REAL-TIME, VARIABLE-DEPTH TILLAGE FOR MANAGING SOIL COMPACTION IN COTTON PRODUCTION

Jonathan Fox
Ahmad Khalilian
Young Han
Phillip Williams
Ali Mirzakhani Nafchi
Joe Mari Maja
Edisto Research and Education Center, Clemson University
Blackville, SC

Abstract

Cotton root growth is often hindered in the Southeastern U.S. due to the presence of root-restricting soil layers. Tillage must be used to temporarily remove this compacted soil layer to allow root growth to depths needed to sustain plants during periods of drought. However, the use of a uniform depth of tillage may be an inefficient use of energy due to the varying depth of this root-restricting layer. Therefore, the objective of this project was to develop and test equipment for controlling tillage depth “on-the-go” to match soil physical parameters, and to determine the effects of site-specific tillage on soil physical properties energy requirements, and plant responses in cotton production. Site-specific tillage operations, reduced fuel consumption by 45% compared to conventional constant-depth tillage. Only 20% of the test field required tillage at recommended depth for Coastal Plain regions (15 inches deep). Cotton taproots in the variable-depth tillage plots were 96% longer than those in the no-till plots (15.4 vs. 7.8 inches). Statistically, there was no differences in cotton lint yield between conventional and the variable-depth tillage. Deep tillage (conventional or variable-rate) increased cotton lint yields by 20% compared to no-till.

Introduction

Cotton root growth is often hindered in the Southeastern U.S. due to the presence of root-restricting soil layers. The hardpan layer exhibits a great amount of variability in depth and thickness in this region. Farmers usually rely heavily on the use of annual uniform-depth deep tillage to manage subsurface soil compaction to allow root growth to depths needed to sustain plants during periods of drought, which have been shown to improve yields (Garner et al., 1989; Khalilian et al., 1991; Khalilian et al., 2004). However, there are several drawbacks to this approach to manage soil compaction. Farmers do not usually know if annual subsoiling is required, where it is required in a field, nor the required depth of subsoiling. In addition, there is significant variability in depth and thickness of hardpan layers from field to field and also within a field (Raper et al., 2000; Gorucu et al., 2006). Therefore, applying uniform-depth tillage over the entire field may be either too shallow to fracture the hardpan or deeper than required resulting in excess fuel consumption and an inefficient use of energy.

Ideally, depth and thickness of the hardpan layer needs to be determined for the optimum tillage depth to remove the hardpan layer. In addition, there is little to gain from tilling deeper than required to fracture the compacted layer and in some cases, penetration into the clay layer may be detrimental (Garner et al., 1986). Our previous work at Edisto REC showed that tilling 3 inches deeper than the clay layer, increased draft requirements by 75% and fuel consumption by 50%, without increasing cotton yields (Garner et al., 1986). Also, spatial cone index measurements to map the variability in root-restricting layers showed that about 75% of the field required shallower tillage depth than 15 inches, the recommended tillage depth for coastal plains soils (Gorucu et al., 2001). This variability leads us to believe that significant savings in tillage energy could be achieved by adjusting tillage depth on-the-go. Currently there is no equipment commercially available to automatically control the tillage depth to match the soil physical properties.

The objectives of this study were a) to develop and test equipment for controlling tillage depth “on-the-go” to match soil physical parameters; b) to determine feasibility of using site-specific tillage to alleviate root-restrictions to improve profitability; and c) to quantitatively determine the effects of site-specific tillage on soil physical properties, energy requirements, and plant responses in cotton production.

Materials and Methods

Researchers at Clemson University have developed an instrumented subsoiler shank to measure mechanical impedance of soil at multiple depths over the entire top 18-in of the soil profile while moving through the soil (Khalilian et al., 2002 and 2014). The instrumented shank (Figure 1) consists of five 3-in long sections attached to the subsoiler shank, using two compression load cells, to measure horizontal force acting on the subsoiler shank. The sum of two load cells is used to calculate the total force acting on each section. In addition, Clemson researchers have developed GPS-based equipment for controlling the tillage depth "on-the-go" to match soil physical parameters (Khalilian et al., 2002).

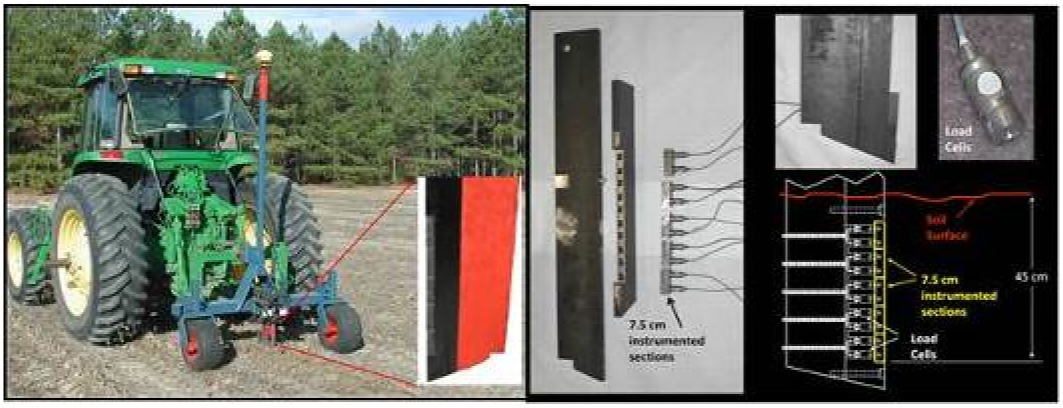

Figure1: The Clemson instrumented shank (left) and schematic diagram (right).

The goal of this project was to develop a system that will mount directly on the tractor and continuously measure the depth to the hardpan and adjust the tillage depth accordingly known as an "intelligent Plow". The new system should be able to measure soil compaction data, calculate the depth and thickness of the hardpan layer, and adjust tillage depth on-the-go for real-time, variable-depth, tillage operations for crop production. This was achieved by combining two systems "instrumented shank" and "Variable-Depth tillage" described above. The new "intelligent plow" was designed using SOLIDWORKS® software. Figure 2 shows the actual plow and the 3D sketch of the new design. The gage wheels on the plow were attached to an electro-hydraulic actuator (Parker Hannifin Co. model 03.25BB-HXLTS24A). The actuator moves the gage wheels upward or downward to control the tillage depth on-the-go. The hydraulic cylinder is equipped with a dual element type linear potentiometer, which provides an analog feedback signal of the cylinder's position. The spool of a proportional directional control valve (Parker series D1FX-CK) shifts in either direction in response to variable command signals, thus providing the desired output flow. The hydraulic cylinder extends 1.8 inch per volt. Once the spool reaches the desired position, the internal potentiometer sends a feedback signal to the drive amplifier to maintain that position.

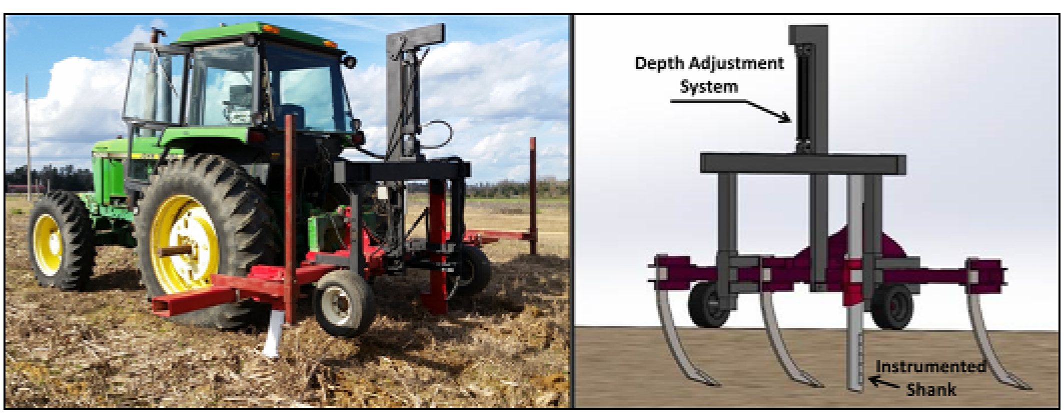

Figure 2: The Clemson Intelligent Plow and its 3D sketch.

A data logger/controller based on the Phidgets Wheatstone Bridge-1046 and Analog Output-1002 (Phidget Inc., Alberta, Canada) was designed and fabricated to collect sensor data and control the tillage depth (Figure 3). Each Bridge can be connected to up to four un-amplified Wheatstone bridges, such as compression load cells on the Instrumented Shank. The data rate and gain values can be configured in the associated software. Custom software was developed in Visual Basic to support the Clemson Intelligent-Plow. The software collects field information, including the soil compaction data (shank index) and corresponding GPS coordinates. This software also utilizes an algorithm developed at Clemson (Gorucu et al., 2006) to determine the optimum tillage depth from soil compaction data, and controls the tillage depth accordingly. The Analog Output produces a voltage range of -5V to +5V, which is being used for controlling the Variable-Depth tillage. With this system, tillage depth can be changed from zero to 18 inches. Input for decision-making is obtained from the instrumented shank (real time), however, the system can also utilize soil compaction maps generated using a cone penetrometer measurement system. The tillage depth could be controlled manually with a one-turn potentiometer located inside the tractor cab.

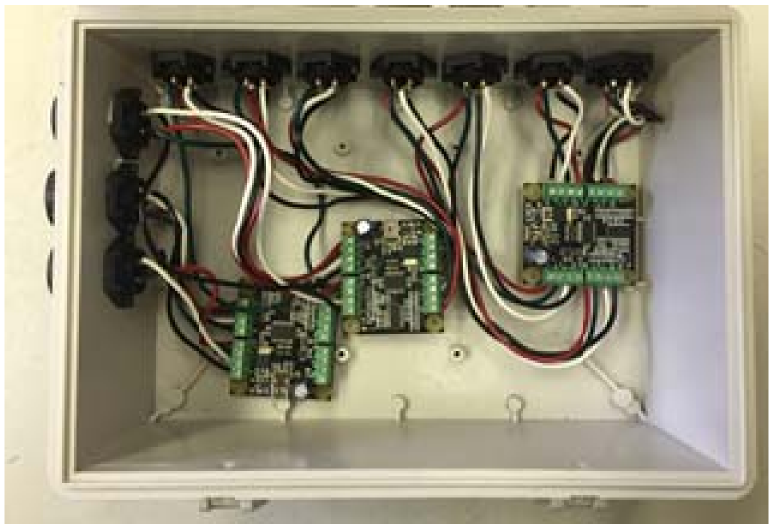

Figure3: Data logger and controller.

Replicated field tests were conducted to determine the performance of the Intelligent Plow. A two-acre test field at the Edisto Research and Education Center was mapped for variation in soil texture, using a soil electrical conductivity (EC) measurement system (Veris-3100). The test field was then divided into two management zones based on soil EC values and 20 rectangular plots (4-row by 90 ft.) were assigned in each zone, for a total of 40 plots in the test field. A microcomputer-based, tractor-mounted recording penetrometer was used to collect soil compaction data from each plot, before tillage operations, around mid-May. Three sets of penetrometer measurements were obtained from each plot. Soil compaction values were calculated from the measured force required pushing a 0.5 in^2 base area, 30-degree cone into the soil. The optimum tillage depth in each plot was determined utilizing the penetrometer data and an algorithm developed at Clemson (Gorucu et al., 2006).

The following four tillage treatments were applied at random to plots of each zone. A randomized complete block design with five replications was the statistical model selected for evaluating treatments.

1. Variable depth tillage based on real-time measurements of depth and thickness of the hardpan layer, using the intelligent plow;
2. Conventional tillage (constant depth, 15 inches);
3. Tillage depth based on penetrometer data; and
4. No deep tillage operations.

An instrumented John Deere 7710 tractor (155-HP) was used to make in field measurements of tractor fuel consumption, ground speed, and draft requirements of the different tillage treatments. Cotton (DP-1646-B2XF) was planted on May 18th, 2017. Temik 15G, (5 lbs./acre) was applied at planting for controlling nematodes and thrips. Cotton was carried to yield using recommended practices for fertilization and insect and weed control. Crop was harvested with a 4-row cotton picker, equipped with weighing baskets for each row in October. A second set of penetrometer measurements (three probes per plot) were made after harvest to determine the effects of tillage systems on soil compaction.

Results and Discussion

Figure 4 shows the required tillage depth of the test field (based on the penetrometer data collected before tillage and the Clemson algorithm) and fuel requirements for each depth category. Based on average penetrometer data (AP), deep tillage was not needed in 53% of the test field (Figure 4-left). Only 20% of the field required tillage at recommended depth for Coastal Plain regions (15 in. deep). As shown in Figure 4-right, the fuel requirement for "No-Tillage" (0 in) was 2.29 gal /hr. This amount of fuel was needed for just driving the JD-7710 (155 HP) tractor from one part of the field to another, without performing tillage operations. Therefore, in this field conventional deep tillage operations (15-in deep) would have required 52% more fuel than site-specific tillage (based on penetrometer data).

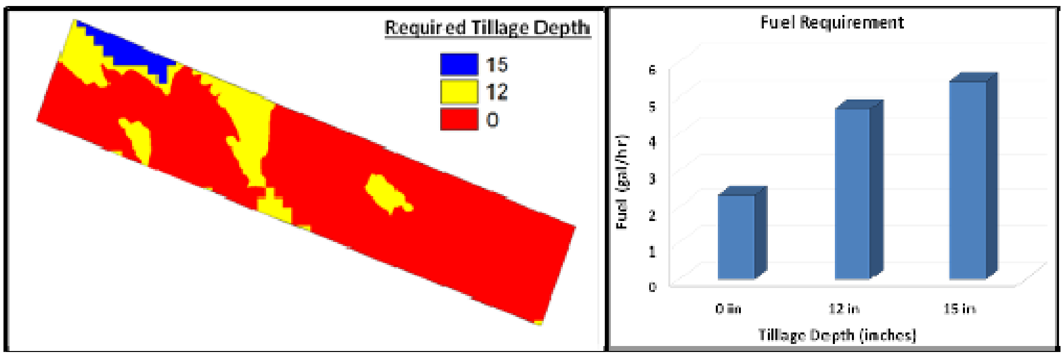

Figure 4: Required tillage depths (left) and fuel consumptions (right) for the 2-acre test field, 2017.

Cotton taproot length was determined by extracting five plants from each plot and measuring root length. Also, roots were oven-dried for determining total dry weights. Cotton taproots in the variable-depth tillage (VDT) plots were 64% longer than those in the no-till (NT) plots (Figure 5-left). Statistically, there were no differences in taproot length between VDT, CON (conventional tillage), and AP (tillage depth calculated based on average penetrometer data). Also, plants in NT plots were 4 inches shorter than those in the VDT plots. Tillage systems had no effect on cotton total root weight. Results also showed that, tillage operations based on either real-time sensor (VDT) or penetrometer data, reduced fuel consumption by 45% compared to conventional constant-depth tillage (Figure 5-right).

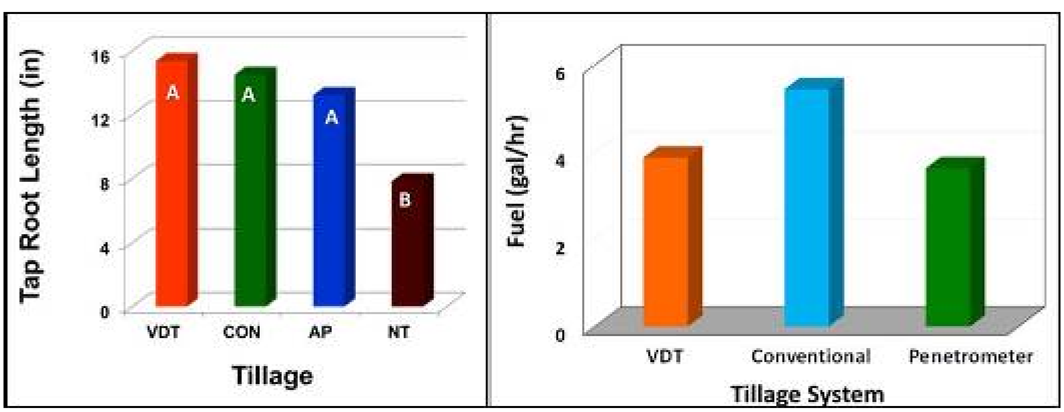

Figure 5: Effects of tillage systems on root length (left) and fuel consumption (right).

Figure 6 shows the effects of tillage system on cotton lint yields. Statistically, there were no differences in cotton lint yields between conventional and the variable-depth tillage, however, as mentioned earlier the variable-depth tillage system required significantly less fuel. Deep tillage (conventional or variable-rate) increased cotton lint yields by 20% compared to no-till (NT).

Figure 7 shows the effects of tillage systems on soil compaction at cotton harvest. Cone index values exceeding 300 psi, limits root penetration below the compaction layer, reducing yields, and making plants more vulnerable to drought stress. Cone index values for both conventional and variable-depth tillage operations were below the limiting value of 300 Psi throughout the tillage depth (15 in.). Tillage significantly reduced soil compaction compared to no-till. Results showed that, tillage operations based average penetrometer data, did not remove the compacted layer (E horizon) in the test field completely. Cotton taproots were 14% shorter in these plots compared to variable-depth tillage plots. However, the difference was not statistically significant.

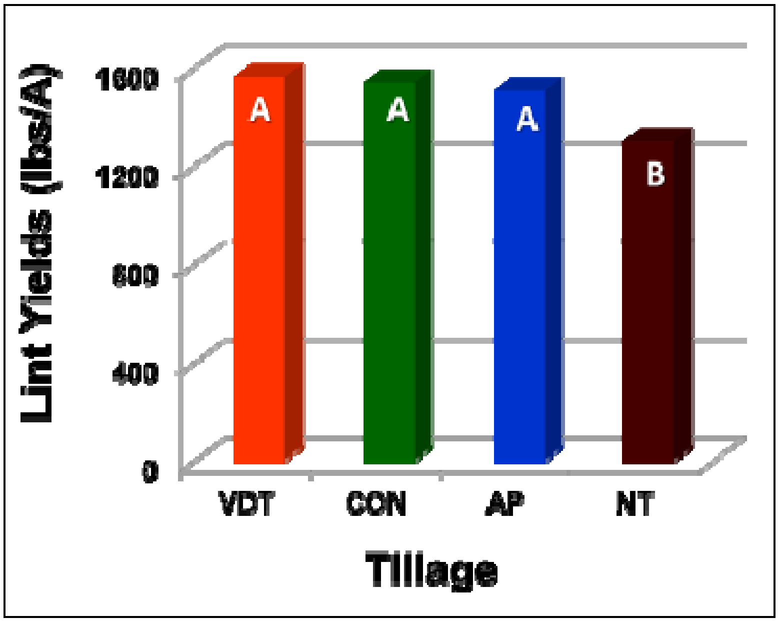

Figure 6: Effects of tillage systems on cotton lint yields (2017).

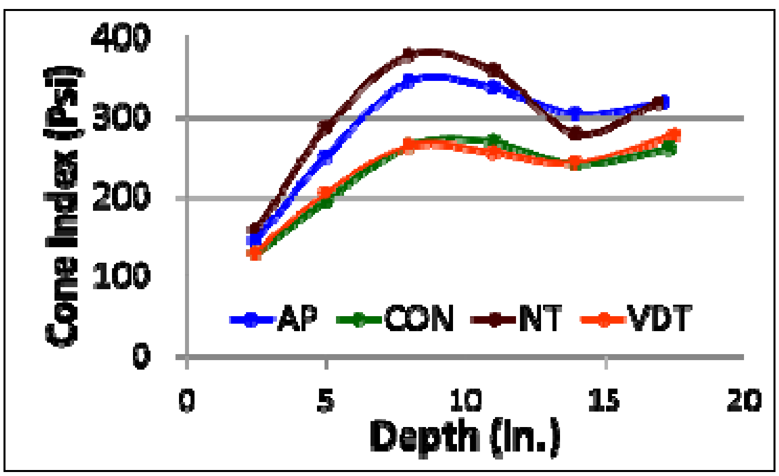

Figure 4: Effects of tillage systems on soil compaction at cotton harvest.

Summary

Equipment were designed and tested for controlling tillage depth “on-the-go” to match soil physical parameters. The new tillage system “Clemson Intelligent Plow” consisted of an instrumented subsoiler shank and on-the-go tillage depth controller. The instrumented shank measures mechanical impedance of soil at multiple depths over the entire top 18-in of soil profile while moving through the soil. The gage wheels on the plow were attached to an electro-hydraulic actuator, which moves the gage wheels upward or downward to control the tillage depth on-the-go. With this system, tillage depth can be changed from zero to 18 inches. Input for decision-making is from the instrumented shank (real time), however, the system can also utilize soil compaction maps generated using a cone penetrometer measurement system. The tillage depth also could be controlled manually with a one-turn potentiometer located inside the tractor cab. Replicated field tests were conducted to determine the performance of the Intelligent Plow. The test field was divided into two management zones based on soil EC data, and four tillage treatments (Variable depth based on real-time sensor measurements; conventional 15-in deep tillage; Tillage depth based on the average penetrometer data; and no deep tillage) were applied at random to plots of each zone.

Site-specific tillage operations, reduced fuel consumption by 45% compared to conventional constant-depth tillage. Only 20% of the test field required tillage at recommended depth for Coastal Plain regions (15 inches deep). Cotton taproots in the variable-depth tillage plots were 96% longer than those in the no-till plots. Statistically, there was no difference in cotton lint yield between conventional and the variable-depth tillage. Deep tillage (conventional or variable-rate) increased cotton lint yields by 20% compared to no-till. Cone index values for both conventional and variable-depth tillage operations (measured at harvest) were below the limiting value of 300 Psi throughout the tillage depth (15 in.). Tillage significantly reduced soil compaction compared to no-till.

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