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TECHNOLOGY FOR VARIABLE DEPTH TILLAGE IN COASTAL PLAIN SOILS

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Abstract

An instrumented shank was designed and built to measure mechanical impedance of soil at multiple depths over the entire top 18 in. of soil profile while moving through the soil. GPS-based equipment was developed and tested for controlling the tillage depth "on-the-go" to match soil physical parameters. An electro-hydraulic actuator and proportional directional control valves were used to move the gage wheels on a four-row subsoiler-bedder upward or downward to control the tillage depth. Also, tests were conducted for two years on a coastal plain soil to compare variable-depth tillage with the constant-depth tillage and no-till system in terms of effects on soil parameters and crop responses.

It was possible to determine the optimum tillage depth using a cone penetrometer, electrical conductivity meter or the instrumented shank. Also, it is possible to control the tillage depth "on-the-go" to match soil physical parameters. Variation in the predicted tillage depths to eliminate the hardpan layer ranged from 10 to 18 in. Based on penetrometer data, approximately 75% of the test area required tillage operations shallower than the recommended tillage depth for coastal plain soils. There was a strong positive correlation between EC readings and seed cotton yield. Also, the predicted tillage depths were inversely correlated to the soil electrical conductivity. Soil texture was found to override the effects of deep tillage operation. For sections of the field with high clay contents and depth to B-horizon less than 13 in., there were no differences in yield between variable depth tillage, no-till, and conventional tillage operations. In the sandier part of the field with depth to clay layer more than 13 in., there was a significant difference in yield between no-till and the other two tillage treatments. The energy savings of 42.8% and fuel saving of 28.4% were achieved by variable-depth tillage as compared to uniform-depth tillage.

Introduction

Soil compaction limits root penetration below the plowing depth, reduces yields, and makes plants more susceptible to drought stress. Most upland sandy soils of the coastal plain have a compacted zone or hardpan about 6 to 14 in. deep and 2 to 6 in. thick. This is called the E-horizon and must be broken so that root can grow into the subsoil or B-horizon for top crop performance. The B-horizon contains additional moisture as well as additional amounts of nutrients (nitrogen, potassium, sulfur, manganese, and boron).

Soil compaction management in the mid-south and southeastern U.S. relies heavily on the use of annual deep tillage, usually to a uniform depth (14 to 16 in.) at a cost of approximately $12 per acre. This practice improves yields in soils of the coastal plain, which are subject to the formation of tillage pans (Garner et al., 1989; Khalilian et al. 1991; Khalilian and Palmer, 2000). 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 a great amount of variability in depth and thickness of hardpan layers. Studies by Raper et al. (2000a; 2000b), Clark (1999), and Gorucu et al. (2001) have shown that the depth of this root-restricting layer varies greatly from field to field and also within the field. 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 the hardpan layer to promote improved root development and increased drought tolerance. Site-specific tillage, which modifies the physical properties of soil only where the tillage is needed for crop growth, could achieve significant savings in tillage energy. Raper (1999) estimated that the energy cost of subsoiling could be decreased by as much as 34% with site-specific tillage as compared to the uniform-depth tillage. Fulton et al., (1996) reported that fuel consumption could be reduced to 50% by site-specific tillage compared to subsoiling the entire field. Site-specific tillage can be implemented either with (1) a pre-tillage map technology, or (2) a real-time sensor. The pre-tillage map technology would be a two-step process in which a sensor such as a soil cone penetrometer or soil electrical conductivity would be used to develop maps showing hardpan existence and depth. This map would then be used in the site-specific tillage equipment control system to control subsoiling location and depth. The real-time sensor would provide a one-step system to control subsoiling location and depth.

Objectives

The objectives of this study were to: a) Develop and adapt GPS-based sensors and equipment to quantify soil-strength and soil hardpan properties of the Southeastern Coastal Plain soils; b) Develop and test equipment for controlling tillage depth "on-the-go" to match soil physical parameters; and c) Quantitatively determine the effects of site-specific tillage on soil physical properties, energy requirements, and plant responses in crop production.

Materials and Methods

Equipment

An instrumented shank was designed and built to measure mechanical impedance of soil at multiple depths over the entire top 18 in. of the soil profile while moving through the soil. The system consisted of five 3-in. sections attached to the shank using load cells (Figure 1). Two compression type load cells (National Scale Technology, model MS-SP-COMP, 2000-pound) were used in each 3-in. section to measure horizontal force acting on the subsoiler. Each section was calibrated in the lab by applying known forces and measuring output voltages. LogBook/360 data logger (IOTech, Inc., Cleveland, OH) with GPS support was used for data collection. The data logger is equipped with 16 analog inputs, two optional 8-channel strain gage modules, and a four-channel frequency input card. Soil strength data was collected at 100Hz. A Trimble AgGPS–132 receivers with "fast rate" option was used to determine the position of the subsoiler in the field. This unit contains both OmniSTAR and Beacon differential technology. Gage wheels were used to control the depth of the subsoiler in a way that the lower part of the bottom instrumented section on the shank always would run 18 in. deep.

A DGPS-based, hydraulically operated penetrometer system mounted on a John Deere Gator was used to quantify geo-referenced soil resistance to penetration (Figure 2). The driver of the Gator could operate the penetrometer. Soil compaction values were calculated from the measured force required pushing a 0.2 in^2 base area, 30-degree cone into the soil (ASAE Standards, 2001b). Probe depth was measured using a circular potentiometer attached to the penetrometer with a sprocket and chain. A rod and an electric switch were used to detect soil surface. A 16 bit based Data Acquisition System (Keithley Instruments, Inc., Model KPCMCIA-16AI-C)) was used to read penetration data, depth and switch status. A program written in TESTPOINT software collected the GPS location and penetrometer data.

A commercially available soil-conductivity-measurement system was used to identify variations in soil physical properties. This equipment (Veris Technologies 3100) resembles a small disk and measures soil electrical conductivity continuously across a field in either the top 12 or 36 in. of soil. The implement can be operated at speeds from 8-12 mph, which allows a 50-acre field to be mapped in a few hours, rather than the several days that would be required for sampling with a penetrometer and data analysis.

GPS-based equipment for controlling the tillage depth to match soil physical parameters was developed. The gage wheels on a four-row subsoiler-bedder 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 (Figure 3). The hydraulic cylinder is equipped with a duel element type linear potentiometer, which provides an analog output 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 desire output flow. Once the spool reaches the desired position, the internal potentiometer sends a feedback signal to the drive amplifier to maintain that position. An onboard computer with FieldLink software (Agris Co.) converts predicted tillage-depth-map data to voltage and extends the cylinder1.8 in. per volt. With this system, tillage depth can be changed from zero to 18 in. Inputs for decision-making could be from the instrumented shank (real time) or from soil compaction maps generated using either the cone penetrometer or the Veris electrical conductivity measurement system. The tillage depth also could be controlled manually with a one-turn potentiometer located inside the tractor cab.

Field Test

The instrumented shank was calibrated against cone penetrometer readings at same depth intervals by collecting intensive geo-referenced penetrometer data from a predetermined path and then running the shank in the same path. The instrumented shank was operated either in the trafficked or non-trafficked middles of the previous year's row crop. The penetrometer data was averaged over 3-in. intervals and compared to the average force measurements from each 3-in. section of the instrumented subsoiler.

The controller system for variable-depth-tillage was evaluated under actual field conditions. A 2-acre field was divided into 60-ft x 60-ft grids. Recommended tillage depth ranging from 0 to 18 in. was assigned at random to each grid. A geo-referenced tillage-depth-map was developed using SSToolbox GIS software and transferred into a FieldLink system. After each tillage operation, the actual tillage depth in each grid was measured manually and compared to the recommended tillage depth assigned to the same grid.

Tests were conducted during 2000 and 2001 on a Dothan loamy sand soil to compare site-specific, variable depth tillage system with the conventional method (constant depth tillage) and no-till system in terms of effects on soil parameters and crop responses. Maps generated during the previous year showed a great amount of variability in crop yield and soil electrical conductivity within the field and it was found to be an ideal site for the variable-depth tillage test. The field was divided into 60 4-row by 80 ft plots and 15 geo-referenced penetrometer measurements were obtained from each plot. Soil moisture samples were also collected whenever penetrometer data were taken.

The depth and thickness of the hardpan were determined from the collected data using the criteria defined by Taylor and Gardener (1963). It was decided to set the tillage depth that would rupture compacted layers of the soil with cone index values above 300 psi. Cone index values deeper than 18 in. were excluded from analysis assuming that it could be the maximum tillage depth.

The predicted tillage-depth maps, generated from penetrometer data and soil electrical conductivity, were used to designate four management zones in year 2000 and three zones in 2001 within the test field. The depth and strength of the hardpan layer was the differentiating factor for each zone. In each zone, five replications of the following tillage treatments were imposed using an in-row subsoiler: no tillage (NT), conventional constant depth tillage (CT), and variable depth tillage (VDT). The depths of tillage were chosen to either a) ignore the root-impeding layer (NT), b) completely disrupt the root-impeding layer (CT), or c) till slightly below this root-impeding layer with variable-depth tillage (VDT). Variable depth tillage was applied according to the application maps generated from soil compaction data. The depth of the tillage within a single plot was constant and it was calculated using the average hardpan depth for that particular plot.

Cotton (Delta Pine 458 RR) was planted each year and carried to yield using recommended practices for seeding, fertilization, and insect and weed control. Ten root samples from each plot were obtained by digging from two middle rows of each plot and their taproot lengths and dry weights were measured. Plant tissues (30 leaves from each plot) were picked from middle two rows at each plot and analyzed for nutrient. Two middle rows of each plot were harvested for yield determination.

A mechanical front-wheel-assist instrumented John Deere tractor was used to make in-field measurements of tractor fuel consumption, ground speed, wheel slip, and draft requirements of different tillage treatments (Gorucu et al., 2001). Energy requirements were determined for variable-depth and constant-depth tillage methods. Implement depths were measured by hand at random locations in each plot following implement passes. A reference was assumed to be level with the undisturbed soil surface adjacent to the tillage area.

Results and Discussion

Figure 4 shows soil compaction data measured with the instrumented shank from trafficked and non-trafficked row-middles at 9-12 in. depth. The test field was planted in soybeans the previous year. The "shank index" was calculated by dividing the total horizontal force from each 3-in.-section by the area of the section (3 in.^{2}). As expected the shank index values were significantly higher from the trafficked row middles compared to non-trafficked middles. There was a strong positive correlation between soil strength values measured with the penetrometer (cone index) and the instrumented shank (shank index, Figure 5). This indicates that it is possible to determine the depth and thickness of the hardpan layers with the instrumented shank either for real time control of subsoiling location and depth or for generating site-specific tillage maps.

The variable-depth-tillage controller system closely followed the recommended tillage-depth map. There was a strong correlation between the recommended and actual tillage depth (Figure 6). The results indicated that it would be possible to control the tillage depth "on-the-go" using inputs from the instrumented shank (real time) or from soil compaction maps generated using either the cone penetrometer or the Veris electrical conductivity measurement system.

Figure 7 shows the geo-referenced predicted tillage-depth map generated using penetrometer data for the year 2000 tests. Based on the map, 75% of the test field required shallower depth than conventional tillage depth of 16 in. for coastal plain soils. Predicted tillage depth for 25% of the test field was only 10 in. About 25% of the test field required tillage operation of 13 in. deep and predicted tillage depth for the remaining 25% was 15 in. For conventional tillage operation the depth was set to 17-18 in to eliminate the hardpan layer throughout the entire field.

Figure 8 shows the soil electrical conductivity for the top 12 in. of the soil. A strong negative correlation was found between soil electrical conductivity and predicted soil tillage depths (r=-0.84). For part of the field with higher clay contents, predicted tillage depths and depth to B-horizon were less than those in the sandier portion of the field. Therefore, it would be possible to use EC maps for identifying areas within individual fields where yield is limited by soil compaction and to determine the required tillage depth without intensive penetrometer sampling.

In both years, cotton taproot length was significantly ($P<0.05$) shorter in the no-till plots compared to conventional and variable depth plots. Deep tillage treatments (conventional and variable depth) increased percent S in plant tissue with no effects on the other plant nutrients (N, P, K, Ca, Mg, Zn, Cu, Mn, Fe and B).

Figure 9 shows fuel and energy requirements of the constant-depth and variable-depth tillage system. Tillage energy was calculated based on the drawbar power and the areas of the field in need of the specific depth of tillage. These values were added to obtain total tillage energy for variable-depth tillage. Fuel consumption for each tillage depth was calculated based on tractor load using the ASAE standard D497.4 for diesel fuel (ASAE standards, 2001a). Since both energy and fuel consumption can vary considerably depending on soil type, for conventional tillage (uniform-depth), experiments were conducted on zones with high clay level and low clay level separately. The energy and fuel use was calculated for the entire field by adding the results from these two sections. The results showed that energy savings of 42.8% and fuel saving of 28.4% could be achieved by adoption of variable-depth tillage as compared to uniform-depth tillage.

Figures 10 and 11 show seed cotton yields for different tillage treatments for 2000 and 2001respectively. The data indicates that the major factor in yield is soil texture. Soil texture was found to override the effects of deep tillage operations. The relationship between tillage operation and yield should be established within a single soil type. For example in sandy soils with a high clay content (depth to clay 13 in. or less), there was no significant difference in yield between variable depth tillage, no-till, and conventional tillage operations. On the other hand in the sandier soils with lower clay content (depth to clay layer more than 13 in.), there was a significant difference in yield between no-till and the other two tillage treatments. Also, there was a strong positive correlation between EC readings and seed cotton yield ($r=0.90$).

Conclusion

- It is possible to determine the optimum tillage depth using a cone penetrometer, electrical conductivity meter or the instrumented shank.
- It is possible to control the tillage depth “on-the-go” to match soil physical parameters.
- Variation in the predicted tillage depths to eliminate the hardpan layer ranged from 10 to 18 in. Approximately 75% of the test area required tillage operations shallower than the recommended tillage depth for coastal plain soils.
- There was a strong positive correlation between EC readings and seed cotton yield. Also, the predicted tillage depths were inversely correlated to the soil electrical conductivity.
- For sections of the field with high clay contents and depth to B-horizon less than 13 in., there were no differences in yield between variable depth tillage, no-till, and conventional tillage operations. In the sandier part of the field with depth to clay layer more than 13 in., there was a significant difference in yield between no-till and the other two tillage treatments.
- The energy savings of 42.8% and fuel saving of 28.4% could be achieved by adoption of variable-depth tillage as compared to uniform-depth tillage.

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Disclaimer

Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that may be available.

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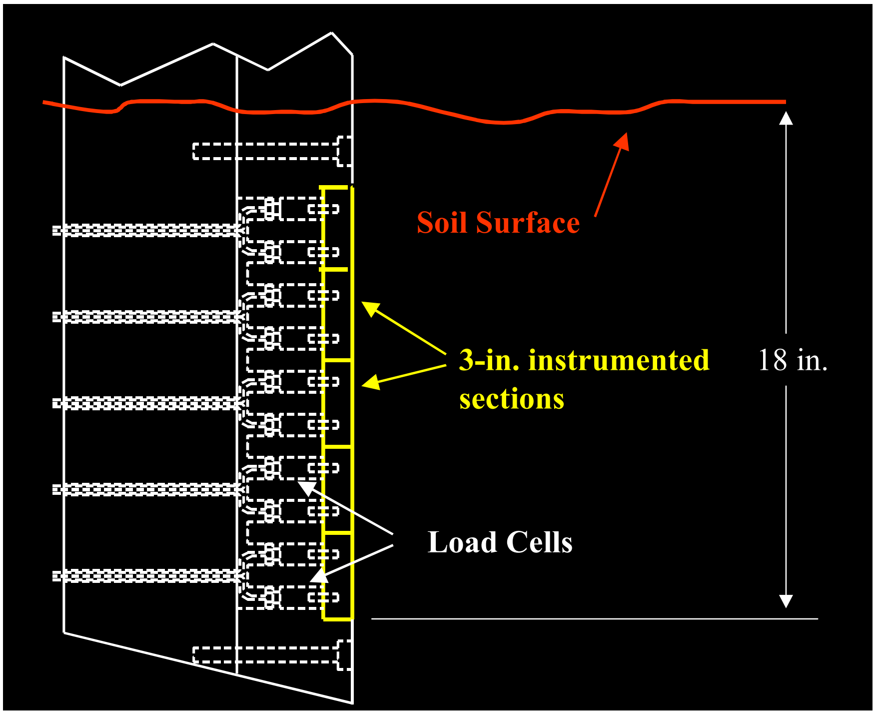

Figure 1. Schematic diagram of the instrumented shank.

Figure 2. Hydraulically operated, penetrometer system with DGPS unit.

Figure 3. The control system for variable-depth tillage operations.

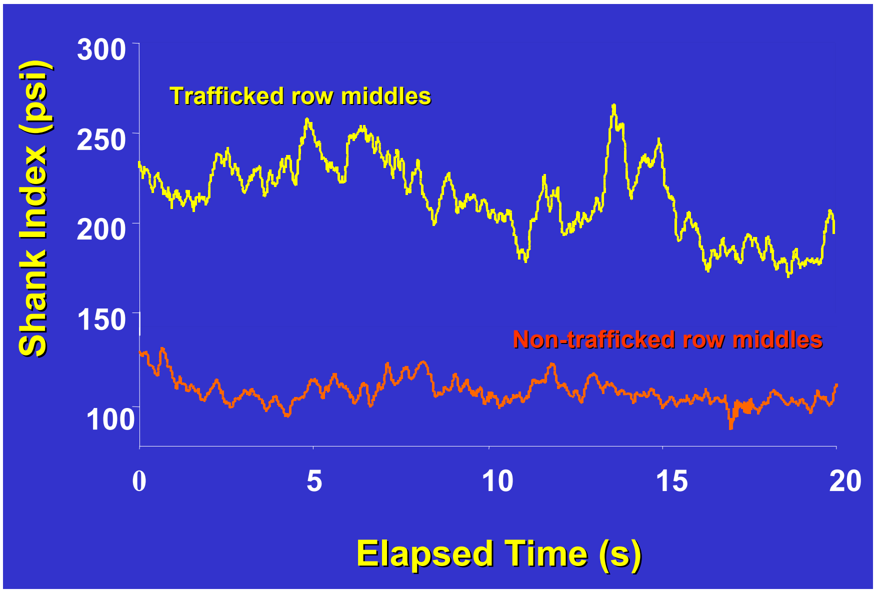

Figure 4. Shank index data from trafficked and non-trafficked row-middles for the 3-in. section operating 9 to 12 in. deep.

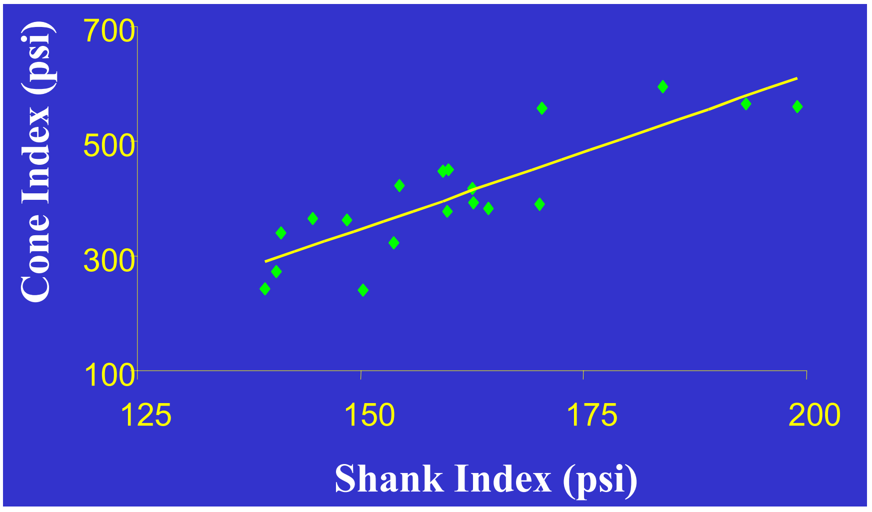

Figure 5. Correlation between soil strength values average over 9 to 12 in. depths as measured with the con penetrometer (cone index) and the instrumented shank (shank index).

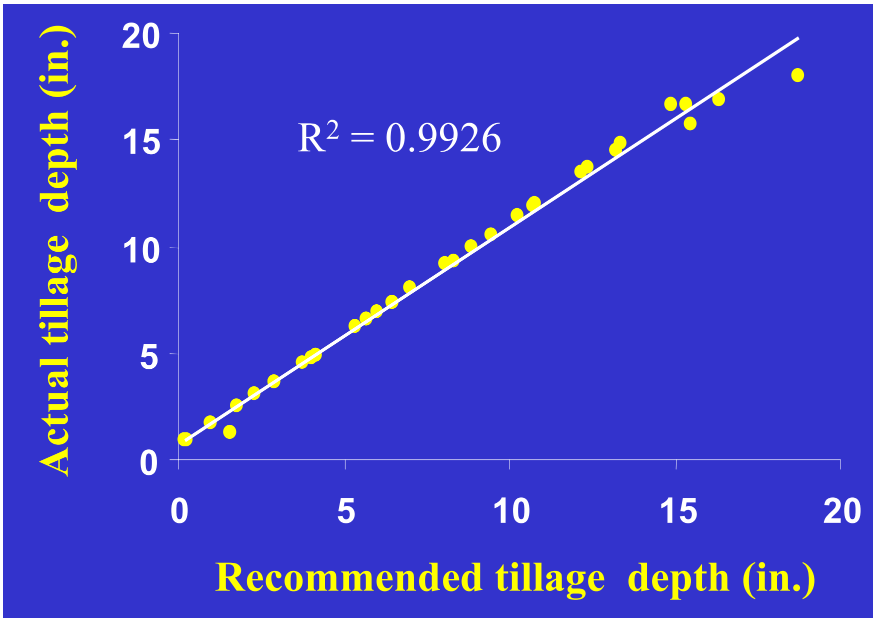

Figure 6. Correlation between recommended tillage depth (from site-specific tillage map) and actual tillage depth performed by the depth-controller system.

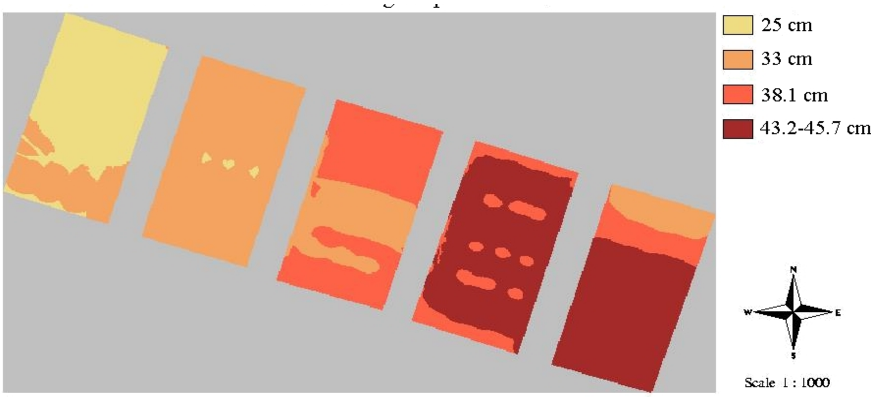

Figure 7. Predicted tillage depths necessary to eliminate root-restricting layer for the test field based on soil penetrometer data.

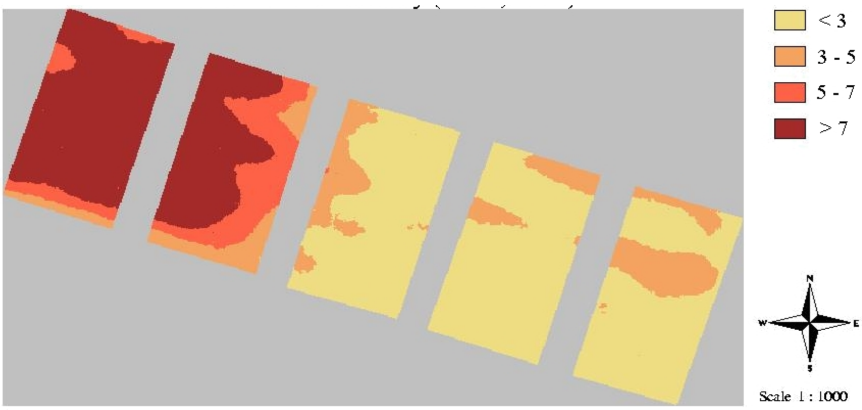

Figure 8. The spatial variability of the electrical conductivity (EC) in the top 12 in of the soil.

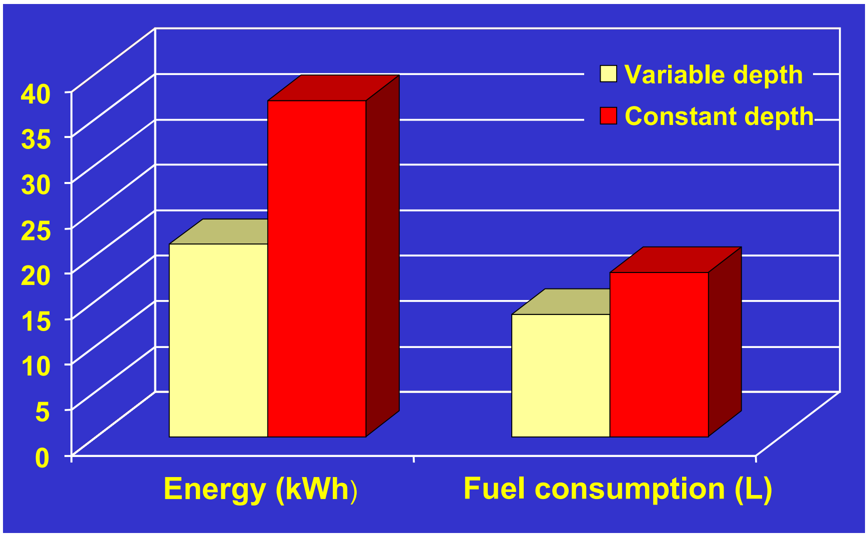

Figure 9. Energy and fuel requirements of constant and variable-depth tillage systems.

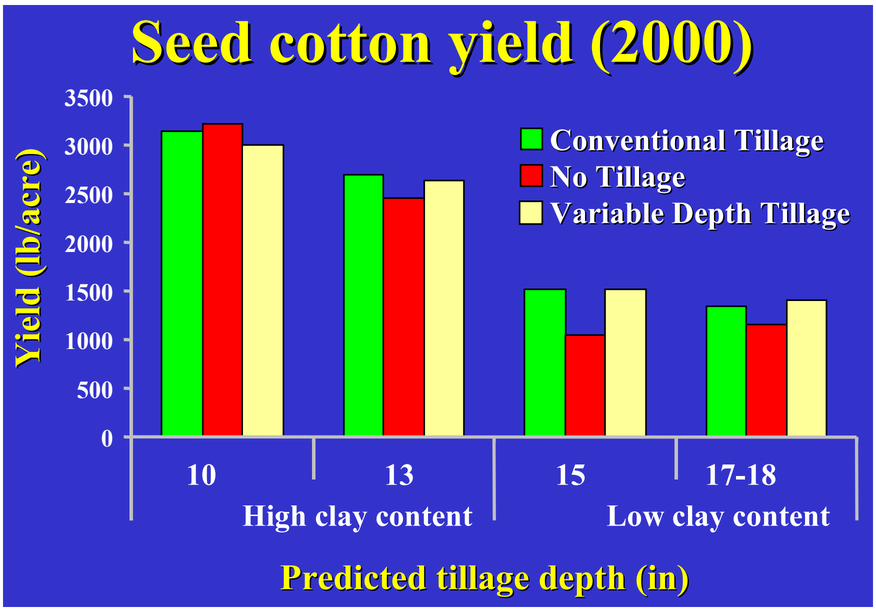

Figure 10. Seed cotton yield for different tillage treatment and depth combinations, 2000.

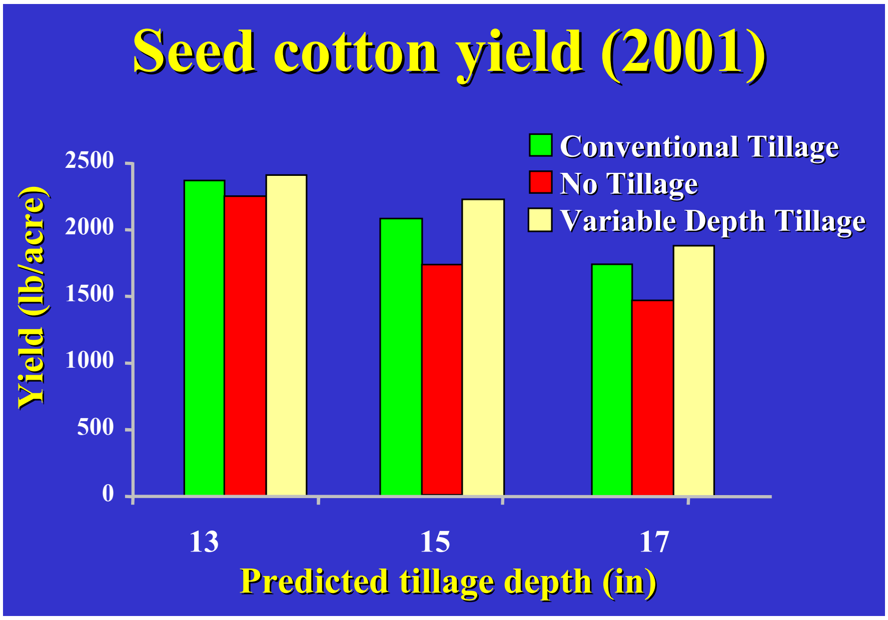

Figure 11. Seed cotton yield for different tillage treatment and depth combinations, 2001.