

Energy Savings with Variable-Depth Tillage "A Precision Farming Practice"

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Abstract: Soil compaction management in the southeastern Coastal Plain soils relies heavily on the use of costly annual deep tillage operations. Variable-depth or site-specific tillage which modifies the physical properties of soil only where the tillage is needed for crop growth, has potential to reduce costs, labor, fuel and energy requirements. Although technology for site-specific tillage is available, there is very limited information on the fuel and energy requirements of site-specific tillage in southeastern coastal plain soils. Tests were carried out on three different coastal plain soils to compare energy requirement of site-specific tillage with uniform-depth tillage operations. Also, the effects of tractor speed, soil texture, moisture contents and electrical conductivity on energy requirement and fuel consumption were determined. The energy saving of 50% and fuel saving of 30% were achieved by site-specific tillage as compared to uniform-depth tillage in a loamy sand soil type. Although draft force increased with an increase in travel speed in all soil types but the tillage depth had bigger effect on the draft and drawbar power than the tractor speed. The effect of soil moisture content on draft force and fuel consumption was not significant in loamy sand and sandy loam soil types. Soil EC was highly correlated to soil texture ($R^2=0.916$) and draft force across the field.

Key words: Tillage energy % precision agriculture % site-specific tillage % tractor speed % soil moisture % electrical conductivity

INTRODUCTION

Soil Compaction is an important problem in the Coastal Plain region. It restricts the root growth into deeper soil layers that are rich in terms of soil moisture and nutrients. Most soils of the southeastern Coastal Plain have a compacted zone or hardpan about 6 to 14 in deep and 2 to 6 in thick. Farmers in this region rely heavily on the use of annual uniform-depth deep tillage to manage soil compaction which improves yields [1, 2]. However, farmers usually do not know if annual subsoiling is required, where it is required in a field, nor the required depth of subsoiling. In addition, there is a great amount of variability in depth and thickness of hardpan layers from field to field and also within the field [3-6]. There is very little to gain from tilling deeper than the compacted layer

and in some cases it may be detrimental to till into the deep clay layer [1]. Applying uniform-depth tillage over the entire field may be either too shallow or too deep and can be costly.

A high-energy input is required to disrupt hardpan layer to promote improved root development and increased drought tolerance. Significant savings in tillage energy could be achieved by site-specific management of soil compaction. Site-specific variable-depth tillage system can be defined as any tillage system which modifies the physical properties of soil only where the tillage is needed for crop growth objectives. Raper [7] estimated that the energy cost of subsoiling can be decreased by as much as 34% with site-specific tillage as compared to the uniform-depth tillage technique currently employed by farmers. Also, Fulton *et al.* [8] reported

a 50% reduction in fuel consumption by site-specific or precision deep tillage.

Tillage implement energy is directly related to working depth, tool geometry, travel speed, width of the implement and soil properties [9, 10]. Soil properties that contribute to tillage energy are moisture content, bulk density, cone index and soil texture [11]. It has been reported that draft on tillage tools increases significantly with speed and the relationship varies from linear to quadratic. Similarly, effect of depth on draft, also varies linearly [12].

The technology for site-specific tillage (variable depth tillage) is available [13] and the concept of site-specific tillage has been studied by some researchers [6, 7]. However, this is an emerging technology and therefore minimal information is available on draft and energy requirements of variable-depth tillage, an important consideration in selecting tillage systems. Furthermore, there is a need to determine the effects of tractor speed and soil parameters such as texture, moisture and electrical conductivity on energy requirements of site-specific and conventional uniform-depth tillage operations in coastal plain soils. The development of this information is the prime concern for an economical management of soil compaction and adoption of this technology by southeastern farmers.

The objectives of this study were:

- C To compare the energy requirement and fuel consumption between site-specific tillage and uniform-depth tillage on three different coastal plain soils.
- C To determine the effects of tractor speed and soil parameters such as texture, moisture and electrical conductivity on tillage energy requirements and tractor fuel consumption.

MATERIALS AND METHODS

Equipment: A commercially available soil electrical conductivity meter, Veris Technologies 3100, was used to map the Electrical Conductivity (EC) of the test field [14]. The system is equipped with six coulter-electrodes. One pair of electrodes applies a current into the soil, while others measure the voltage drop between the coulters. The system can measure the EC in either the top 30 or 90 cm of soil.

A DGPS-based penetrometer system mounted on a John Deere Gator was used to quantify geo-referenced soil resistance to penetration [13]. The driver of the Gator could operate the penetrometer (Fig. 1). Soil cone index values were calculated from the measured force required pushing a 130-mm² base area, 30-degree cone into the soil [15].

A front-wheel-assist, 78.3 kW (105 HP) instrumented tractor (John Deere 4050) was used to collect the energy consumption data during the tillage operations. The instrumentation system consisted of a three-point-hitch dynamometer, a fuel flow meter, engine speed (RPM) sensor, several ground speed sensors (fifth wheel, radar and ultrasonic), Differential Geographical Positioning System (DGPS) unit, a data logger and an optical sensor determining the start and end of each plot [6].

DGPS-based equipment for controlling the tillage depth to match soil physical parameters was used in this experiment (Fig. 2). This equipment can control the tillage depth "on-the go" using either a soil compaction map, inputs from an instrumented shank, or entering the tillage depth data manually in the computer [13]. The two outside shanks of a 4-row subsoiler were removed for the tillage energy requirement study.

Field test: Field experiments were carried out, on coastal plain soils, in the fall of 2004 at the Edisto Research and Education Center of Clemson University near Blackville, South Carolina (Latitude 33°21"N, Longitude 81°18"W). The 6-acre test field had three different soil types: Faceville loamy sand, Fuquay sandy loam and Lakeland sand.

Prior to initiation of tests, EC measurements were obtained with the Veris unit to determine variations in soil texture and soil physical properties across the field. A geo-referenced EC map was developed using SStoolbox GIS software. The results showed a great amount of variability in soil EC and the field was found to be an ideal site for variable-depth tillage study. The test field was then divided into 12.5×50 ft rectangular plots and soil samples were collected from each plot and analyzed for soil texture. Figure 3 shows soil electrical conductivity map, soil types and plot arrangements over the entire field.

A complete set of cone penetrometer measurements were obtained with the DGPS-based penetrometer system across the entire field. Nine geo-referenced penetrometer measurements, 5 ft apart, were taken from each plot. The



Fig. 1: Hydraulically operated penetrometer system with DGPS unit



Fig. 2: The control system for variable-depth tillage operations

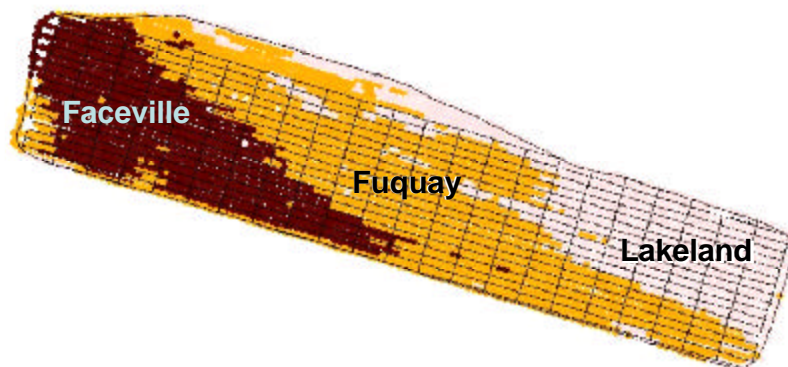


Fig. 3: Aerial photograph and soil electrical conductivity map of the experimental field

depth and thickness of the hardpan were determined from the collected data using the criteria defined by Taylor and Gardener [16]. Within each plot, it was decided to set the tillage depth that would rupture compacted layers of the soil with cone index values above 300 psi.

Tillage experiments consisted of twelve treatments arranged in randomized complete blocks with three replications in each soil type. The treatments included two tillage systems (site-specific and uniform-depth), three levels of tractor speed (4, 5 and 6 mile/h) and two levels of soil moisture contents.

RESULTS AND DISCUSSION

The penetrometer data in each location was analyzed using an algorithm written in QBASIC program [6] for determining the tillage depth. A single depth-value was assigned to each plot by averaging the nine predicted-tillage-depth values within that particular plot. Using these data three tillage zones were identified in each soil type. In each zone, the two tillage treatments (uniform-depth and site-specific) were replicated 3 times.

The uniform-depth tillage was performed 18 in deep to completely disrupt the root-impeding layer. The site-specific tillage was applied according to the application maps generated from soil compaction data. The predicted tillage depth in Faceville soil type ranged from 8 to 14 in. In both Fuquay and Lakeland soil types, the tillage depth varied from 11 in to 18 in

Statistical analysis of energy requirement by using Proc ANOVA in SAS software [17] clearly showed significant difference between tillage treatments in every soil types ($p < 0.01$). Also fuel consumption was significantly different in Faceville soil ($p < 0.01$) and also in the other two soil types ($p < 0.05$) between site-specific and uniform-depth tillage.

Comparison of tillage energy and fuel consumption for both tillage systems in Faceville soil type showed that energy saving of 50% and fuel saving of 30% could be achieved by using site-specific tillage system. Also energy and fuel savings were 21 and 8% for Fuquay and 26.1 and 8.5% Lakeland soil type respectively. Figure 4 shows the energy requirements and fuel consumption for both tillage systems in each soil type.

Although not statistically different, the draft force increased with an increase in tractor speed in all soil types. Also the results showed a strong correlation between the tractor speed and fuel consumption (gal/acre) in each soil types. This is due to increase in draft force

and consequently increase in drawbar power. However, the tillage depth had bigger effect on the draft and drawbar power than the tractor speed.

The effect of moisture content on draft force and fuel consumption was not significant at loamy sand (Faceville) and sandy loam (Fuquay) soil types. However, an increase in soil moisture content resulted in a decrease in draft forces and fuel consumptions. In sandy soil type (Lakeland), draft forces and fuel consumptions decreased significantly when soil moisture content increased. This could be due to significant changes in cone index values, since only in this soil type cone index values were significantly affected by soil moisture contents compared to other soil types.

Results showed that use of soil electrical conductivity (soil EC) to predict soil texture and tillage draft requirement was very successful. There was strong linear correlation between soil EC and both soil texture and tillage draft requirement at a given depth and speed. This indicates that draft requirement strongly vary with soil texture and depends on clay and sand content of soil. Also for practical applications, EC data can be used to predict areas of the field with high or low tillage draft requirements. The Veris system provided reading from 0.1 to 7.0 mS mG^{-1} , predicting percentage of clay across the field with a linear correlation coefficient of 0.912 and percentage of sand with a correlation coefficient of 0.916. Figure 5 shows the effects of soil texture (%clay) on soil electrical conductivity. A portion of the draft-requirement data with the same tillage depth (18 in) was selected to investigate the correlation between draft and soil EC. There was a very strong correlation between EC data and tillage draft force at a given speed. Figure 6 shows the effects of EC data on draft force at three different speeds that have been obtained within three different soil types.

CONCLUSIONS

The site-specific tillage resulted in a considerable energy saving of 50% and fuel saving of 30% in loamy sand soil type compared to conventional uniform-depth tillage. Also, energy and fuel savings were 21 and 8% for sandy loam and 26.1 and 8.5% for sandy soil type respectively.

The draft force increased as the travel speed increased in all soil types. However, the tillage depth had bigger effect on the draft and drawbar power than the tractor speed.

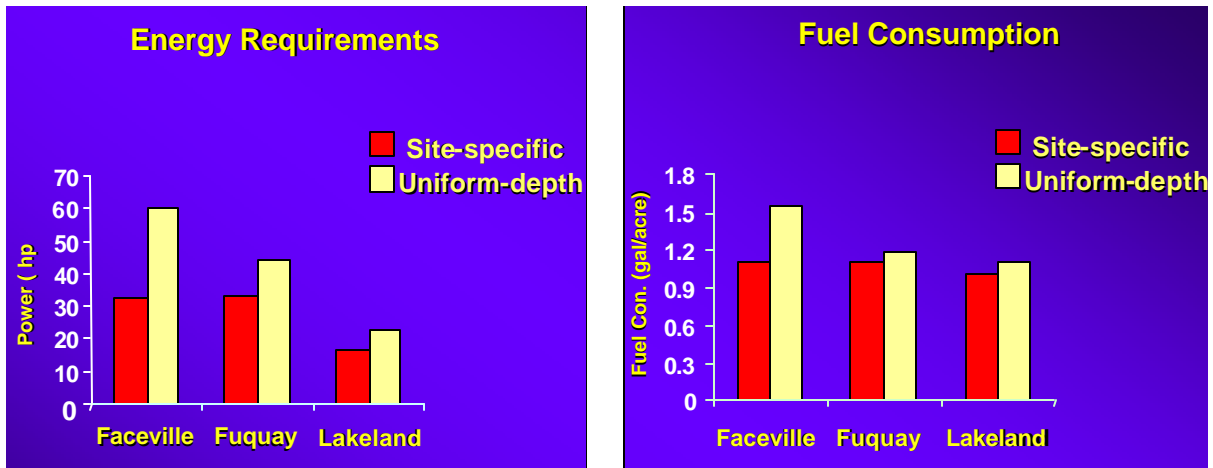


Fig. 4: Energy requirements and fuel consumption for site-specific and uniform-depth tillage

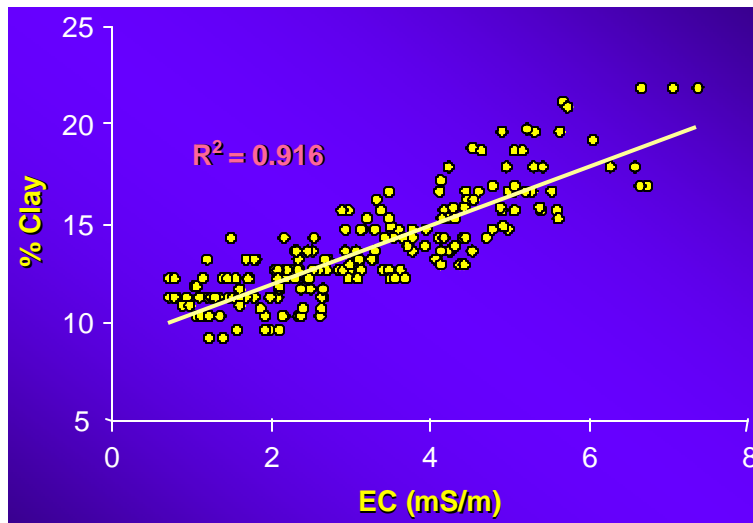


Fig. 5: Effect of soil texture (percentage of clay) on soil electrical conductivity

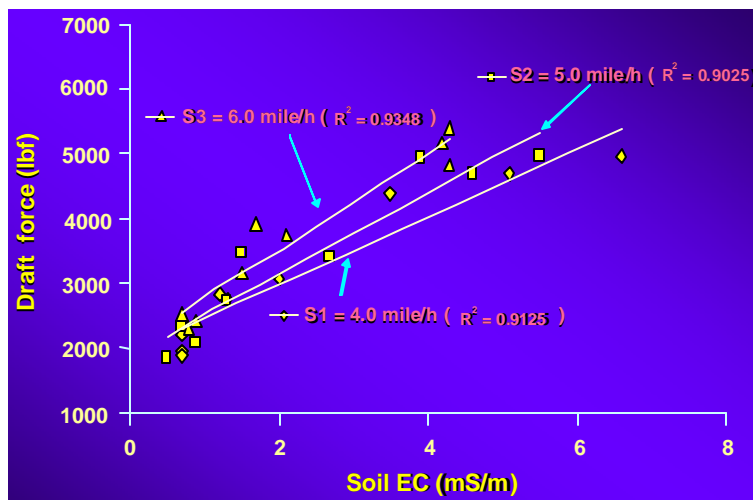


Fig. 6: Effect of soil electrical conductivity on draft force

The effect of soil moisture content on draft force and fuel consumption was not significant in loamy sand and sandy loam soil types. However, draft force and fuel consumption had a negative correlation with the soil moisture contents.

Soil EC data were highly correlated to soil texture (%clay content) with a correlation coefficient of 0.916.

There was a strong linear correlation between soil electrical conductivity and draft force across the field.

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