved shank manufactured by Powell Manufacturing Co. (Bennettsville, S.C.; fig. 3). Each shank was of slightly different construction with the angled shank being made of 3.2−cm (1.25−in.) thick steel and the curved shank being made of 2.5−cm (1−in.) thick steel. Slightly different wear tips were also used by the different manufacturers with the tip for the angled shank having a 4.4−cm (1.75−in.) width and the curved shank having a 5.1−cm (2−in.) width. Original equipment manufacturer 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 a dynamometer car to a three−dimensional dynamometer, which has an overall draft load capacity of 44 kN (10,000 lb). 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 mph). Three depths of operation were conducted for each shank: 23, 30.5, and 38 cm (9, 12, and 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 plots were created side−by−side across the width of the bin with eight separate blocks being created along the length of the bin. Two adjacent blocks are joined lengthwise to form a complete replication. This arrangement allowed all 24 runs to be conducted with one soil fitting. The approximate size of each plot was therefore 2 m wide × 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. The location of the shanks and their depth of operation were randomized within each replication. 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 0 to 15 cm (0 to 6 in.) and 15 to 30 cm (6 to 12 in.) immediately after the experiment was completed. Bulk

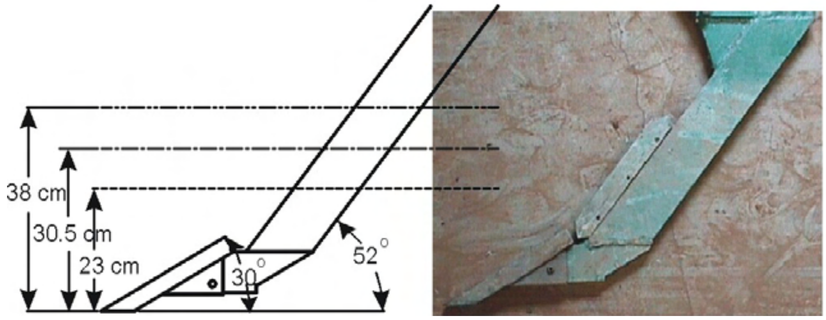

Figure 2. Photo and schematic drawing of angled shank showing different depths of operation.

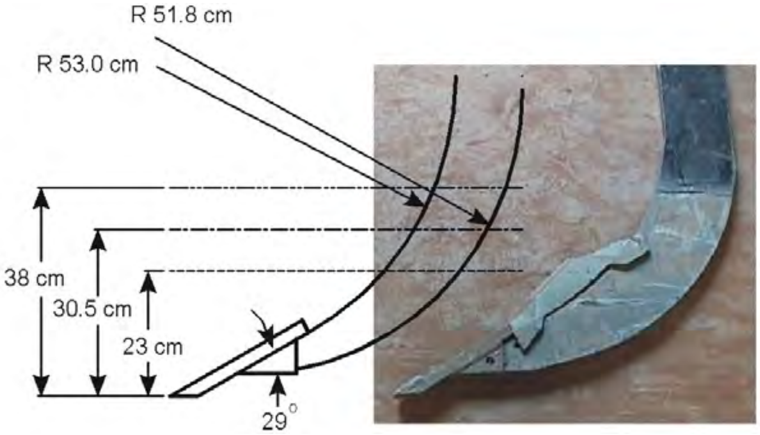

Figure 3. Photo and schematic drawing of curved shank showing different depths of operation.

density values were taken at depths of 5 to 10 cm (2 to 4 in.), 20 to 25 cm (8 to 10 in.), and 30 to 35 cm (12 to 14 in.).

Results and Discussion

The gravimetric moisture content (dry basis) of the Norfolk sandy loam soil was 9.4% d.b. at the 0− to 15−cm (0− to 6−in.) depth and at 10.0% d.b. at the 15− to 30−cm (6− to 12−in.) depth (table 1). The moisture content of the Decatur clay loam soil was slightly higher at 12.3% d.b. at the 0− to 15−cm (0− to 6−in.) depth and 14.8% d.b. at the 15− to 30−cm (6− to 12−in.) depth.

The bulk density values obtained for both soils showed the approximate location of the hardpan in the soil bins. In the Norfolk sandy loam soil, the surface bulk density was 1.24 Mg/m^3 while the soil within the hardpan 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 cone index values taken at the same depths as the bulk density more clearly showed the location of the hardpan (table 1). In the Norfolk sandy loam soil, small values of cone index [0.15 MPa (22 psi)] were measured down to depths of 20−25 cm (8−10 in.) where the hardpan caused higher values of cone index [1.96 MPa (288 psi)]. Cone index remained constant below the hardpan profile for this soil type [1.94 MPa (286 psi)]. Similar trends were found for cone index in the Decatur clay loam soil with minimal values of 0.30 MPa (44 psi) being found near the surface, but increasing to 2.45 MPa (360 psi) at the 20− to−25 cm (8− to 10−in.) depth and then decreasing slightly to 2.15 MPa (316 psi) below the hardpan.

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; table 2). However, in the

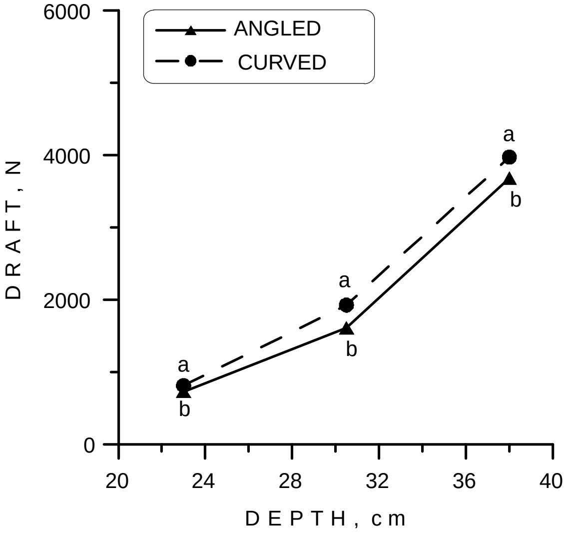

Figure 4. Draft (N) of shanks operating at three different depths in Norfolk sandy loam soil. The letters indicate statistical differences at all three depths at the 0.1 level.

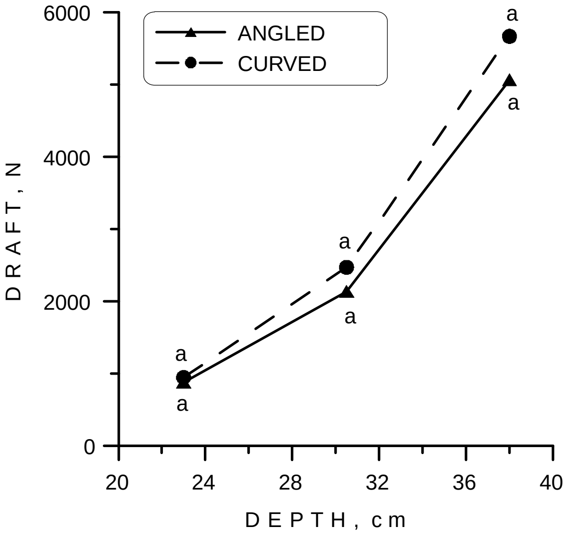

Figure 5. Draft (N) of shanks operating at three different depths in Decatur clay loam soil. The letters indicate statistical differences at all three depths at the 0.1 level.

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 (9−in.) depth, the angled shank required 10% less draft than the curved shank ($P \leq 0.075$); at the 30.5−cm (12−in.) depth, the angled shank required 16% less draft than the curved shank ($P \leq 0.032$); and at the 38−cm (15−in.) depth, the angled shank required 7% less draft than the curved shank ($P \leq 0.098$). In the Decatur clay loam soil, the variations in draft data were extremely large and masked any statistical differences in shank draft force even though a trend existed (fig. 5).

Vertical and side forces were similar for all tests with the exception of the shallow tests in both soil types (table 2). In the Norfolk sandy loam soil, the angled shank required 5% less vertical force than the curved shank ($P \leq 0.037$). In the Decatur clay loam soil, the angled shank required 22% less vertical force than the curved shank ($P \leq 0.063$).

The draft measurements, particularly in the Norfolk sandy loam soil, tended to indicate that 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. Reduced draft for the curved shank 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.

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

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

[a] Within each soil type, depth, and column, means followed by the same letter are not statistically different at the 0.1 level.

To simplify the discussion, only the middle cone index measurement taken in the path of the shank will be presented. Measurements of cone index averaged across all replications 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 to be seen. These differences were probably caused by the different shanks and the various depths of tillage. In the Norfolk soil, tillage at the 23−cm (9−in.) depth (fig. 6A) 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 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 (fig. 6C), 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 (fig. 6E), 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 were more evident. At a tillage depth of 23 cm (9 in.), the angled shank only showed soil strength reductions down to a depth of 10 cm (4 in.) while the curved shank showed differences down to 30 cm (12 in; fig. 6B). Increasing the tillage depth to 30.5 cm (12 in.) only slightly reduced soil strength, with both shanks exhibiting cone index reductions down to the same values as previously mentioned for the 23−cm (9−in.) tillage depth (fig. 6D). 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.; fig. 6F).

The cone index values obtained after subsoiling with the two shanks were compared using a paired t−test at each depth in the centerline of the shank. These comparisons showed few differences occurred between 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 (10.6 and 13.6 in.) 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 (9−in.) depth of tillage, the curved shank showed reduced cone index values from 7.5 to 21 cm (3 to 8.3 in.). An interesting anomaly occurred between the depths of 34.5 and 40.5 cm (13.6 and 15.9 in.) where the angled shank showed reduced cone index. This anomaly occurred well below the tillage depth of 23 cm (9 in.), however, and must be due to random variation in cone index data. Cone

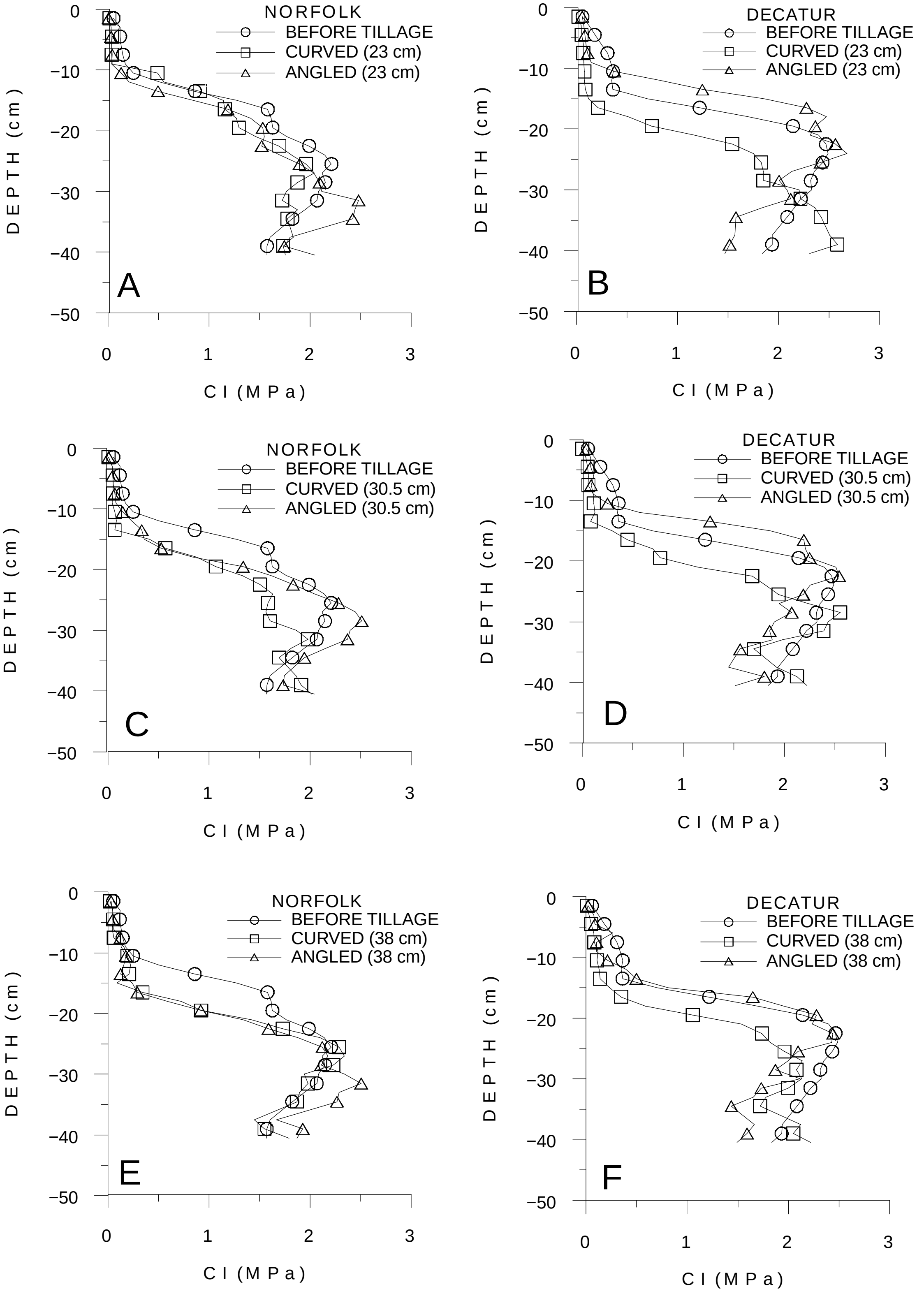

Figure 6. Cone index measurements before and after tillage directly in the path of the shank.

index data obtained after tillage with the curved shank were lower than those obtained after tillage with the angled shank at the 30.5− and 38−cm (12− and 15−in.) depths in the Decatur clay loam soil. These benefits occurred between depths of 7.5 and 19.5 cm (3 and 7.7 in.) when the soil was tilled down to 30.5 cm (12 in.) and between the depths of 16.5 and 24 cm (6.5 and 9.4 in.) when the soil was tilled down to 38 cm (15 in.).

The measurements of cone index seemed to show that the reduced draft requirements for the angled shank came at a price of reduced soil disruption. In both soil types, at most depths of operation, the angled shank did not show the

Table 3. Statistical significance (0.1 level) of differences in cone index taken in the path of the shank immediately after tillage.[a]

Depth (cm)	Tillage Depth[b] (cm)					
	Norfolk Sandy Loam Soil[c]			Decatur Clay Loam Soil		
	23	30.5	38	23	30.5	38
1.5						
3.0						+
4.5						
6.0			+			
7.5				+	+	
9.0						
10.5					+	
12.0				+	+	
13.5				+	+	
15.0				+	+	
16.5				+	+	+
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24.0						+
25.5						
27.0		+				
28.5						
30.0		+				
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31.5	+	+	+			
33.0	+		+			
34.5	+			−		
36.0				−		
37.5				−	−	
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39.0				−		
40.5				−		

[a] Cone index values were compared between the curved and the angled shank treatments.

[b] Double lines in columns indicate depth of tillage.

[c] + indicates Curved Shank Cone Index < Angled Shank Cone Index significant at 0.1 level.
− indicates Curved Shank Cone Index > Angled Shank Cone Index significant at 0.1 level.

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 reducing force requirements was the main objective. In this case, a narrow zone of disturbance through a compacted soil layer may be all that was provided. Plants would have to be grown in this medium in order to completely understand whether both subsoilers would adequately disrupt the compacted soil profiles.

Engineers who design subsoilers for producers who may operate their subsoiler at varying depths should be aware that the curved shanks used in this test require excessive draft energy as compared to angled shanks, particularly in a sandy loam soil where subsoiling is often conducted. These engineers should recognize that angled shanks are the more energy efficient choice for multiple depths of operation as compared to curved shanks, which are designed for a single depth of subsoiling.

CONCLUSIONS

The conclusions drawn from this experiment were:

- The angled shank was found to have reduced draft requirements compared to the curved shank in the Norfolk sandy loam soil but only exhibited a trend (not statistically different) toward having reduced draft in the Decatur clay loam soil.
- Differences in cone index taken after subsoiling in the centerline of the shank were found with the soil strength being reduced by a greater amount with the curved shank than with the angled shank in the Decatur clay loam soil. These differences were found to be statistically significant at approximate depths of 12 to 21 cm (4.7 to 8.3 in.).

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