The Society for engineering in agricultural, food, and biological systems

An ASAE Meeting Presentation

Paper Number: 051025

Site-Specific Subsoiling Benefits for Cotton Production

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Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. *The negative impacts of soil compaction on crop yields can often be alleviated by subsoiling. However, this subsoiling operation is often conducted at unnecessarily deep depths where it wastes energy and disturbs surface residue necessary for erosion control and improved soil quality. A corn (Zea mays L.)-cotton (Gossypium hirsutum L.) rotation experiment was conducted over four years on a Coastal Plain soil with a hardpan in east-central Alabama to evaluate the potential for site-specific subsoiling (tilling just deep enough to eliminate the hardpan layer) to improve crop yields while conserving energy. Seed cotton yield showed benefits of subsoiling compared to the no-subsoiling treatment. Site-specific subsoiling produced yields equivalent to deep subsoiling while not excessively disturbing surface soil and residues. Significant reductions in draft force and drawbar power were found for site-specific subsoiling as compared to uniform deep subsoiling. Producers in the Coastal Plains who can determine the depth of their root-impeding layer and can provide site-specific subsoiling to loosen compacted soil profiles should have comparable yields and reduced energy requirements as those producers implementing uniform deep subsoiling*

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Keywords. Site-specific, precision agriculture, subsoiling, soil compaction, draft, drawbar power

Introduction

Cotton production in the southeastern U.S. has been negatively affected by soil compaction (McConnell et al., 1989). Vehicle traffic coupled with naturally compactable soils has significantly contributed to shallow crop rooting, drought, and reduced crop yields (Raper, 2003).

Subsoiling has been found to reduce the ill effects of soil compaction and therefore increase cotton yields (Melville, 1976; Tupper and Spurgeon, 1981; McConnell et al., 1989; Raper et al., 2000a; Raper et al., 2000b). However, the energy requirements and costs associated with subsoiling can be substantial and have been shown to increase dramatically with increased tillage depth (ASAE Standards, 2003). Reductions in tillage depth could save producers significantly if soil compaction was still eliminated (Fulton et al., 1996; Raper, 1999).

Soils in the Southeastern US have exhibited large amounts of variability in soil compaction (Raper et al., 2001). Not only has soil compaction been proven to vary across the row from untrafficked middle to trafficked middle, soil compaction also varies spatially across the field partially due to prior cropping systems which include traffic patterns and tillage systems. Using varying soil compaction information obtained from previous measurements may offer a method of maintaining crop productivity while conserving energy.

Therefore, the objectives of this experiment were:

1) to determine the effect of site-specific subsoiling on cotton yield,
2) to determine the reductions in draft force due to site-specific subsoiling, and
3) to determine the reductions in fuel requirements for site-specific subsoiling.

Methods and Materials

This experiment was performed on an 8-ha field at the E.V. Smith Research and Extension Center located near Shorter, AL which is part of the Alabama Agricultural Experiment Station. The soil type was a Toccoa fine sandy loam of the Coastal Plain. This field has been annually subsoiled to compensate for excessive soil compaction which frequently restricted plant roots.

To facilitate appropriate crop management typical for southeastern producers, a corn-cotton rotation system was established (table 1). The entire field was split into two halves: field 1 and field 2. A split-split-plot experiment was conducted on these fields in a completely randomized design with four replications. Mainplot treatments were hardpan depth, subplot treatments were cover crops, and sub-subplots were subsoiling depth.

Table 1. Rotation for cash crops and cover crops.

	FIELD 1	FIELD 2
Fall 1999	Crimson Clover	Rye
Spring 2000	Corn	Cotton
Fall 2000	Rye	Crimson Clover
Spring 2001	Cotton	Corn
Fall 2001	Crimson Clover	Rye
Spring 2002	Corn	Cotton
Fall 2002	Rye	Crimson Clover
Spring 2003	Cotton	Corn

Many southern producers use cover crops to protect soil from rainfall during winter months. There are also some indications that a cover crop may reduce the need for subsoiling by increasing water-holding capacity of the soil. To test this hypothesis, half of each plot was planted with a cover crop and the other half left bare during winter months. Rye (*Secale cereale* L.) cv. Wren's Abruzzi.Prior was used as a cover crop prior to planting cotton and crimson clover (*Trifolium incarnatum* L.) cv. AU Robin was used as a cover crop prior to planting corn.

The experiment was initiated during the spring of 1999 with the planting of a corn crop. No subsoiling was used to prepare the field with the intent of discovering the field's natural variation in soil compaction. Data obtained from this test showed variations in corn yield from 0 to near 100 kg/ha.

In the fall of 1999, a complete set of cone index measurements (ASAE Standards, 1999a; ASAE Standards, 1999b) were obtained with the Multiple-Probe Soil Measurement System (Raper *et al.*, 1999) using an approximate 100 m grid. Peak values of cone index were determined for each sampled profile. These peak values were assumed to occur at the depth of the existing soil hardpan, which is the root-restricting layer commonly found in this region. A great deal of variation was found in this field for the soil hardpan with values mostly being found in the 15-45 cm depth range (fig. 1). Three distinct depth ranges were created from this data: 15-25 cm, 25-35 cm, and 35-45 cm which were replicated four times over the field. From the figure, one can also see that not all areas within the field had defined hardpan profiles. These areas were omitted from the experimental plots.

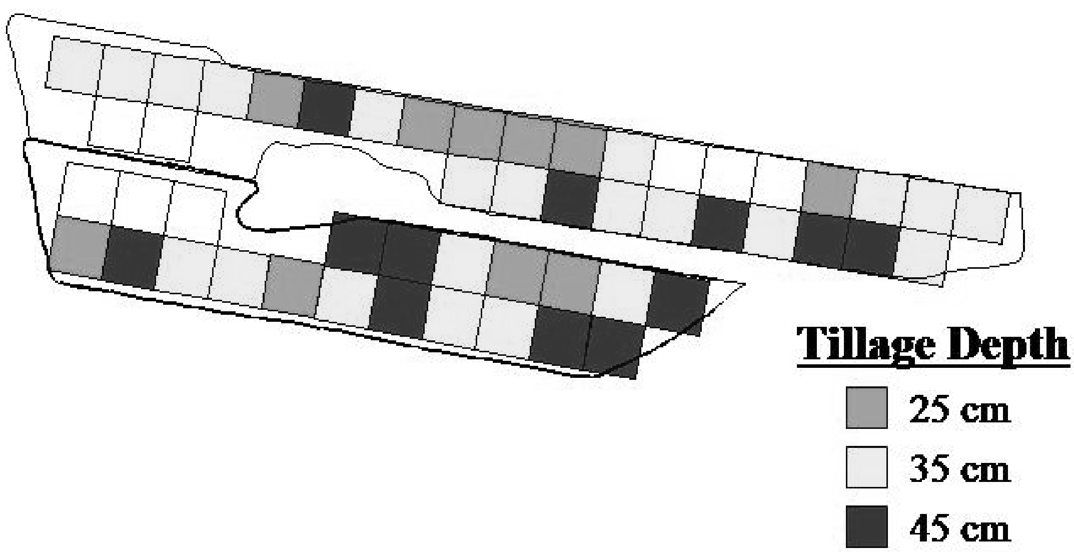

Figure 1. Cone Index map showing locations of measured hardpan depth.

Prior to planting in the spring of 2000, 2001, 2002, and 2003, three subsoiling treatments were imposed on each of the experimental plots:

1. no-subsoiling (zero-depth subsoiling)
2. site-specific subsoiling (25-cm, 35-cm, or 45-cm depth subsoiling)
3. deep subsoiling (45-cm depth subsoiling)

Our procedure can be illustrated best by an example. In plot number 3 (fig. 2), for example, the hardpan depth has been established to exist at a depth of 35 cm. Therefore, the site-specific subsoiling treatment would be applied slightly below a depth of 35 cm in this plot. Two other treatments would also be applied: no subsoiling (zero-depth subsoiling) and deep subsoiling (45-cm-depth subsoiling).

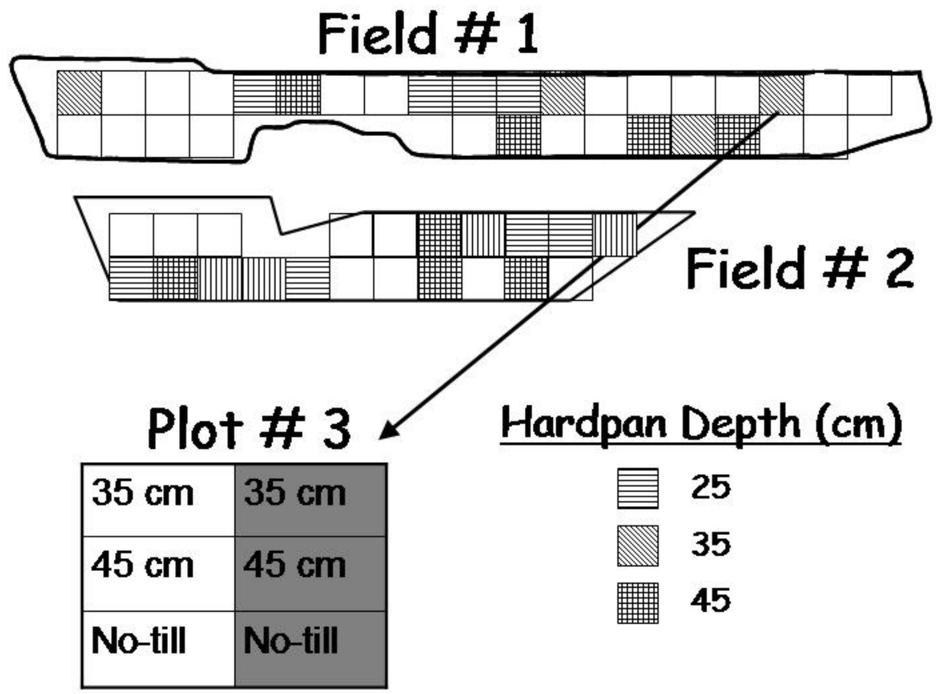

Figure 2. Experimental layout of entire field showing location of plots, hardpan depths, location of cover crops (shading over right half of plot #3), and location of subsoiling treatments.

Site-specific and deep subsoiling was conducted using a John Deere 955 Row Crop Ripper which had been supplied as part of a Cooperative Research and Development Agreement with Deere and Co. (Moline, IL). This subsoiler was equipped with 7-cm wide LASERRIP™ Ripper Points (fig. 3). Due to initial problems with this subsoiler that prevented the areas behind the shank from closing up after tillage, additional components were supplied from Yetter Mfg. (Colchester, Ill.) that assisted with moving soil into this zone and allowing planting immediately after subsoiling. To facilitate site-specific subsoiling, several items were manually repositioned allowing the subsoiler to function properly at various depths of tillage. The Yetter closing components, coulters, and gauge wheels were all manually adjusted for the desired three site-specific subsoiling depths.

Figure 3. John Deere 955 used for subsoiling treatments.

To measure draft, vertical, and horizontal subsoiling forces, the JD 955 implement was mounted on a 3-dimensional dynamometer which was attached to a John Deere 8300 MFWD tractor. Speed was acquired with a radar gun.

Four-row equipment was used for cotton establishment with a row spacing of 1.02 m while six-row equipment was used for corn with a row spacing of 0.76 m. Plot length was 30.5 m.

Only data collected from the cotton experiment will be discussed in this paper. The corn data was previously published in Raper et al. (2005). Cotton spatial yield information was obtained with an Agleader Technology, Inc. (Ames, Iowa) cotton yield monitor over the middle 2-row section of each plot. This information was averaged over the entire length of the plot to obtain one yield value.

A split-split plot arrangement with four replications with main plots of hardpan depth, subplots of cover crop, and sub-subplots of tillage treatment were analyzed with an appropriate GLM model using SAS (Cary, North Carolina). A predetermined significance level of $P \leq 0.1$ was chosen to separate treatment effects.

Results and Discussion

Discussions will be limited to main treatment effects and significant interactions between depth of hardpan and subsoiling treatments.

Cotton Yields

Seed cotton yield averaged across replications, depth of hardpan, and cover crop for years 2000-2003 showed that site-specific subsoiling had yields equivalent to those plots that received deep subsoiling ($P \leq 0.01$). Site-specific subsoiling (2030 kg/ha) and deep subsoiling (2152 kg/ha) both had yields which were greater than no-tillage (1839 kg/ha) due to the yield-limiting soil compaction that was present in the Coastal Plain soil found within the experimental field.

The depth of hardpan was not found to affect cotton yield (P ≤ 0.16) although a significant interaction with subsoiling treatment was found (P ≤ 0.05; fig. 4). The largest differences occurred at the hardpan depths of 35 and 45 cm where no-tillage resulted in significantly decreased yields compared to either site-specific subsoiling or deep subsoiling. A trend seemed to exist that indicated decreased yields were found at deeper hardpan depths.

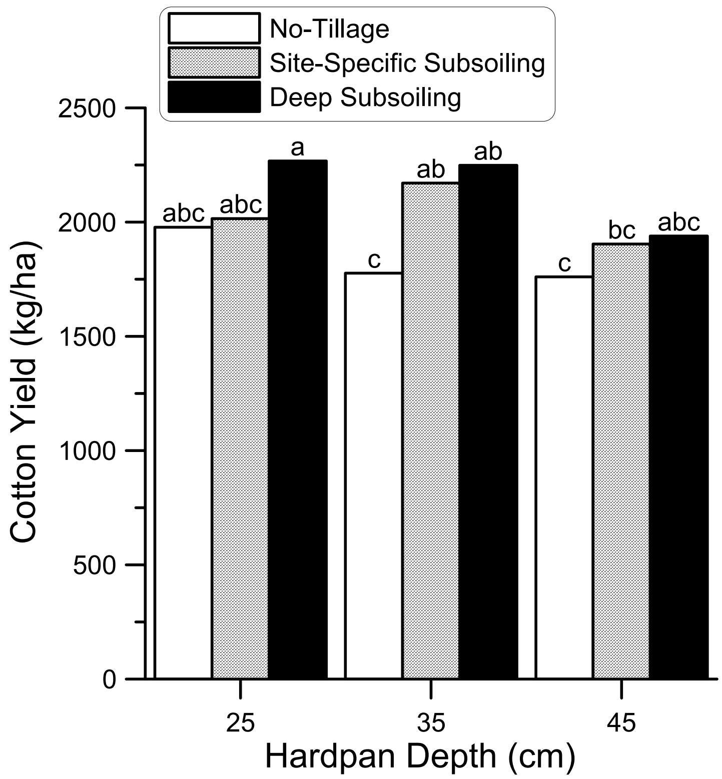

Figure 4. Seed cotton yield (kg/ha) averaged across years and cover crops. Letters indicate differences using $LSD_{0.1}$.

Implement Draft Force

Draft forces declined from the highest values which were measured at the initiation of the experiment in 2000 (60 kN) to the smallest values which were measured at the conclusion of the experiment in 2003 (36 kN). During the intermediate years of 2001 and 2002, we measured 43 kN and 48 kN, respectively.

The depth of the hardpan (P ≤ 0.01) and the subsoiling depth (P ≤ 0.01) were found to interact and to be significant main effects on subsoiling draft force (P ≤ 0.01; fig. 5). At the shallow hardpan depth of 25 cm, site-specific subsoiling resulted in a 59% draft reduction as compared to uniform deep subsoiling. At the medium hardpan depth of 35 cm, site-specific subsoiling also reduced draft by 35%. As a check, site-specific subsoiling and deep uniform subsoiling resulted in similar drafts of 57 kN at the deep hardpan depth of 45 cm. It is also interesting to note that deep uniform subsoiling conducted at a depth of 45 cm took similar draft forces at all three hardpan depths of 25, 35, or 45 cm. The depth of the root-impeding layer did not affect draft forces except when subsoiling force was reduced.

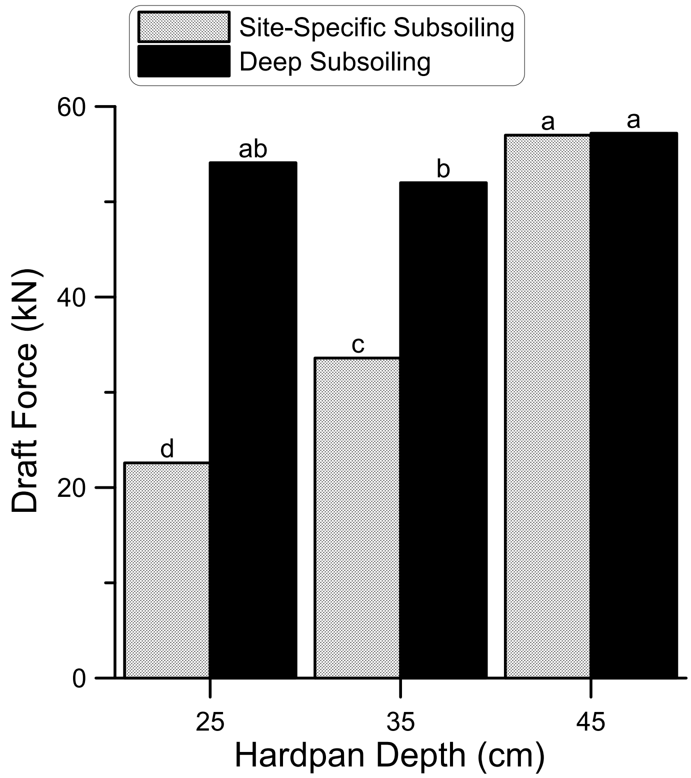

Figure 5. Implement draft (kN) averaged across years and cover crops. Letters indicate differences using $LSD_{0.1}$.

Implement Vertical Force

Implement vertical force was found to be affected by main effects of subsoiling depth ($P \leq 0.01$) and hardpan depth ($P \leq 0.01$). An interaction between subsoiling depth and hardpan depth was also found for vertical force ($P \leq 0.01$; fig. 6). Significantly larger values of vertical force were found for site-specific subsoiling at hardpan depths of 25 and 35 cm. At the hardpan depth of 25 cm, 37% more vertical force was required for site-specific subsoiling. Similarly at the hardpan depth of 35 cm, 25% more vertical force was necessary for site-specific subsoiling. These increased values of vertical force indicate that the subsoiler required additional force to push it into the soil at the shallower subsoiling depths.

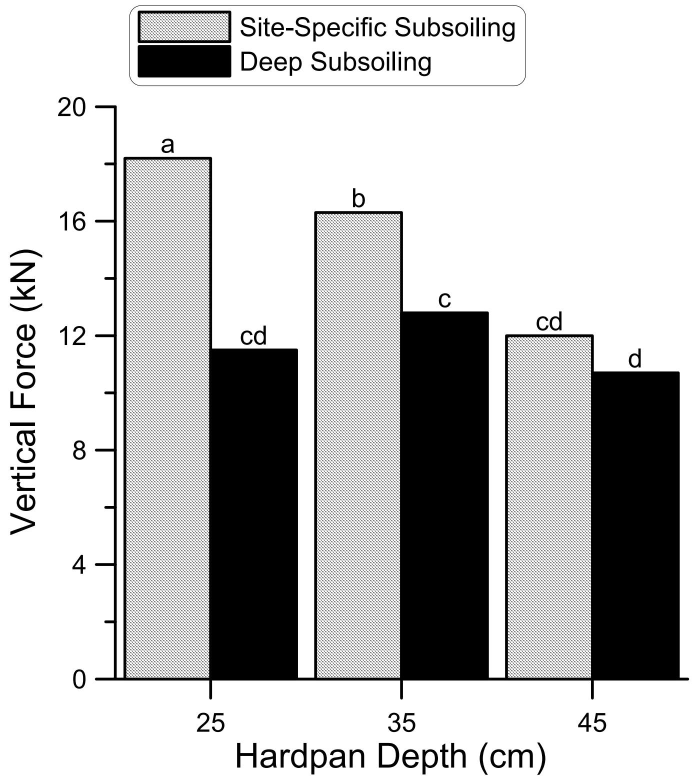

Figure 6. Implement vertical force (kN) averaged across years and cover crops. Letters indicate differences using $LSD_{0.1}$.

Implement Power

Some variation in subsoiling speed was found with deep subsoiling being conducted at slower speeds than site-specific subsoiling. At the shallow hardpan depth of 25 cm, site-specific subsoiling was conducted at 5.3 m/s which was greater than the deep subsoiling speed of 4.8 m/s ($P \leq 0.01$). At the medium hardpan depth of 35 cm, site-specific subsoiling was again conducted at a higher speed of 5.2 m/s compared to deep subsoiling which was conducted at 4.7 m/s. At the deepest hardpan depth of 45 cm, no differences in subsoiling speeds were expected, nor were they found with site-specific subsoiling being conducted at 4.4 m/s and deep subsoiling being conducted at 4.6 m/s ($P \leq 0.39$).

Power requirements required for subsoiling were calculated by multiplying the draft force by the subsoiling speed (ASAE Standards, 2003). Subsoiling depth and hardpan depth were both found to significantly affect implement power ($P \leq 0.01$). The interaction of subsoiling depth and hardpan depth was also found to significantly affect implement power as well ($P \leq 0.01$; fig. 7). Greatest reductions were obtained at the shallow hardpan depth of 25 cm, with site-specific subsoiling requiring 52% less power than uniform deep subsoiling. At the medium hardpan depth of 35 cm, a 26% reduction in implement power was required for site-specific subsoiling compared to uniform deep subsoiling. Not surprisingly, no differences were found at the 45-cm hardpan depth layer for site-specific subsoiling and deep subsoiling.

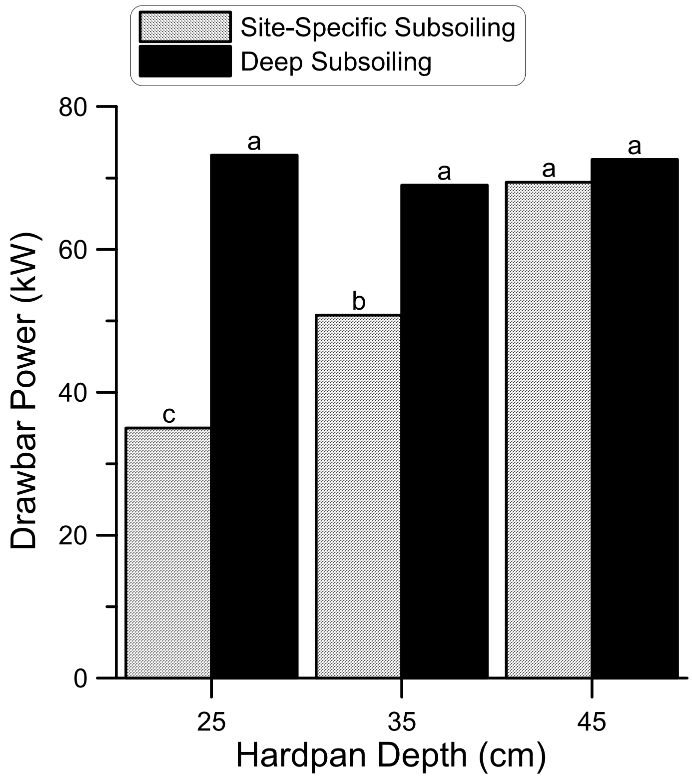

Figure 7. Drawbar power (kW) averaged across years and cover crops. Letters indicate differences using $LSD_{0.1}$.

Estimated Fuel Use

A procedure was developed that allowed fuel use to be estimated for subsoiling depth (Raper et al., 2005). The procedure involved converting variable power-take-off data (from the Nebraska OECD Tractor Test for a John Deere 8300 tractor (Leviticus et al., 1995)) to drawbar power by multiplying 0.73 for a mechanical front-wheel assist tractor on tilled ground (ASAE Standards, 2003). A linear relationship was created between drawbar power and fuel rate which had a correlation coefficient of 0.99:

$$FR = 0.31 * DP + 9.14 \quad (1)$$

Where FR = fuel rate (l/hr)

DP = drawbar power (kW)

Information from fig. 7 was used in equation 1 to determine fuel rate for the different subsoiling treatments. Fuel use was obtained by dividing fuel rate by the speed and width of the subsoiling operation.

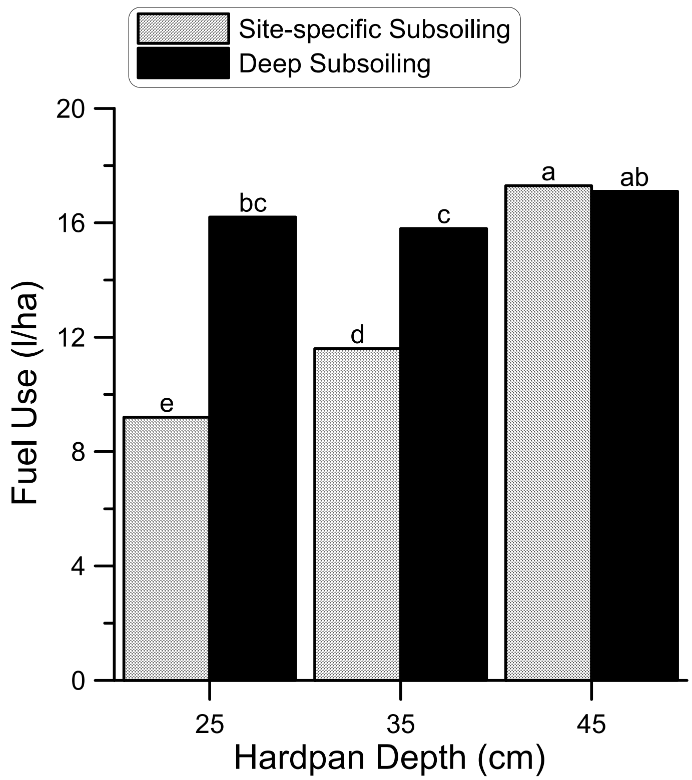

Figure 8. Estimated fuel use (l/ha) averaged across years and cover crops. Letters indicate differences using $LSD_{0.1}$.

The results for estimated fuel use were similar to results for implement power. The depth of hardpan and the subsoiling treatments were both found to be statistically significant as well as a significant interaction between the two parameters (*$P \leq 0.01$ for each parameter and the interaction*; fig. 8). On the shallow hardpan plots (25 cm depth), site-specific subsoiling required 43% less fuel than deep subsoiling. On the medium-depth hardpan plots (35 cm), site-specific subsoiling required 27% less fuel.

Considering the whole field used in this experiment enabled estimates to be made for total savings associated with the use of site-specific subsoiling. Of the 4.4 ha actually used for the experiment, 1.0 ha had a hardpan depth of 25 cm, 2.2 ha had a hardpan depth of 35 cm, and 1.2 ha had a hardpan depth of 45 cm. If the whole field was subsoiled to the uniform deep depth of 45 cm, it would require a total fuel amount of 71.5 l. If site-specific subsoiling could be employed, the entire field could be subsoiled using only 55.5 l of fuel, saving 22% of the estimated fuel requirements for uniform deep subsoiling on this Coastal Plains soil.

Conclusion

The conclusions of this experiment were:

1) Site-specific subsoiling had similar seed cotton yields compared to deep uniform subsoiling. Both subsoiling treatments yielded greater than no-tillage in this Coastal Plain soil type.

2) Site-specific subsoiling resulted in 59% and 35% reduced draft force in the shallow depth hardpan plots (25 cm) and medium depth hardpan plots (35 cm), respectively, compared to uniform deep subsoiling conducted at 45 cm depth.
3) Site-specific subsoiling resulted in 43% and 27% reduced calculated fuel use i n the shallow depth hardpan plots (25 cm) and medium depth hardpan plots (35 cm), respectively, compared to uniform deep subsoiling conducted at 45 cm depth.

Acknowledgement

This research was conducted as part of a Cooperative Research and Development Agreement with Deere & Co., Moline, IL.

Disclaimer

The use of trade names or company names does not imply endorsement by USDA-ARS or Auburn University.

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