DROUGHT CONDITION ENERGY REQUIREMENT AND SUBSOILING EFFECTIVENESS FOR SELECTED DEEP TILLAGE IMPLEMENTS

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ABSTRACT

Draft requirement, fuel consumption, wheel slip, engine speed, and forward speed were measured for two-row Brown-Harden SuperSeeder, BushHog RoTill, Tye ParaTill, and Kelley (KMC) In-Row Tillage System on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) near Florence, SC. Cone index was measured with a recording penetrometer before and after tillage to evaluate soil disruption patterns. Cone index values before tillage showed that non-disked plots on which corn had been grown the previous year had higher soil resistance at all depths than disked (conventional tillage) plots. The non-disked tillage plots had a lower initial soil water content because winter weeds had depleted soil moisture by evapotranspiration to greater depths than had been depleted by evaporation in the disked plots. Higher soil resistance and lower water content in non-disked tillage plots resulted in a wider pattern of soil disturbance for all implements, except the KMC, when compared to the disked plots; however, volume of soil disturbed was greater in the disked plots because subsoiler penetration was greater. Implement draft, wheel slip, and drawbar power were also significantly greater in non-disked plots. Among implements, there were significant differences (P = 0.05) for all measured parameters except engine speed. This study shows that when water is limited, the primary benefit of disking prior to deep tillage is for weed control. Weed control eliminates transpiration of soil water and thus reduces soil resistance and the energy required for subsequent deep tillage. **KEYWORDS.** Tillage, Conservation, Implements, Drought, Energy requirements.

INTRODUCTION

Conservation tillage systems can reduce soil erosion, conserve soil water and decrease traffic required for field crop production. The potential for saving energy for the individual farmers is also available (Lockeretz, 1983), but before conservation tillage systems will be voluntarily adopted by farmers, the systems must be understood and provide yield/cost relationships that are similar or superior to conventional tillage systems (Karlen and Sojka, 1985; Karlen and Gooden, 1987). Conservation tillage systems vary with soil type and/or geographic region. In the southeastern Coastal Plain, most production systems include some form of deep (> 0.4m) tillage. This is needed to disrupt dense, root-restrictive layers caused by tillage operations, traffic patterns, or natural reconsolidation of an eluviated (E) horizon (Campbell et al., 1974; Trouse, 1983; Box and Langdale, 1984; Busscher et al., 1986; Busscher and Sojka, 1987).

In evaluating energy implications of conservation tillage, Lockeretz (1983) reported fuel consumption for a variety of tillage operations but not for deep tillage or in-row subsoiling. Information such as draft, wheel slip, speed and power requirement were not available but would have been helpful to quantify energy requirements for new tillage implements and to assist farmers who are evaluating alternate crop production practices such as conservation tillage. Garner et al. (1987) measured the amount of energy required to operate subsoiling and subsoil-bedding implements in five Coastal Plain soils, but conservation tillage conditions and alternate deep tillage implements were not evaluated. Furthermore, Bowers (1985) recommended that future tillage energy evaluations should include measurements of operational energy required for various tillage implements on various soil types, thorough documentation of soil conditions, and reporting of both fuel consumption and draft data.

The objectives of this study were to:

- Quantify the energy requirements for operating four deep-tillage implements when used in disked and non-disked field conditions in Norfolk loamy sand;
- Evaluate the effectiveness in loosening subsurface horizons by measuring soil disruption patterns associated with those tillage implements; and
- Study the effects of limited soil water on the tillage process.

MATERIALS AND METHODS

A field research project was conducted on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) near Florence, SC, in 1986. Conventional (disked)

Article was submitted for publication May 1990; reviewed and approved for publication by the Power and Machinery Div. of ASAE in May 1991.

Contribution of the USDA-Agricultural Research Service, Coastal Plains Soil and Water Conservation Research Center, Florence, SC, in cooperation with the South Carolina Agricultural Experiment Station, Clemson University, Clemson, SC.

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and non-disked tillage treatments had been compared at this site using a corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean (*Glycine max* L. Merr.) rotation during the previous eight years. A split-plot experimental design with four replicates was used. Whole plots were 20 m long × 28 m wide areas that were established on long-term conventional and conservation tillage treatments. Uniform soil surface conditions were provided for all tools by chopping corn stover and winter weed residue from the non-disked tillage plots with a flail chopper three days before conducting the experiment on 22 May 1986. Conventional tillage plots had been tilled periodically during the winter with a tandem disk to prevent establishment of weeds. The conventional plots were disked twice (depth of 0.09 m) and smoothed with a field cultivator two days before conducting the study. Initial soil water content was measured using the gravimetric method on soil tube samples pulled from the 0.0- to 0.1-, 0.1- to 0.2-, 0.2- to 0.3-, 0.3- to 0.4-, 0.4- to 0.5, and 0.5- to 0.6-m depth increments immediately before the energy measurements were made.

Four tillage implements, a Brown-Harden Superseeder (SS), a BushHog RoTill (RT) unit, a Tye ParaTill (PT) system, and a Kelley Manufacturing Company (KMC) in-row tillage system, were evaluated in both the disked and non-disked plots. All four implements can combine deep tillage with a planting operation, but the units use different shanks and seedbed preparation attachments ahead of the planting units. The systems are described as follows:

The SS system had a 50 mm wide forward angled subsoiler shank with a 125 mm long × 64 mm wide point and strip tillers at the side of each shank in the form of wide-fluted rolling coulters.

The RT system had a 32 mm wide parabolic subsoil shank with a 40 mm point following a standard 0.46 m diameter coulter. This shank was followed by 50 mm wide fluted coulters on each side of the shank and an adjustable, reversible rolling basket as a seedbed finishing tool.

The PT system had a serrated coulter followed by a 25 mm wide bent-leg shank with a 0.94 m beam to ground clearance and a 45° bend (left row to right and right row to left) 0.69 m below the beam. The 64 mm wide points were positioned 0.76 m apart. Legs of the PT system are 0.25 m wide and have adjustable shatter plates just above and behind the points to provide lifting of the soil. Seedbed preparation for the PT implement was completed with Yetter "Trash Master" attachments connected to each tillage unit.

The KMC system had a 45° forward-angled subsoil shank that was 32 mm wide with a 32 mm point following a 0.51 m diameter serrated, adjustable, spring-tensioned coulter. This shank was followed by twin, fixed-tilt, adjustable angle, pneumatic rubber tires to close the ripper slot and form a smooth, level seedbed for the planter unit.

A two-row version of each implement was connected to a John Deere 3020 tractor equipped with a three-point hitch dynamometer and a microcomputer-based data acquisition system (Reynolds et al., 1982; Garner and Dodd, 1985). Subsoiling depth for each implement was approximately 0.4 m and was obtained by using the tractor hydraulic system in the "position control" mode and making trial runs for both disked and non-disked surface conditions. Because of the dry soil condition, soil resistance to implement penetration was extremely high and tractor forward speed was lower than normal. Forward speed, engine speed, wheel slip, fuel requirement, and draft data were collected at a rate of 83 observations per second (Reynolds et al., 1982). Data were transferred from the tractor-mounted microcomputer to another microcomputer after each 12 m pass for preliminary processing and storage on digital diskettes.

Slip was computed using the equation:

$$S = \left(\frac{V_t - V_a}{V_t}\right)(100)$$

where

V_t = theoretical speed obtained from sensors on the rear axles,

V_a = actual speed obtained from a fifth-wheel sensor.

Both sensors were calibrated based on no load tests on a non-tilled sod which, in this dry year provided a firm surface. As a check on the fifth-wheel calibration, all plot runs were timed by hand. There was close agreement between computer-measured and hand-measured forward speeds for both the disked and non-disked plots.

Instrumentation and methods used for these measurements have been described by Reynolds et al. (1982), Garner and Dodd (1985), and Garner et al. (1987). An average of 1755 analog data points were collected for each replicate of each measured parameter and analyzed statistically using mean values for each implement.

Soil resistance before and after tillage with each implement was evaluated by measuring cone index with a 30° cone tip attached to a tractor-mounted recording penetrometer hydraulically forced downward at a constant rate of 1.83 m/min to a maximum depth of approximately 0.6 m (Garner et al., 1987). In performing a penetrometer scan, the tip of the cone was lowered until it touched the soil surface. Depth and probe force measurements were begun at this point. For the penetrometer measurements made before deep tillage, the soil surface was approximately plane for both the disked and non-disked plots. Penetrometer depth readings were not corrected for surface profile irregularities in the post, deep tillage, cone index measurements. It is estimated that the surface relief after deep tillage was less than 0.05 m. After deep tillage, penetrometer scans were made across each two-row treatment at approximately 5 m from the end of the plots. The base of the cone-shaped probe was 18.9 mm in diameter at the beginning of the study and 16.9 mm in diameter at the end of the study. Corrections for this change in area caused by the abrasiveness of this soil were made for each set of 13 probings assuming constant wear throughout the study. An x-y plotter was used to record the penetrometer data. These data were subsequently digitized using the method presented by Busscher et al. (1986). Resistance data consisted of cone indices for each of 13 depths at 13 positions spaced 0.61 m apart across two rows (1.93 m) for all four tillage implements. Resistance measurements were made in disked and non-disked tillage blocks before operating the implements so that subsoil disruption patterns for each tool could be evaluated. Data for the two rows were used as duplicate readings and averaged to minimize sampling error. These averages were analyzed to evaluate effects of depth and position across the row. Statistical analyses were made using SAS regression after the cone indices were log transformed as suggested by Cassel and Nelson (1979). The regression equation included the first four orders of position and depth variables and the first and second order interaction terms. Significance was determined by calculating F-values using pooled effects of the appropriate individual treatments and their combined effect as shown in Draper and Smith (1966).

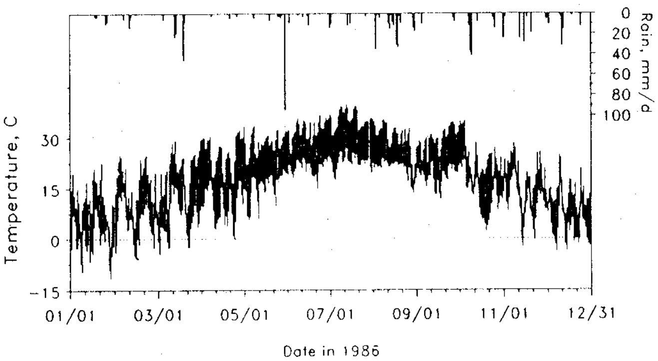

Figure 1–Daily rainfall and temperature data for the plot area, 1986. (USDA Coastal Plains Soil and Water Research Laboratory, Florence, SC)

RESULTS AND DISCUSSION

Initial soil water content was lower in non-disked plots than in disked treatments at all sampling depths (Table 1). Those differences were presumably caused by winter weeds growing in non-disked plots prior to conducting the study. Campbell et al. (1984) identified transpiration by winter weeds or cover crops as a soil water sink. This would be a problem for conservation tillage on Coastal Plain soils when winter rainfall is low. To prevent the moisture losses, winter weeds or cover crops could be chemically controlled leaving the residue on the soil surface. Water loss to winter weeds was especially significant in 1986 which was a drought year. During the first 140 days of 1986, rainfall at this site totaled 180 mm compared to a 30-year average of 405 mm. The severity of the drought with regard to both low rainfall and high temperatures is documented in figure 1. Using simulated tree ring data for this region, this drought resulted in the lowest Palmer Drought Severity Index since 750 AD (Stahle et al., 1988).

Low soil water content significantly increased pretillage soil resistance as measured by cone index (CI) for each layer (Table 2). Soil resistance at this site averaged 4.7 and 6.5 MPa in the top 0.6 m of disked and non-disked blocks, respectively. The fact that the non-disked plots had higher penetrometer resistance values even though the disked plots received more traffic indicates the strong influence of soil water content on soil resistance. These average levels of soil resistance were higher than maximum CI levels reported by Garner et al. (1987). These high CI values demonstrate the severity of soil resistance problems in Coastal Plain soils with low moisture levels.

TABLE 1. Initial soil water content (dry weight basis) measured at six depths in Norfolk loamy sand

Soil Depth	Disked	Non-disked
m	% db	
0.0 - 0.1	4.9	4.2
0.1 - 0.2	3.8	2.4
0.2 - 0.3	6.0	4.4
0.3 - 0.4	11.2	9.6
0.4 - 0.5	13.6	11.4
0.5 - 0.6	14.4	11.5
Average	9.0a*	7.2 b

* Tillage means followed by different letters are significantly different at P(0.01) with an LSD value of 0.96.

Pretillage soil resistance data for disked and non-disked plots are also summarized in figure 2. Isolines for CI values of 0.5, 2.0, 4.0, and 8.0 MPa are centered across one 0.96 m wide row. The 0.5 MPa isoline shows the effective depth of disking (~ 0.09 m) in figure 2 (di). The 2.0 MPa

TABLE 2. Initial soil resistance (cone index) measured at six depths in Norfolk loamy sand

Soil Depth	Disked	Non-disked
m	MPa	
0.0 - 0.1	0.7	2.4
0.1 - 0.2	3.4	6.3
0.2 - 0.3	7.1	9.5
0.3 - 0.4	7.1	8.6
0.4 - 0.5	5.3	6.4
0.5 - 0.6	4.7	5.8
Average	4.7	6.5

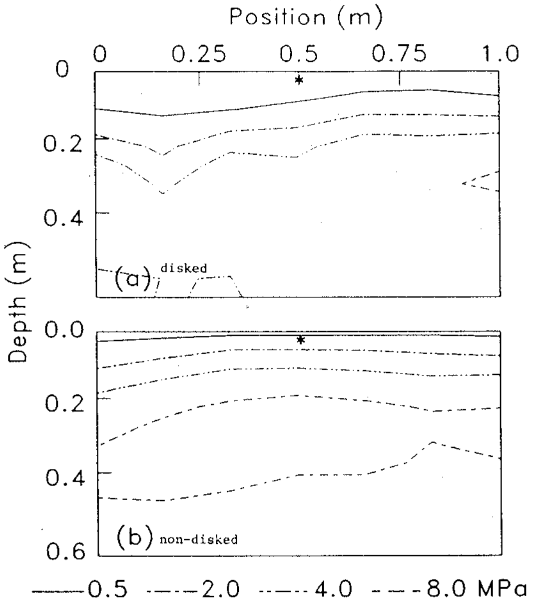

Figure 2–Soil resistance measured by cone index (CI), centered across a width of one row. Resistances were recorded as a function of depth for the disked (di) treatment and the non-disked (nd) treatment. These measurements were made prior to the subsoiling operations.

isoline shows the root-limiting depth for these two soil conditions at the existing soil moisture content prior to deep tillage. The 4.0 and 8.0 MPa isolines are primarily for reference. These soil resistances are well above levels that plant roots can penetrate (Campbell et al., 1974). Soil cone index before tillage was higher in the non-disked plots throughout the entire depth profile. An index of 8.0 MPa in the B-horizon indicates that transpiration had removed a high percentage of the plant available water.

Eight parameters were measured to determine the energy (drawbar power) and related performance factors required to operate each of the implements in disked and non-disked surface soil conditions (Table 3). The effects of the implements on soil resistance after deep tillage are shown for both surface soil conditions in figure 3.

Main effects of surface tillage and implement on each of the eight parameters are summarized in Table 3. Forward travel speed in the non-disked plots was significantly slower at P (0.05) than in the disked plots. Implement draft, wheel slip, and drawbar power requirement were significantly greater for non-disked treatments than for disked treatments. These surface tillage effects are a direct result of the lower soil water content and higher soil resistance for the non-disked treatments.

For three parameters (draft, vertical force, and drawbar power), there was a significant implement-by-surface tillage interaction. The primary cause for the draft and drawbar power interactions is a difference between the Superseeder (SS) and the RoTill (RT) response to disked and non-disked treatments. Vertical force was the downward force caused by the implement (suction) exerted on the tractor hitch. A high negative value for vertical force would indicate a higher load on the rear tractor tires; consequently, slip should be reduced.

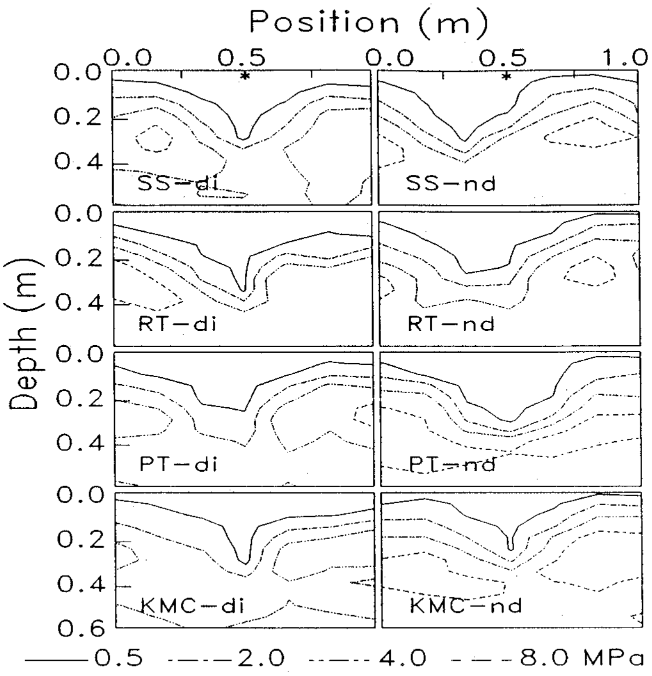

Figure 3–Soil resistance to penetration, measured by cone index (CI), centered across one row after operating the following implements in the specified conditions:

SS – Superseeder
RT – RoTill
PT – Paratill
KM – KMC Subsoiler
di – Plots disked over winter to control weeds
nd – non-disked plots
*** – Denotes the center of the row area. Average of four replicates.**

Multiple regression analyses were performed on the slip, draft and vertical force data for the disked and non-disked treatment means. These analyses were to fit an equation of the form, $Y = A + B X_1 + C X_2$, where Y equals percent slip, X_1 represents draft kN, X_2 equals

TABLE 3. Results of a split-plot analysis of variance for tractor performance parameters measured for four deep-tillage implements on a Norfolk loamy sand*

Surface Tillage	Implement	Forward Speed (m/s)	Engine Speed (rpm)	Draft (kN)	Fuel Req. (L/ha)	--Wheel Slip-- Right (%)	Left (%)	Vertical Force (kN)	Drawbar Power (kW)
Disked	Superseeder (SS)	0.88	1659	17.3	20.8	2.6	2.8	– 12.1	15.2
Disked	RoTill (RT)	0.83	1641	20.3	22.7	6.2	6.2	– 9.1	16.9
Disked	ParaTill (PT)	0.85	1631	18.9	23.0	4.1	4.2	– 6.7	16.1
Disked	KMC	0.86	1639	16.6	20.6	3.7	3.8	– 7.8	14.3
Non-Disked	Superseeder (SS)	0.84	1610	20.7	22.2	4.4	4.5	– 13.7	17.4
Non-disked	RoTill (RT)	0.82	1628	20.7	23.5	7.8	7.8	– 9.5	17.0
Non-disked	ParaTill (PT)	0.83	1626	19.6	22.5	6.2	6.4	– 6.1	16.3
Non-disked	KMC	0.84	1634	18.3	21.8	5.3	5.7	– 7.7	15.4
Interaction	LSD (0.10)	NS	NS	1.4	NS	NS	NS	1.0	1.1
Average Surface Tillage Effects:									
Disked		0.86	1643	18.3	21.8	4.2	4.3	-8.9	15.6
Non-disked		0.83	1624	19.8	22.5	5.9	6.1	-9.3	16.4
Surface tillage	LSD (0.05)	0.02	NS	0.04	NS	0.7	0.6	NS	0.5
Average Implement Effects:									
Superseeder (SS)	0.86	1634	19.0	21.5	3.5	3.7	– 12.9	16.3	
RoTill (RT)		0.82	1635	20.5	23.1	7.0	7.0	– 9.3	16.9
ParaTill (PT)		0.84	1628	19.3	22.7	5.2	5.3	– 6.4	16.2
KMC		0.85	1636	17.4	21.2	4.5	4.8	– 7.8	14.8
Implement	LSD (0.05)	0.03	NS	1.2	1.3	2.5	2.6	0.8	0.9

* Data obtained with two-row implements.

vertical force (absolute value) kN, and A, B and C are constants.

For the disked area, the following equation was obtained: $Y = -7.48 + 0.703 X_1 - 0.126 X_2$ with $r^2 = 0.78$. For the non-disked area, the equation obtained was: $Y = -5.72 + 0.788 X_1 - 0.430 X_2$ with $r^2 = 0.83$. These coefficients and the r^2 values indicate that slip was influenced by both draft and the vertical force transferred from the implement to the tractor hitch. The SuperSeeder had fewer rolling components that supported the vertical force; hence, more of the implement vertical force was transferred to the rear tractor tires and slip was reduced for this implement.

Forward travel speed and wheel slip were significantly different for the SS and RT implements. The PT and KMC implements had intermediate values for those parameters and were not significantly different from either the SS or RT unit. Slower travel speed and higher wheel slip for the RT unit presumably occurred because the RT unit disrupted a greater volume of soil at a deeper depth, with a resulting higher draft and the implement supported a greater portion of the suction force.

The desired tillage depth for each implement was approximately 0.4 m. That depth is normally required at this experimental site to penetrate an eluvial (E) horizon that is very characteristic of many Coastal Plain soils in this region (Campbell et al., 1974). The very dry soil conditions, combined with the limited power available from the tractor being used, prevented operation at this depth (fig. 3).

Strength differences between disked and non-disked plots as measured by CI, were significant before and after tillage treatments. Before tillage, the F-value for evaluating significance of cone index differences was 166 for the comparison between disked and non-disked treatments. Differences near the surface (fig. 2) were caused by disking. Differences at lower depths were caused by continued weed growth that dried the profile and increased CI for the non-disked treatment (Table 1). After tillage, the F-value was 23 for the comparison of the disked and non-disked treatments across all tillage implements. These F-values indicated that there was a significant difference between disked and non-disked treatments before and after deep tillage.

The F-values for comparison of after tillage CI among deep-tillage implements were 2.8 and 6.0 for the disked and non-disked treatments. Both were significant at the 1% probability level. Comparisons of CI for disked and non-disked treatments with the four deep-tillage implements resulted in F values of 10.5, 3.7, 12.6, and 8.6 for the SS, RT, KMC, and PT, respectively. These were all significantly different at the 1% level of probability. Detailed study of the CI measurements (fig. 3) shows these differences in the volume of disturbed soil following deep tillage with each implement. Volume of disturbed soil, as indicated by soil penetration resistance, was less for non-disked plots than for disked plots, and this was primarily due to decreased depth of tillage. Decreased tillage depth more than offset the greater width of the disturbed area which occurred in the non-disked plots. This difference in the depths of disturbed patterns is more clearly manifest in the depths of the transition from the 2.0 MPa to the 4.0 MPa isolines.

Fuel requirement among implements showed significant differences between the SS and RT or KMC units, as well as between the PT and KMC units. The numerically highest fuel requirement was measured for the RT unit which is related to higher draft and wheel slip and slower forward speed. The lowest fuel requirement was measured for the KMC unit, but this unit did not till as deeply (fig. 2).

Implement draft measurements showed significant differences at P (0.05) between the RT and the SS or KMC units and also between the PT and KMC units. Numerically, draft measurements showed the same pattern as fuel consumption with the RT implement having the highest value and the KMC implement the lowest value. Drawbar power requirement for the SS, RT, and PT units averaged 16.5 kW per two shanks, while the KMC unit averaged 14.8 kW per two shanks. The relatively low power requirement per shank measured in this study reflects the slow forward travel speed. Adjusting travel speed to a more normal operating value of 1.8 m/s and conservatively assuming that draft remains the same (overall average = 19.05 kN), the individual drawbar power requirement per two shanks would increase to 34.3 kW. For the disked treatments, power requirement at this speed for two shanks would be 32.9 kW while for the non-disked treatments 35.6 kW would be required. Garner et al. (1987) reported data that would indicate a drawbar power requirement of 23.9 kW for a subsoiler bedder operating at 0.4 m depth on a disked Norfolk loamy sand with good soil water condition. The slow forward travel speed in this study was necessary because the high magnitude and variability of soil penetration resistance created conditions which loaded the tractor to the limit of its drawbar pull capability at the selected engine speed.

CONCLUSIONS

Performance factors for a two-wheel-drive tractor pulling selected deep-tillage implements in a Norfolk loamy sand were measured during drought conditions. These factors were measured for two soil treatments: 1) plots that had been disked during the winter to control weeds; and 2) plots on which winter weeds had been allowed to grow until three days before the measurements were made.

Soil water content and soil cone index were measured immediately prior to the tillage operations. Soil cone index variations across the tilled areas were also measured after tillage.

Soil water depletion caused by evapotranspiration from winter weeds resulted in increased soil resistance to penetration by a cone penetrometer. In addition, draft, power, and fuel requirements were increased due to the reduction in soil water level.

Drawbar power requirement to pull these two-row deep tillage implements at a depth of approximately 0.4 m and at a field speed of 1.8 m/s would be in excess of 33 kW for disked treatments and greater than 36 kW for a two-row implement operating in dry non-disked soil conditions. Garner et al. (1987) reported data that would indicate 23.9 kW for a subsoiler bedder operating at 0.4 m depth on a disked Norfolk loamy sand with soil water content at a good level for field work.

Suction forces from tillage implements can be transferred to the rear tractor tires and result in reduced wheel slip if these forces are not carried by implement support wheels or other soil engaging components.

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