EFFECTS OF FIVE PRIMARY TILLAGE IMPLEMENTS ON SOIL STRENGTH, ENERGY REQUIREMENTS AND YIELD FOR COTTON PRODUCTION IN OKLAHOMA

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Bachelor of Science in

Agricultural Engineering

Oklahoma State University

Stillwater, Oklahoma

1982

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1984

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PREFACE

This research is concerned with the effects of selected primary tillage implements on cotton production in Oklahoma. The effects of the several primary tillage implements on cotton yield, plant characteristics and fuel energy requirements were examined. This work was supported by the Oklahoma State University Experiment Station for cotton mechanization.

I wish to express my deep appreciation and thanks for the assistance and advice from my major adviser, Professor David G. Batchelder. He was always willing to be of assistance for any problem concerning this research or any other difficulties during this time. I would also like to extend thanks to Professor Peter Bloome and Associate Professor Richard W. Whitney for their suggestions and cooperation.

I am grateful to the Agricultural Engineering Department for supplying research assistance and financial support for the research and for myself through a research assistantship. I would also like to acknowledge A. Khalilian and G. McLaughlin for their much appreciated help during the analysis and collection of data for this work.

I would like to acknowledge my parents for their love, support and understanding during this work and for their faith and encouragement to achieve my goals.

Finally, I want to express my heartfelt thanks to my wife Joanna, for her love, patience, encouragement and many sacrifices during this study.

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LIST OF SYMBOLS

CI	Soil Cone Index
cm	Centimeters
db	Dry Basis
F	Variance Ratio
H	Plant Height
h	Hours
ha	Hectare
kg	Kilo-Grams
kPa	Kilo-Pascals
kW	Kilo-Watts
L	Liters
mm	Millimeters
PTO	Power Take-off Shaft
R^2	Coefficient of Determination
Y	Yield of Clean Seed Cotton

CHAPTER I

INTRODUCTION

Relevance of Research

Cotton is one of the most important textile fibers with many uses worldwide. Cotton and its by-products are utilized in everything from blue jeans to cooking oil, from absorbent sterile cotton for hospitals to feed for cattle. Barlowe (1982) states the world cotton crop output in 1981 was estimated above 71 million bales. Of this the United States alone produced 15.6 million bales. At a cotton price of $0.75 per pound and an average weight of 500 pounds per bale, the world cotton crop was worth approximately 27 billion dollars in 1981. In the same year the United States cotton crop was valued at just under 6 billion dollars.

Oklahoma normally ranks high on the list of cotton producing states, but Oklahoma farmers encounter unique difficulties compared to other portions of the country. On a typical farm in California a yield above 1,000 pounds of ginned cotton per acre is not uncommon; in contrast, a yield of slightly more than 400 pounds is more common to the Oklahoma farmer. These facts justify the importance of cotton as a crop to the American and Oklahoma farmers, but also the need for research, looking for ways to reduce costs while maintaining yields.

Barlowe (1982) also predicts that the amount of cotton produced in the world will drop in the coming year, because of the current high carryover stocks. These stocks imply lower cotton prices worldwide.

Another problem faced by the cotton farmer of today is the cost of production increasing faster than crop prices. This is a trend that has been growing in the last decade and has increased with the fuel embargo in 1973 and 1974. As stated in "Fuel" (1983), at the time of the fuel embargo, fuel prices were being predicted to go as high as 2 to 3 dollars per gallon by the 1980's. Though the prediction of 2 to 3 dollars per gallon fuel did not come to pass, significant increases did occur during the last decade. Experts agree that the long term trends in fuel costs show them continuing to increase along with many other products necessary for the production of cotton. Therefore, the cotton farmer must be continually striving to hold the line on costs in order to make a profit.

Primary tillage can be one of the most expensive operations in cotton production. Carter and Colwick (1971) state primary tillage normally consumes as much as 20 percent of all machine production costs.

Batchelder and McLaughlin (1978) have shown that higher yields may result from the most intensive tillage operations; but, also suggest that net returns might be increased by reducing tillage, which would lower yields, but also lower expenses.

Decreasing soil strength by primary tillage has been shown to increase yields. This increase in yield, as a result of working the soil through primary tillage, results in increased amounts of fuel used. Thus a tradeoff exists between increased yields and increased fuel use. A point may exist at which net returns are at a maximum.

Therefore, with the continually rising costs of cotton production, particularly because of the rising cost of fuel and the overproduction of cotton causing low crop prices, the cotton farmer is in need of a way of reducing costs while maintaining crop yields. This research was done to investigate the fuel requirements, effects on soil cone index, plant characteristics and crop yield, resulting from utilizing different primary tillage implements for cotton production in Oklahoma.

Scope of Investigation

Research was conducted to examine the effects of primary tillage on cotton production. Measurements of draft and power requirements for five different primary tillage tools were obtained. From draft and power requirements, an estimate of the fuel requirements for each tool was calculated. Cotton yields were measured for the plots on which each primary tillage tool was used. Therefore, knowing fuel requirements for each primary tillage tool and cotton yields for the plots on which each primary tillage tool was used, one can determine which tillage tool, if any, is better in terms of cotton yield and fuel requirement.

To determine the effects of primary tillage on the soil's resistance to penetration and moisture infiltration, soil cone index values and moisture samples were taken before and after primary tillage. Soil cone index values and moisture samples were also taken after harvest, to obtain an indication of the residual effects of tillage. Harvest data from each of the tillage plots and soil cone index values were investigated to ascertain if a statistical relationship exists between them.

The overall importance of this research will be demonstrated by using estimates of the total fuel requirements and by determining the percentage of fuel used by each tillage tool.

Objectives

1. To test the null hypothesis of no differences in fuel requirements for five primary tillage implements on a cotton field.

2. To test the null hypothesis of no differences in cotton yield for treatments of five primary tillage implements.

3. To test the null hypothesis of no differences in effects of treatments of five primary tillage implements for the following parameters:

A. Soil strength as measured by soil cone index.

B. Soil moisture content.

C. Physical characteristics of cotton plant.

4. To determine if any statistical relationship exists between soil strength as measured by the soil cone penetrometer and cotton yield.

5. To estimate total energy requirement in the preparation, planting and harvesting of the cotton with each primary tillage implement.

CHAPTER II

REVIEW OF LITERATURE

Cotton is one of the most important textile fibers, even though many man-made fibers are being produced. Cotton remains economical because of its low costs and highly desirable properties. The farmer has little control over the price at which his product is sold; therefore, for the farmer to keep pace with rising production costs, he must increase efficiency or yield.

Increasing yield and efficiency in cotton production has led to several areas of research. Three areas of primary interest to this work are primary tillage and its effects on cotton, soil penetrometer resistance and its effects on cotton, and power and fuel requirements for cotton production.

Primary Tillage

Primary tillage is conducted for a number of reasons: to bury plant residue from weeds and previous crops, to increase moisture infiltration, to increase soil aeration and to reduce soil strength or soil compaction. These factors influence crop yield and plant characteristics. Primary tillage can be one of the most expensive operations in cotton production and may have a very significant affect on yield.

Some research into the effects of primary tillage has dealt with precision tillage as it was defined by Carter et al. (1965). This is a tillage system in which deep tillage is accomplished in the root zone surrounding the plant. Carter stated that increased compaction caused by today's tractors tends to compact the soil area under the cotton plant, thus reducing the ability of roots to grow properly and reduces water movement through the soil. To reduce this compaction, a tool which does its deepest tillage below the plant is used and lesser amounts of tillage are done between plants.

Carter and Tavernetti (1968) have shown average increases of 30 percent in cotton yields using precision tillage as compared to conventional tillage techniques, but only on course textured soils. On fine textured soils, no improvement in yield was observed. The tillage implement used was a deep running chisel plow with a wide sweep mounted on the shanks. Between the deep shanks was a shallower running chisel with the same wide sweep. The deep running shanks were operated at depths down to 61cm.

Tillage systems have been evaluated to determine which systems are more useful for primary tillage. Carter and Colwick (1971) studied a system of cotton tillage which they termed as optimum tillage. Optimum tillage, as defined by Carter, is a separation of the soil into zones in which each zone is proposed to be managed separately to obtain the optimum response. The three zones proposed were a root development zone, a water infiltration zone and a traffic support zone. The results indicate that a zone type of operation could be expected to reduce the number of operations necessary and thus costs of production may be reduced. Yields tended to be higher for the optimum tillage system but were not significantly higher.

Minimum tillage has been proposed as a way of decreasing costs for cotton production. Porterfield and Davidson (1974) studied minimum tillage utilizing herbicides for weed control as a substitution for a portion of primary tillage. The results showed that a substitution of chemicals for all or part of the tillage did not achieve adequate results. They state that for both yield and weed control, primary tillage at planting time still seems desirable.

The effects of zone tillage and different primary tillage tools on the cotton crop were examined by Batchelder et al. (1974). He studied the effects of different primary tillage implements on emergence, harvest stand counts, soil moisture and yields of clean seed cotton. Batchelder reported the best results were obtained from the Allis Chalmers No Till Coulter and moldboard plowed plots; these resulted in increased seedling emergence and yield.

Row spacings and four different primary tillage tools were the subject of study by Batchelder and McLaughlin

(1978). The row spacings tested were 25, 51 and 102 cm. The primary tillage tools tested were a moldboard plow, modified lister sweep, Allis Chalmers coulter and chisel plow. The highest yields were associated with the 102 cm row spacing and the moldboard plow. The height of the low boll, plant width, plant height, soil moisture, maximum emergence, harvesting losses and harvest population were also examined. The chisel resulted in the highest low boll and maximum emergence. The tallest plants were from the use of the moldboard plow.

The effects of subsoiling in Tennessee at different times of year was the subject of a study conducted by Tompkins (1979). He concluded that fall subsoiling did increase plant size but not yield.

The effects of subsoiling and controlled traffic was studied by Colwick and Barker (1980). Deep tillage tended to increase yield in both the controlled and normal traffic plots but the differences were not statistically significant.

Soil Strength Effect on Cotton

Soil strength and soil characteristics, whether given in terms of shearing strength, bulk density or penetrometer resistance, can have significant effects on crop yields and characteristics. Soil strength can affect such parameters as water infiltration, seed germination, root development, plant growth and plant characteristics; but probably more importantly, it has a significant effect on crop yield because of its effects on these other parameters.

Reduction in the penetration of the cotton taproot through the soil may be influenced by several different factors. Taylor and Gardner (1963) studied the effects of bulk density, soil moisture and soil strength on penetration of cotton seedling taproots. In general, root penetration is reduced as bulk density goes up. They also reported a very significant decrease in root penetration as soil strength goes up as measured by a soil cone penetrometer. At 1000 kPa, 80 percent of the cotton seedling taproots could penetrate the soil, at 2000 kPa, only 30 percent were observed to be penetrating the soil and at 3000 kPa, root growth was stopped completely. They also stated that since bulk density and cone index are related, they concluded that soil cone index, and not bulk density, is the critical factor in cotton taproot penetration.

Lowry et al. (1970) studied the effects of depth of a compacted layer, bulk density and soil strength as measured by a soil cone penetrometer on cotton yield and growth rate. Compacted layers were constructed at different depths and the effects on cotton were determined. He shows that yields of seed cotton decline exponentially with increasing penetrometer resistance above 1500 kPa, regardless of the depths of the soil pans tested, but to a lesser extent as depth of the soil pan increases. He also reports that compaction layers around 20 cm can affect plant height in only five weeks of growth. While plant height is affected throughout the growing season, the affects are more pronounced with shallower compacted layers.

Carter and Tavernetti (1968) also studied the effects of compaction on cotton yields. They show significant decreases in cotton yield as soil strength increases. They also point out the effects of precision tillage in reducing soil strength and bulk density. They show substantial increases in yield on a very hard soil by utilizing precision tillage over more conventional tillage techniques. The more highly compacted soil showed the largest yield increases as a result of precision tillage in place of conventional methods.

Batchelder and Porterfield (1966) tested a type of zone tillage method for cotton production. They tested four tillage tools to accomplish primary tillage. Conventional tillage methods utilizing a moldboard plow showed slightly higher yields, but zone tillage techniques were not far behind. Conventional tillage plots exhibited higher moisture levels than did the zone tillage plots. They attribute the higher yields to the increase in soil moisture, which may be a result of the decreased soil strength.

As the weight of tractors and machinery increases, so does the compaction caused by their movements over the soil. Dumas et al. (1973) studied the effects of controlled traffic versus normal tillage traffic. He concluded that controlling traffic to permanent traffic lanes can reduce the area of compaction caused by different tire spacings of machinery. The controlled traffic system exhibited good results by reducing soil compaction, increasing moisture availability and increasing plant growth and yield.

The effects of soil compaction between cotton rows was studied by Mogilevets and Khallyyev (1979). Compaction results from numerous passes over the field by equipment and results in the destruction of soil structure. They concluded that this destruction of soil structure reduces moisture capacity and provides poor conditions for seed germination. It also has detrimental effects on yield, because maximum yields were obtained from the least compacted soils.

Soil recompaction to provide a good seedbed and prevent moisture losses was studied by Batchelder et al. (1974). A zero pressure tire was used to recompact the soil after a zone tillage tool had passed. This soil recompaction was not to the point of reducing yield or growth and was used to settle and reconsolidate the soil after tillage. Some slight increases in yield were seen for recompacted soils over noncompacted soils.

The effects of subsoiling in a controlled traffic system were studied to determine the effects on yield and residual soil strength. This was done over several seasons by Colwick and Barker (1980). The effect of controlling traffic and deep subsoiling was to decrease soil strength.

They stated deep subsoiling effects took over three years to dissipated for this controlled traffic situation. No increases in yield were observed as a result of the subsoiling when compared to the control plots. The yield from the control traffic plots was slightly lower over the four year study, but not significantly.

The effects of subsoil compaction on corn yield was studied by Gaultney et al. (1980). He states that the major detrimental effect of soil compaction lies in the disruption of soil moisture supplies. The effects of subsoil and surface compaction were to decrease yield.

Energy and Fuel Requirements

Fuel is one of the major considerations and expenses in cotton production. In 1971, fuel prices were relatively low compared to today's fuel prices. Fuel costs for primary tillage are a great part of the machine costs today, as primary tillage requires a large percentage of the fuel requirements for cotton production. Several researchers have studied the power and fuel requirements of primary tillage implements and also the fuel requirements of cotton production in general.

Frisby and Summers (1979) show the draft and fuel requirements of six tillage implements and two planting implements in three soil types. The primary tillage implements and planters tested were a moldboard plow, chisel plow, field cultivator, tandem disk, row crop cultivator, hipper-ripper, grain drill and row crop planter. Fuel consumption for all four primary tillage implements fell in the range of 20.11 to 24.86 liters per hectare for all three soil types.

The fuel requirements for a wide bed controlled traffic system of cotton production were studied by Williford (1981). In a multiyear study, he measured fuel requirements of several production practices in a wide bed and controlled traffic situation. He presents fuel requirements for stalk cutting, subsoiling, disking, fertilizing, planting, cultivating and harvesting. Total fuel requirement was approximately 88 liters per hectare.

Energy requirements of five primary tillage implements operated at three speeds were the subjects of a test run by Tompkins and Wilhelm (1981). They investigated gear setting, speed, pull, power and fuel consumption for five primary tillage implements. The five tools included in these tests were a light tandem disk, heavy tandem disk, chisel plow, soil pulverizer and subsoiler. The subsoiler used the most fuel at over 24 liters per hectare, while the light tandem disk used the least at 4.6 liters per hectare.

Dumas and Renoll (1982) researched fuel requirements for many of the normal practices in cotton production. They show fuel use for the following practices: cutting stalks, disking, moldboard plowing, bedding by use of a disk, incorporating herbicides, planting, cultivating, fertilizing, insect spraying and harvesting. They also state that seedbed preparation and harvesting utilized over 75 percent of the total fuel requirement.

Fuel requirements of several tillage implements and planters used in the production of cotton were presented by Tomkins and Wilnelm (1982). Some of the implements and planters included in these tests that were not included in Tomkins and Wilhelm (1981) were a cultimulcher and two planters, a row crop planter and a no-till planter. The row crop planter required approximately 4.7 liters per hectare for its operation, while the no-till planter required up to 25 percent more fuel than did the row crop planter.

The fuel requirements of three cotton production systems were studied by Williford and Smith (1982). The three systems examined were: limited seedbed preparation, wide-bed system and conventional production practices. Total fuel requirements ranged from 84 liters per hectare for the wide-bed production system to over 121 liters per hectare for the conventional production practices. These fuel requirement data do not include end turns, idling fuel usage or other miscellaneous fuel usage.

Draft and power requirements of several primary tillage implements were studied by Self et al. (1983). Seven different implements were studied at three locations. Drawbar power and fuel requirements were reported for each implement. Implements tested included a moldboard plow, a chisel plow used in three configurations, tandem disk, offset disk and v-blade plow. Significant differences were observed in the fuel requirements of these primary tillage tools when each was used in normal operation. The moldboard plow required the most fuel at 12.9 liters per hectare and the chisel with points spaced at 51 centimeters had the lowest fuel requirement at 3.1 liters per hectare.

A tractor use study was done by Hauck et al. (1983), in which 130 farm tractors were monitored. Twenty seven farming operations were recorded. A short list of the operations recorded were: moldboard plowing, disking, chisel plowing, cultivating, harrowing, rod weeding, rotary hoing, planting, drilling, fertilizing and chemical application. Hauck et al. (1983) reported that individual fuel consumption rates vary substantially from farm to farm. They also stated that increased tillage depth required increased amounts of fuel, but an increase in travel speed decreased fuel consumption on an area covered basis.

CHAPTER III

EXPERIMENTAL MATERIALS AND EQUIPMENT

Experimental Materials

Research on the effects of primary tillage for cotton production systems was started in the spring of 1982 on approximately 3 hectares at the South Central Research station at Chickasha, Oklahoma. The field had a Tuttle silt loam type of soil with level terrain and adequate drainage.

After primary tillage, but before planting, Treflan was incoporated approximately 5cm deep. Cotton (Cascot L-7) was planted in a north and south direction on the field at a seeding rate of 123,000 seeds per hectare. Extra ground was provided to be used for set up and adjustment purposes prior to each test.

Experimental Equipment

Primary tillage was provided by five different tillage implements. The first was a moldboard plow. Figure 1 shows the moldboard plow being used during these tests. The plow was a 6 bottom by 41 cm implement and was 2.44 meters wide. A closeup of the moldboard is shown in Figure 2.

Another tillage implement used was a chisel plow with points. The chisel plow used was a 4.88 meter wide, with

Figure 1. Moldboard Plow in Use

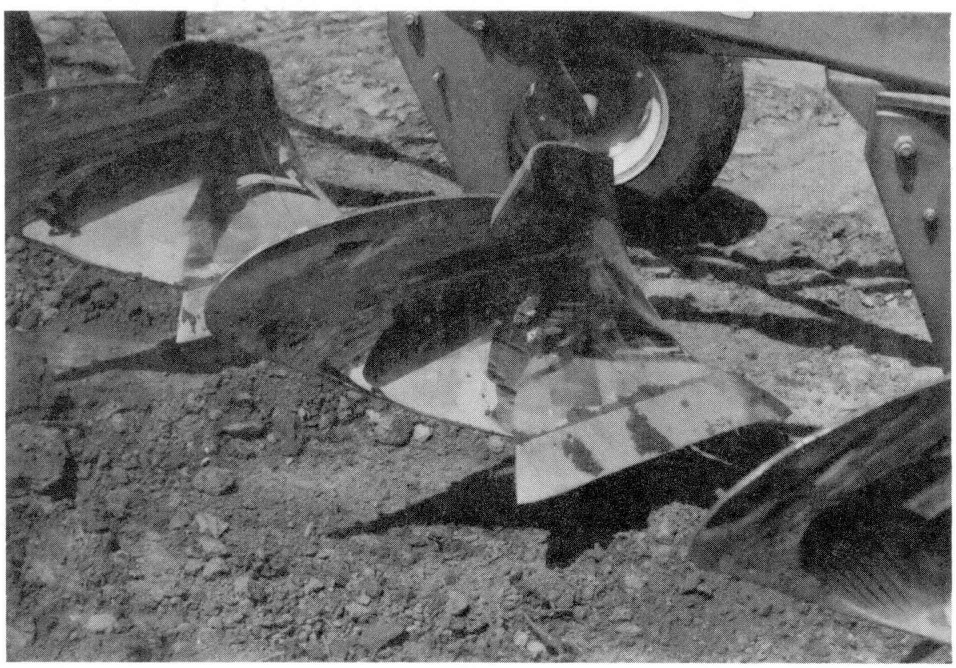

Figure 2. Moldboard (40.6 cm)

the chisel shanks placed on 30.5 centimeter centers. Figure 3 shows the chisel plow in use during these tests. The points placed on the chisel plow are shown in Figure 4 and were 5.08 centimeters wide.

The same chisel plow was utilized as a field cultivator by replacing the points by sweeps and operating at a shallower depth. The cultivator, as it will be termed throughout this text, is shown in Figure 5. The cultivator was 4.88 meters wide with the shanks on 30.5 cemtimeter centers. The sweeps being used on this implement are shown in Figure 6 and were 40.6 cm wide.

A second chisel plow was used in a strip tillage type of operation. A 7.11 meter wide chisel was used with the chisel shanks spaced on 50.8 centimeter centers. The points on this implement were 7.6 cm in width. This tillage implement will be termed "shovel in a row" throughout this text and is shown in Figure 7. The shovel was used in a type of operation in which the chisel shanks were spaced one half the width of the proposed cotton rows. The cotton rows were planted directly over every other tilled row.

The fifth implement used in this research was a 4.27 meter wide tandem disk. The tandem disk is shown in operation in Figure 8 with the disk shown in Figure 9.

Two other implements were utilized during the cotton production, but not analyzed as to their fuel requirement or their effect on the cotton crop. A tandem disk was used in the fall of 1981 to cut the stalks and level the irrigation

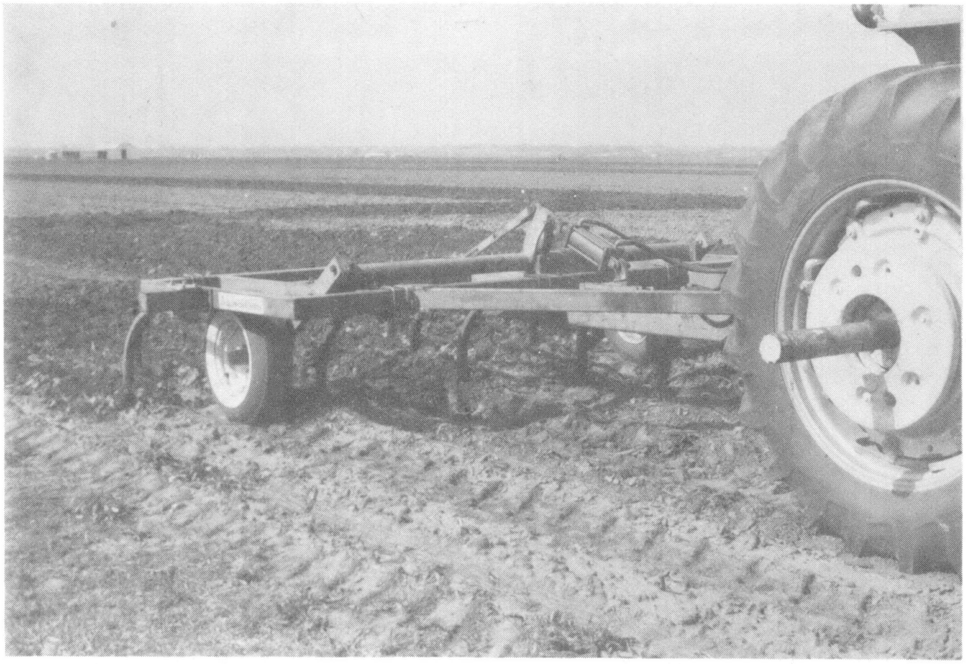

Figure 3. Chisel Plow in Use

Figure 4. Chisel Points (5.08 cm wide)

Figure 5. Cultivator in Use

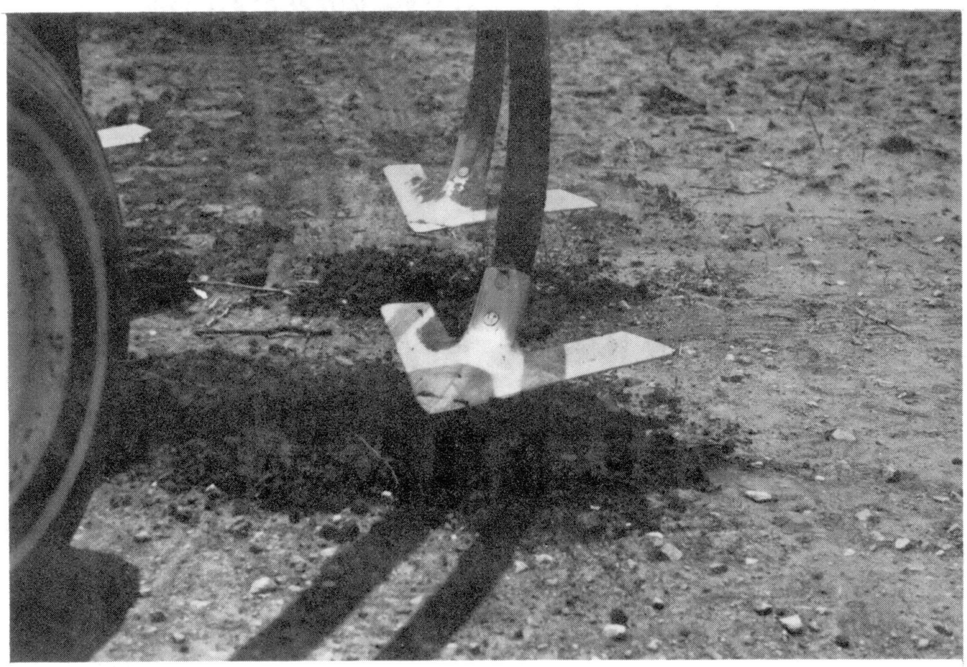

Figure 6. Cultivator Sweeps (40.6 cm wide)

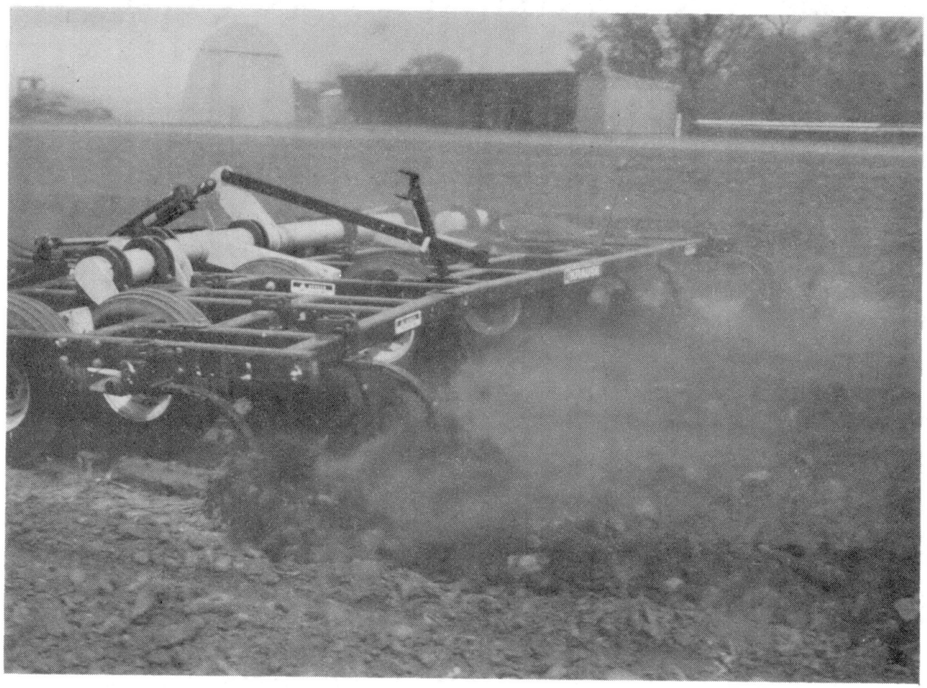

Figure 7. Shovel in a Row in Use

Figure 8. Tandem Disk in Use

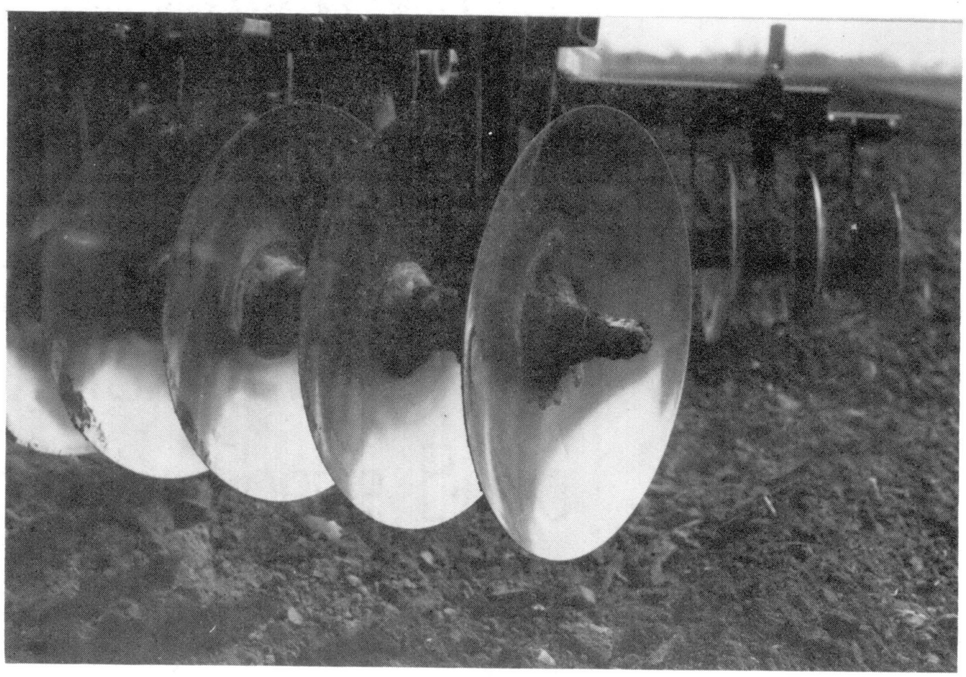

Figure 9. Disk

ridges after the cotton was harvested that season. A springtooth was used prior to planting to incorporate herbicide into the soil.

An International 185 4-row cotton planter was used to plant the cotton. Shown in Figure 10 is the John Deere model 282 2-row brush roll stripper that was used to harvest the cotton. Several cotton wagons, similar to the one shown in Figure 11, were used at harvest to collect the cotton from each plot and then hauled to the scales to be weighed.

A 93 kW instrumented Allis-Chalmers 7020 tractor was used to collect the draft and speed data for each of the primary tillage implements used in this test (Figure 12). The tractor as described by Grevis-James et al. (1983) uses a microcomputer based system (Figure 13) to measure drawbar pull, groundspeed, wheelslip, fuel flow and engine speed. The system stores the collected data on cassette tape as well as providing a hardcopy output on paper tape. After the data is collected, it is transferred to a mainframe computer to be analyzed by a data management system described by Devoe et al. (1982).

To quantify tillage effects on soil strength, a soil cone penetrometer was used (Figure 14). The system is a tractor mounted, hydraulically operated, recording soil cone penetrometer system described by Riethmuller et al. (1983). Soil cone index is an index of soil strength and is expressed in pressure terms such as kilopascals or psi. Soil cone index is used to quantify soil strength throughout

Figure 10. John Deere model 282 Brush Roll Stripper Harvester

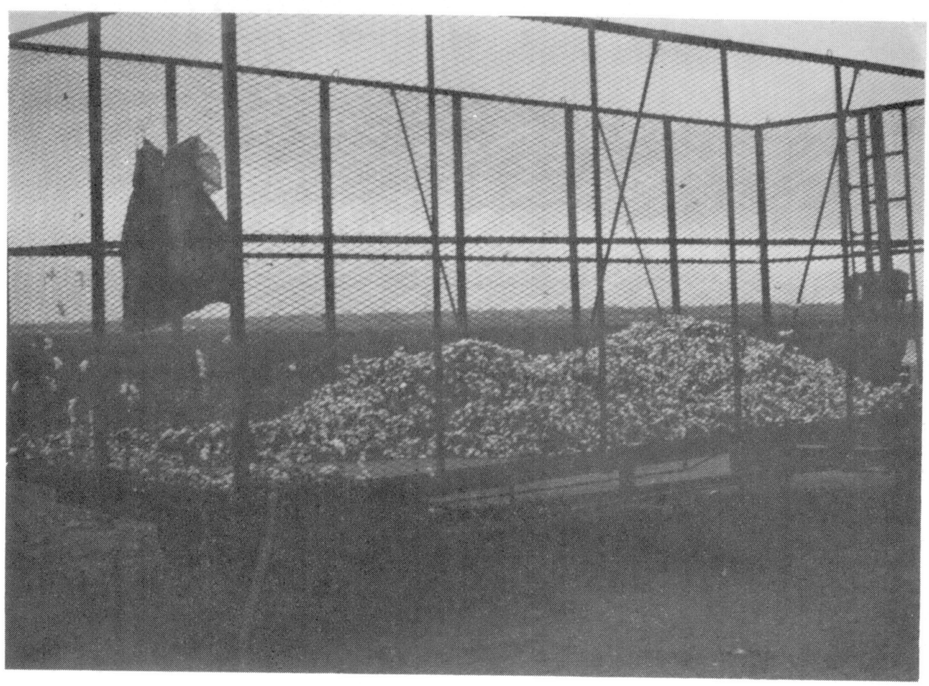

Figure 11. Cotton Wagon with Harvested Cotton from one Plot

Figure 12. Allis-Chalmers 7020 Diesel Tractor

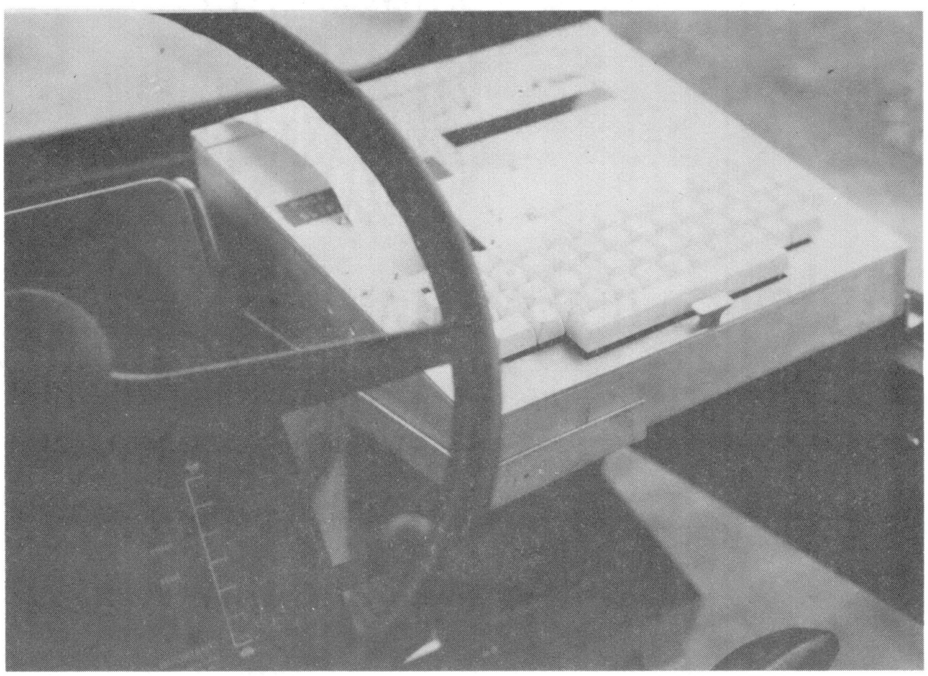

Figure 13. Tractor Microprocessor System

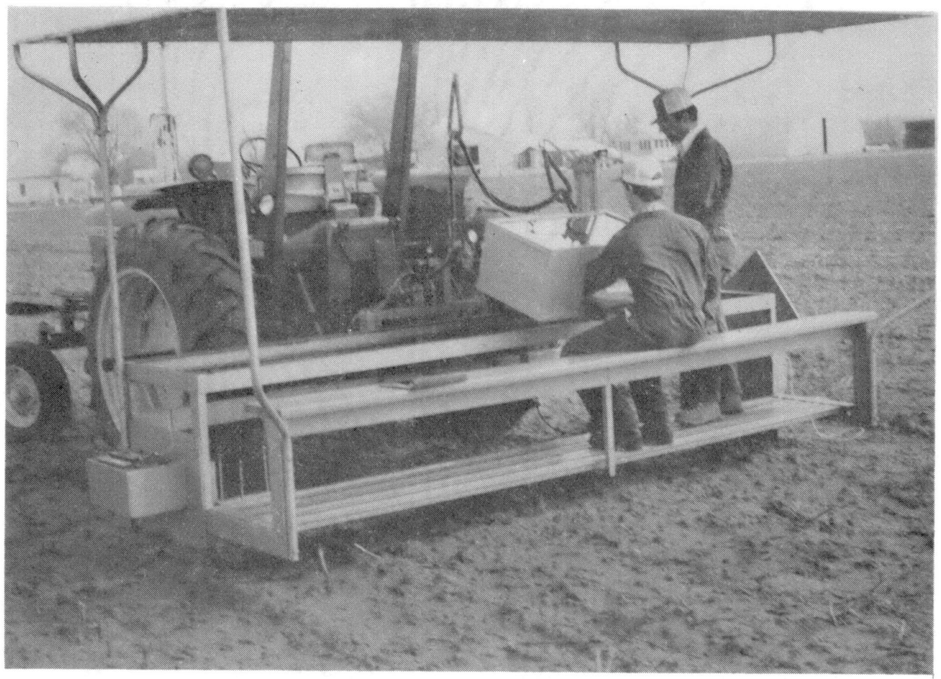

Figure 14. John Deere 2520 Diesel Tractor and Soil Cone Penetrometer in Use

this text. Data is recorded on cassette tape as well as a hardcopy on paper tape. The data is later transferred from cassette to a mainframe computer for analysis.

Soil moisture samples were taken at the same time as soil cone index values. The method for taking soil moisture samples was a hand operated probe which has the capability to collect soil samples to a depth of 38 centimeters. Sealed moisture tight containers were used to hold the samples until they were processed. A weight scale and drying oven were used in the determination of soil moisture content.

Several other pieces of equipment and materials were used during this research. A large number of burlap sacks were used to collect cotton samples for later analysis as shown in Figure 15. A laboratory burr-extractor was used to clean the cotton of leaves, stems and trash. Weight scales were used to measure soil and cotton samples.

Figure 15. Burlap Sacks Containing Samples From each Plot and a Portion of the Harvested Cotton

CHAPTER IV

EXPERIMENTAL PLAN AND PROCEDURES

Experimental Plan

The field utilized in this research was approximately 135 by 219 meters. A randomized complete block design was chosen to eliminate variation in the field from entering into the error term of the experiment. Five treatments, each representing a primary tillage tool were chosen. The field was divided into six replications with five treatments per replication. The five primary tillage implements each representing a treatment were: #1 moldboard plow, #2 standard chisel plow with points, #3 cultivator, #4 tandem disk, #5 shovel in a row.

Treatments were assigned at random through a simple process of using a random selection of numbers from one to five. Numbers were selected one at a time and assigned a position in the first replication from left to right. A second number was selected and assigned to the second position in replication one. This process continued until each position in replication one was filled and then the same was done for each replication until all six were complete. Treatments were then associated with a number to determine where each tillage treatment was to be conducted.

Field layout is shown in Figure 16. Each replication contained 40 cotton rows with 8 rows of cotton per plot. A constant row spacing of approximately 1.02 meters was used. Each replication was approximately 40.64 meters wide by 91.5 meters long. Each plot was approximately 8.13 meters wide. Length of the plots was chosen to allow the data collection system on the tractor to complete a cycle of ten sets of readings.

Experimental Procedure

Information concerning production practices and research procedures are presented in this chapter. The description and methods of research and production practices is presented in a chronological order.

Cotton was produced on the test field the season before and the field was disked after harvest to cut the cotton stalks and level all irrigation ridges. This was done in the early fall of 1981 soon after harvest. The field was left fallow until spring when research began. The field was flagged and laid out in the early spring in the manner shown in Figure 16.

To determine the effect of primary tillage tools on soil strength, soil cone index values were taken before and after primary tillage. When soil cone index readings are taken, several factors may interfere with the quality of the values: hard spots, trash, or holes in the soil may interfere or affect the resistance indicated by the probe.

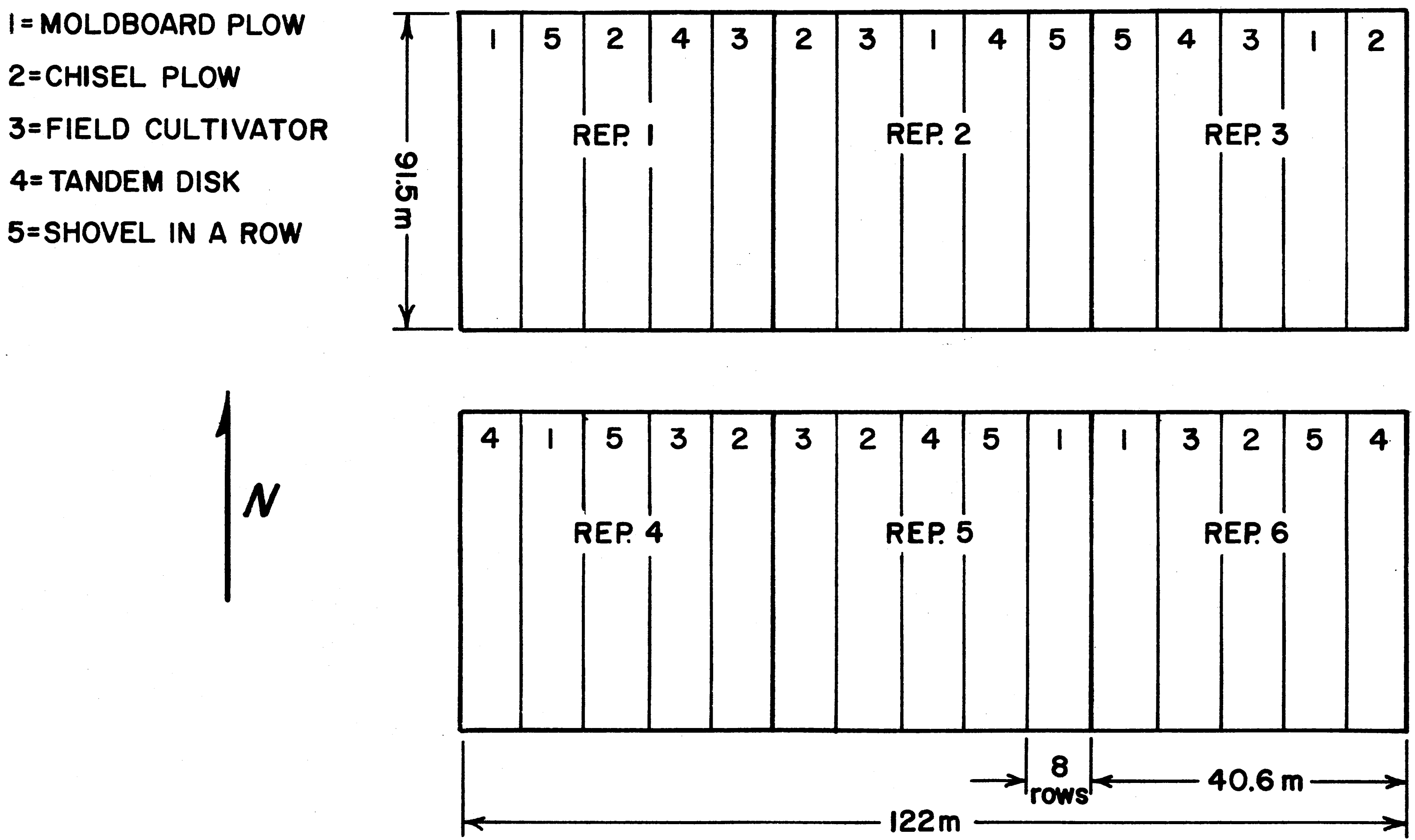

Figure 16. Field Layout of Cotton, Replications and Primary Tillage Treatments

To eliminate effects of a non-uniform soil, five penetrometer readings were taken, distributed across each plot, and then averaged for analysis. Before actual readings of cone index were taken, the penetrometer was calibrated. The "before primary tillage" penetrometer readings were taken on 3-17-82.

To determine the effects of primary tillage tools on moisture infiltration, soil moisture samples were taken before and after primary tillage. Soil moisture samples were taken to a depth of 38.1 centimeters. The samples were divided into five 7.6 centimeter increments, placed in sealed cans and returned to the lab for analysis. The samples were removed and placed in numbered trays to be placed in the oven. Weights of the samples and trays were recorded. All samples were dried for 24 hours at 105 degrees centigrade, at which time they were reweighed. The "before primary tillage" soil moisture samples were taken on 3-17-82.

Tillage using the moldboard plow, chisel plow with points, cultivator and tandem disk implements were conducted on 3-28-82. The shovel in a row implement was not available on this date. Tillage using the shovel was conducted on 4-20-82. Approximately 0.3 cm of rain fell between these two dates. Soil moisture levels and conditions, at the time the shovel in a row plots were completed, were very similar to the condition of the soil when the other tillage plots were done.

Primary tillage was conducted using the Allis-Chalmers 7020 as the power unit. The instrumentation measured and recorded draft and speed of operation. Before tillage, speed was calibrated and draft was zeroed for the no load condition. The implements were operated on a test area before being taken to the test site. This was done to insure that they were operating correctly and at the desired depth.

The moldboard plow was operated twice on each plot. The first time was to provide a furrow for the second pass to follow. Data concerning the plow was obtained during this second pass. For all other implements only one run was used to collect the data. All replications using one implement were completed before proceeding to the next implement. The herbicide Treflan was incorporated by a spring tooth harrow on 4-28-82.

After primary tillage, a second set of cone index values and soil moisture samples were obtained. The tractor with the cone penetrometer system mounted, was backed across the field to eliminate the effects of the tractor wheels on the cone index values. Cone index values and soil moisture samples were taken after primary tillage on 5-11-82. Soil cone index values were taken according to the American Society of Agricultural Engineer's standard 313.1.

Before planting, two passes of a springtooth were conducted to prepare the seedbed for planting. These were conducted at angles to the proposed cotton rows and were done to all treatments equally. This seedbed preparation was conducted on 6-4-82. Also on 6-4-82, all the plots were planted with the cotton variety Cascot L-7, at a seeding rate of 123,000 seeds per hectare. The plots were all planted uniformly using an International model 185 4-row cotton planter.

Plant emergence measurements were recorded for 15 and 21 days after planting. These measurements were taken on rows #3 and #4 going from west to east in each plot. A random starting point was selected and emergence counts were recorded for 3 meters of row length.

A third set of plant characteristics were taken on 11-17-82, approximately one week before harvest. Plant height, plant width and height of the low boll were measured.

Harvest stand counts were taken at the same time as plant characteristics on 11-17-82, about one week before harvest. Harvest stand counts were obtained by counting the number of plants in the same 3 meter length of the 3rd and 4th rows of each plot, as were plant emergence counts.

Cotton harvesting was done with a 2-row model 282 John Deere brush roll stripper on 11-23-82. Four cotton wagons were used in the harvesting of the cotton. Each wagon was initially weighed empty. Each plot was harvested separately and dumped into a wagon. The cotton that was harvested from only one plot was taken to the scales at the research building where the gross weight was determined and recorded. From each wagon load, a random grab sample weighing between 4 and 5 kilograms, was taken by hand, tagged with the replication and plot numbers, and hung inside the wagon as shown in Figures 11 and 15. This procedure continued until all plots were harvested.

After harvesting, the grab samples were weighed and taken to a laboratory burr-extractor to remove trash, stems and leaves. Cotton from the burr-extractor was termed clean seed cotton, which was then weighed and recorded. The weight of seed cotton obtained from each sample divided by the weight of the original grab sample in the sacks, yields the ratio of seed cotton for each grab sample. This ratio is assumed representative of the actual percent of seed cotton harvested from each plot.

CHAPTER V

RESULTS AND DISCUSSION

Soil Strength Before Primary Tillage

Appendix A contains the measured penetrometer data for various depths before primary tillage, after primary tillage and after harvest.

Shown in Figure 17 are the average cone index values before primary tillage. Lowry et al.(1970) shows that cotton yields decline significantly at penetrometer resistance values above 1500 kPa. Before primary tillage, all of the plots on which the tillage implements were proposed to be used, were above 1500 kPa at depths greater than 100 mm and above 2000 kPa at depths greater than 275 mm.

Shown in Table I is an analysis of variance table for mean soil cone index before primary tillage. Using the F test at the 5 percent significance level, there is no evidence to conclude that a statistical significant difference exists between the plots before primary tillage.

Soil Strength After Primary Tillage

Soil cone index profiles are shown in Figure 18. Soil cone index values were changed dramatically as a result of

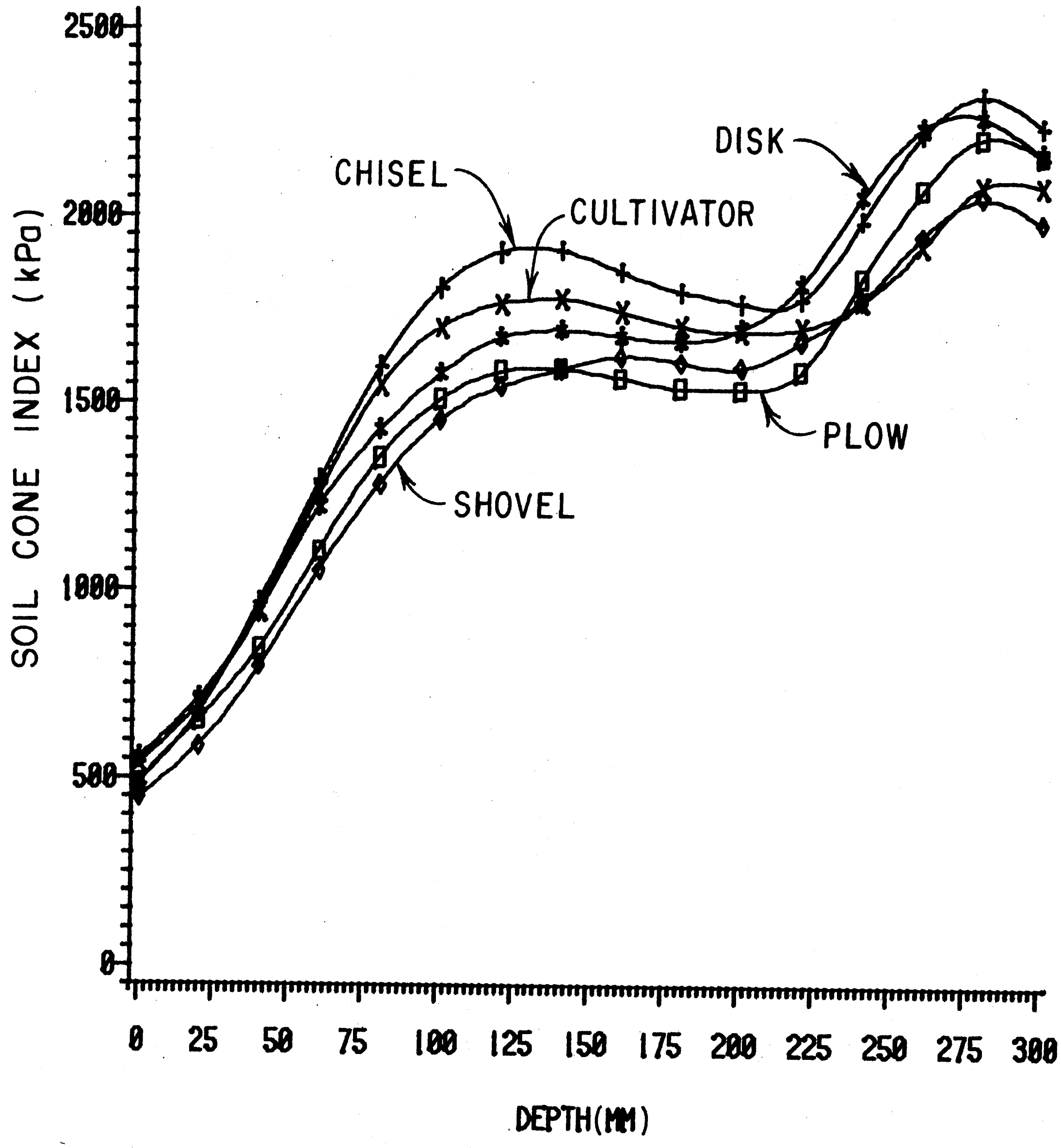

Figure 17. Soil Cone Index Vs. Depth of Penetration for each Tillage Treatment Before Primary Tillage

TABLE I

ANALYSIS OF VARIANCE OF MEAN SOIL CONE INDEX BEFORE PRIMARY TILLAGE

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	479	208803703.5		
Tillage treatments	4	3029404.8	2.32	0.0560
Replications	5	52431393.8	32.14	0.0001
Residuals (error)	470	153342904.9		

*Probability of an error in rejecting a null hypothesis of significance of the source of variation.

primary tillage. The moldboard plow caused the most dramatic change in cone index values. The moldboard plow reduced the soil's resistance to penetration to a uniform value of approximately 300 kPa from the soil surface to a depth of approximately 225 mm. Even to a depth of 300 mm the measured soil cone index value had not reached the 1500 kPa point.

Another primary tillage tool that indicates good results, when attempting to reduce the soil's resistance to penetration below the 1500 kPa value, is the chisel plow with points. Use of the chisel plow resulted in soil cone index values less than 1500 kPa to a depth greater than 250 mm.

The cultivator also showed good results, by producing cone index values less than 1500 kPa to an average depth of 250 mm. But the profile of the cultivator plots rose to a value of just less than 1500 kPa at approximately 125 mm and stayed at that level until it continued to rise at the 250 mm depth.

The tandem disk and shovel in a row exhibited little change and thus little benefit in terms of reducing the soil's resistance to penetration. By comparing Figures 17 and 18 for these two tillage tools, one can observe that there is little change in the shape or values of cone index at any depth. After primary tillage, measured values of cone index exceeded 1500 kPa at approximately 100 mm. This is the same depth at which these two implements exceeded

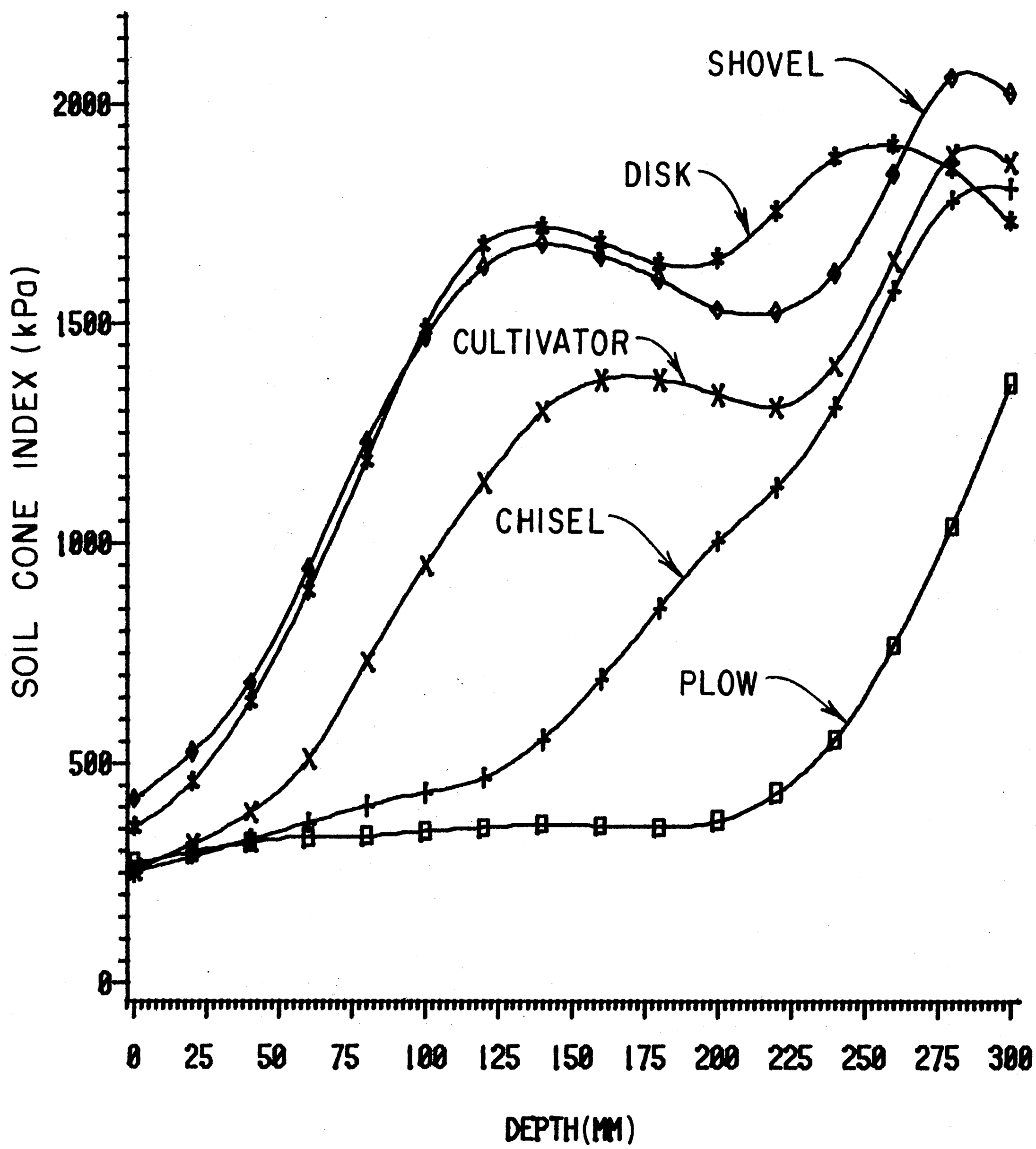

Figure 18. Soil Cone Index Vs. Depth of Penetration for each Tillage Treatment After Primary Tillage

1500 kPa before primary tillage was conducted.

Shown in Table II is the analysis of variance table for mean soil cone index values after primary tillage. Using the F test at the 5 percent significance level, there is evidence to conclude that a significant difference does exist between plots on which different tillage implements were used.

According to Duncan's multiple range test, shown in Table III, significant differences exist between treatments in terms of soil cone index after primary tillage. There exists a significant difference between the moldboard plow, the chisel with points, the cultivator and the other two implements. No difference exists between the tandem disk and shovel in a row.

In terms of reducing soil resistance to penetration, the cultivator and the chisel with points both did an adequate job of reducing the cone index to less than restrictive levels. The moldboard plow did the best job of reducing soil cone index to less than 1500 kPa and the soil remained below this restrictive level to a depth of over 300 mm.

Soil Strength After Harvest

According to numerous references, root growth, crop yield and plant characteristics exhibit a relationship to soil cone index. Therefore, the degree to which the soil is recompacted during the growing season is important to

TABLE II

ANALYSIS OF VARIANCE OF MEAN SOIL CONE INDEX AFTER PRIMARY TILLAGE

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	479	197845516.1		
Tillage Treatments	4	59124683.3	53.39	0.0001
Replications	5	8594133.1	6.21	0.0001
Residuals (error)	470	130126699.6		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

TABLE III

DUNCAN'S MULTIPLE RANGE TEST FOR MEAN SOIL CONE INDEX AFTER PRIMARY TILLAGE

Tillage Implement	Mean Cone Index	Grouping*
Tandem Disk	1404.9	A A
Shovel in a Row	1399.6	A
Cultivator	1108.8	B
Chisel Plow	825.0	C
Moldboard Plow	489.9	D

*Means with the same letter are not significantly different at an alpha level of 0.05.

continued plant growth and yield. To gain some information concerning the effects of the growing season, equipment traffic and environmental conditions on soil recompaction, a third measurement of cone index was taken after harvest.

By comparing Figure 18 which represents the measured cone index values on the plots just after primary tillage with Figure 19 which is the measured cone index values for the plots after harvest, significant compaction can be observed to have occurred during the growing season on all plots. The moldboard plow plots are the only ones that still showed significant effects from the primary tillage done at the beginning of the season.

After harvest all plots had soil cone index profiles similar in magnitude and shape to those determined prior to primary tillage in the spring. Only the moldboard plow plots retained a residual effect from primary tillage. After harvest, all the plots exceeded 1500 kPa at approximately 100 mm depth, with the exception of those from the moldboard plow. All of the plots except the moldboard plow plots exceeded 2000 kPa at a depth of approximately 150 mm. By comparing Figures 17 and 19 one may observe that all of the plots, except for the moldboard plow plots, were more compacted after harvest than they were before primary tillage was conducted.

Table IV shows the analysis of variance table for mean soil cone index values after harvest. Using the F test at the 5 percent significance level, there is evidence to

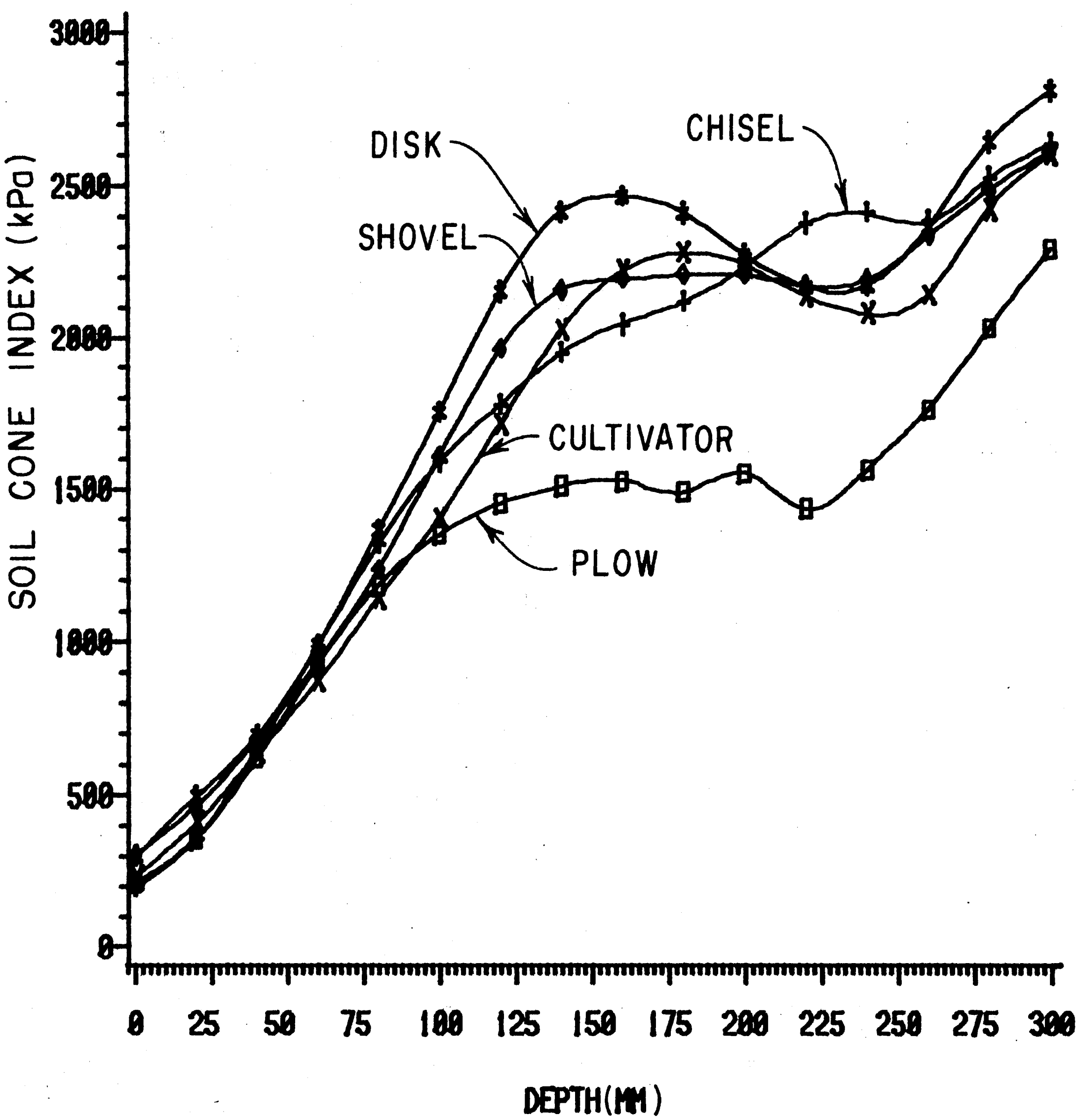

Figure 19. Soil Cone Index Vs. Depth of Penetration for each Tillage Treatment After Harvest

conclude that a statistical difference does exist between at least one plot and the rest. Through the use of Duncan's multiple range test (Table V), it may be found that the only significant difference lies between the moldboard plowed plots and all others.

The moldboard plow appears to be the best primary tillage tool for reducing cone index. It was the only primary tillage implement that reduced soil cone index below the 1500 kPa point and stayed below that point throughout the growing season.

Soil Moisture

The effects of primary tillage on soil moisture were determined by obtaining soil moisture measurements at the same time as cone penetrometer values. These soil moisture measurements were taken before tillage, after tillage and again after harvest.

Appendix B contains the data concerning soil moisture contents at various depths before tillage, after tillage and after harvest for each primary tillage tool. This information is also shown in Figure 20, which shows in a bar graph format the average soil moisture content for each plot.

Based on an analysis of variance for mean soil moisture content (Table VI), there is no evidence to indicate that there exists a significant difference between tillage implements in terms of average soil moisture content before

TABLE IV

ANALYSIS OF VARIANCE OF MEAN SOIL CONE INDEX AFTER HARVEST

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	479	320786216.1		
Tillage Treatments	4	14463017.3	5.77	0.0002
Replications	5	11897021.0	3.80	0.0023
Residuals (error)	470	294426177.8		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

TABLE V

DUNCAN'S MULTIPLE RANGE TEST FOR MEAN SOIL CONE INDEX AFTER HARVEST

Tillage Implement	Mean Cone Index	Grouping*
Tandem Disk	1837.5	A
		A
Shovel in a Row	1731.7	A
		A
Cultivator	1719.6	A
		A
Chisel Plow	1658.2	A
Moldboard Plow	1327.5	B

*Means with the same letter are not significantly different at an alpha level of 0.05.

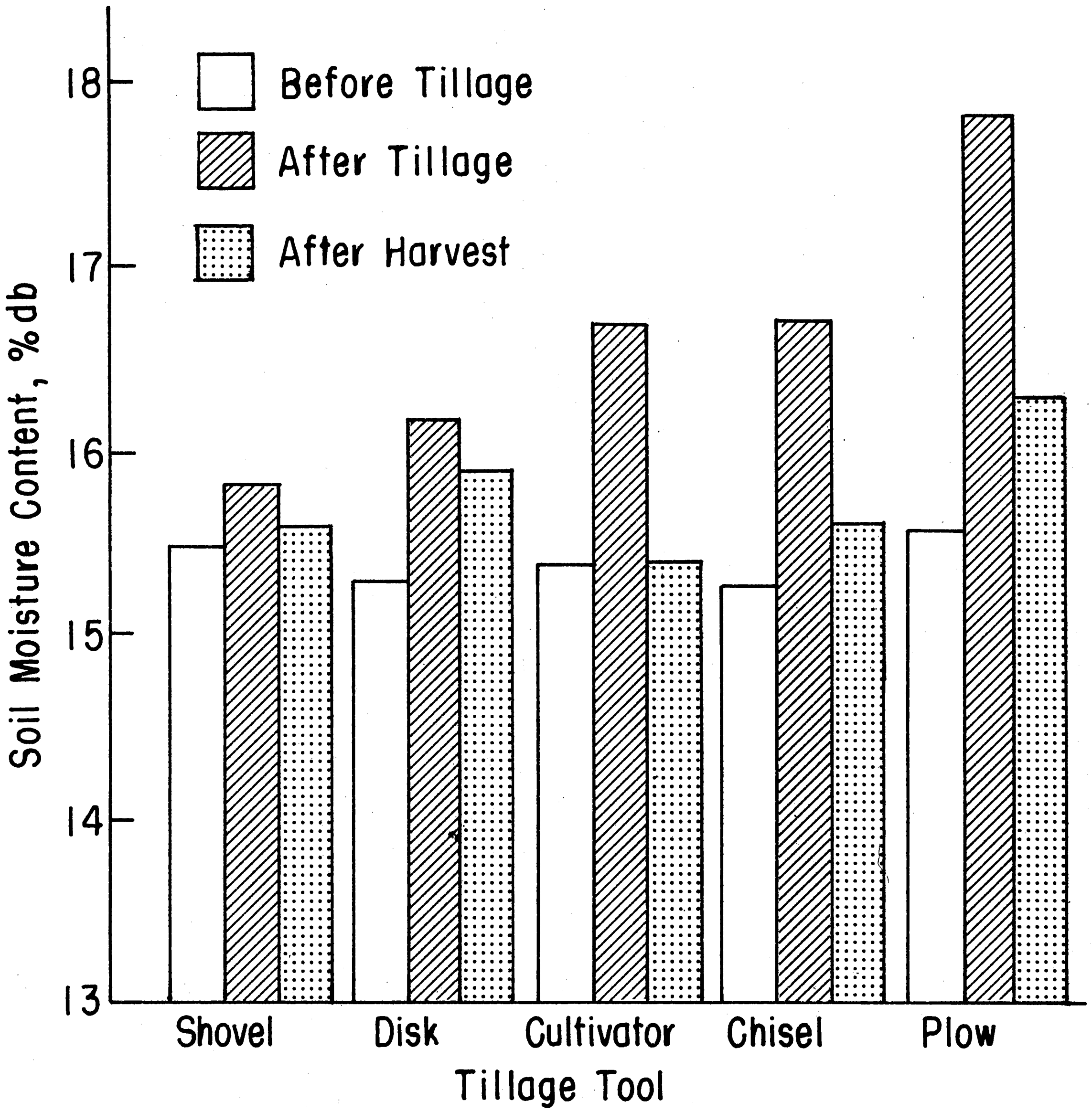

Figure 20. Mean Moisture Content for each Tillage Treatment Before Primary Tillage, After Primary Tillage and After Harvest (Averaged over 38 cm)

TABLE VI

ANALYSIS OF VARIANCE OF MEAN SOIL MOISTURE CONTENT BEFORE PRIMARY TILLAGE

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	149	292.62		
Tillage Treatments	4	2.33	0.32	0.8630
Replications	5	36.34	4.01	0.0021
Residuals (error)	140	253.94		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

primary tillage.

After primary tillage about 10 cm of rain was received before the next soil moisture measurements were taken. Figure 21 contains the rainfall history for the period during the tests. An analysis of variance for mean soil moisture content after primary tillage (Table VII) shows significant differences in soil moisture levels. These differences indicate different infiltration rates as a result of the primary tillage tool utilized.

The moldboard plow accomplished the most tillage and had a soil moisture content of 17.8 percent after primary tillage. The shovel in a row did the least tillage and had a soil moisture content of 15.8 percent. Based on Duncan's multiple range test (Table VIII), there is evidence which indicates significant differences existed between the tillage tools in terms of soil moisture content after primary tillage. At the 5 percent significance level, the moldboard plow plot was shown to have a significantly higher soil moisture content than the other plots one month after tillage. The other tillage tools were shown to have statistically the same soil moisture content one month after tillage.

After harvest, soil moisture content was measured again for each plot on which the tillage tools were used. According to the analysis of variance table for mean soil moisture content after harvest, shown in Table IX, there is evidence indicating significant differences existed among

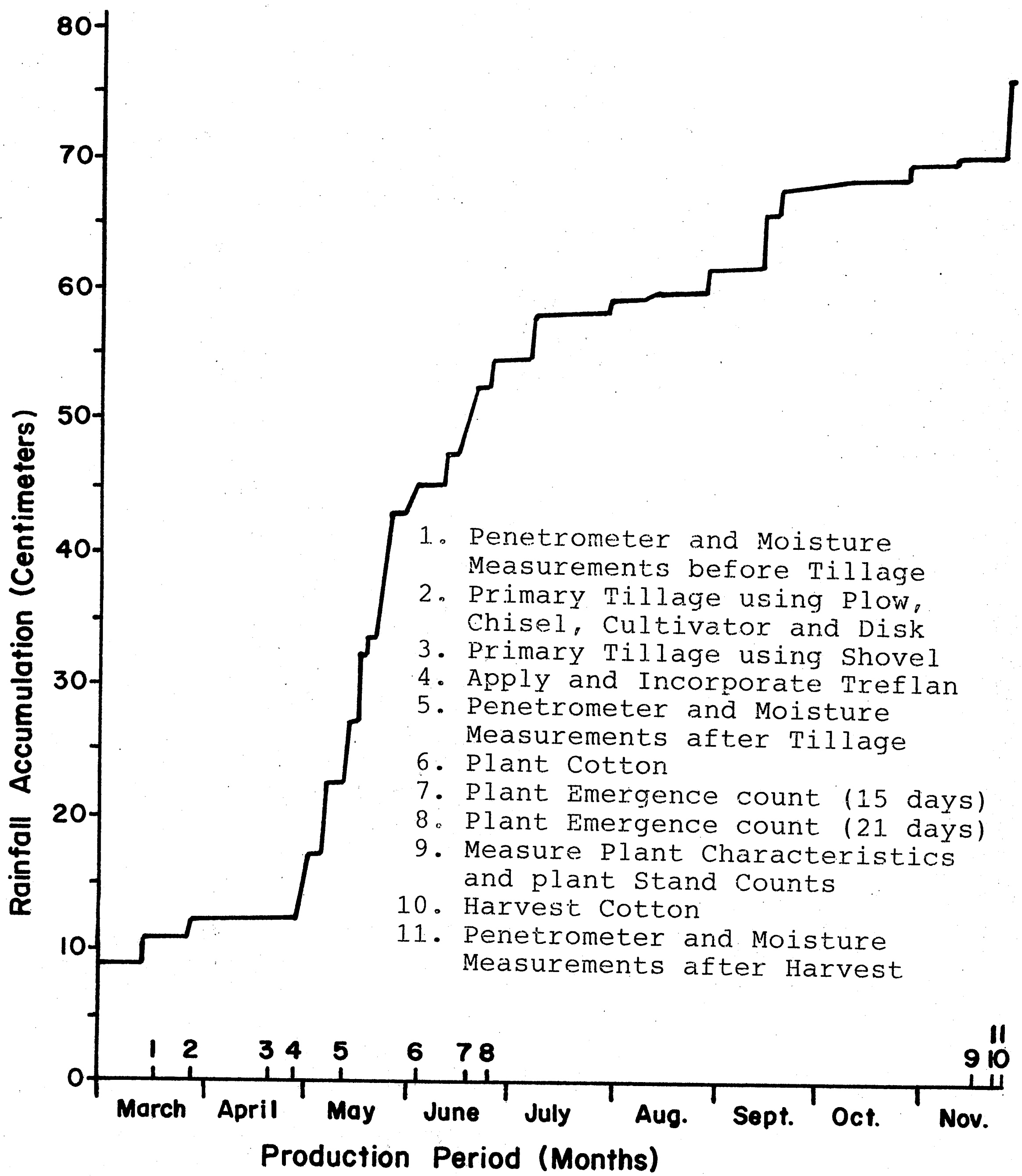

Figure 21. Rainfall Accumulation During Production Period

TABLE VII

ANALYSIS OF VARIANCE OF MEAN SOIL MOISTURE CONTENT AFTER PRIMARY TILLAGE

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	149	667.24		
Tillage Treatments	4	67.99	4.44	0.0021
Replications	5	63.14	3.30	0.0077
Residuals (error)	140	536.12		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

TABLE VIII

DUNCAN'S MULTIPLE RANGE TEST FOR MEAN SOIL MOISTURE CONTENT AFTER PRIMARY TILLAGE

Tillage Implement	Mean Soil Moisture	Grouping*
Moldboard Plow	17.81	A
Chisel Plow	16.68	B B
Cultivator	16.67	B B
Tandem Disk	16.18	B B
Shovel in a Row	15.81	B

*Means with the same letter are not significantly different at an alpha level of 0.05.

the different primary tillage tools in terms of soil moisture content.

Through the use of Duncan's multiple range test (Table X), it is shown that the moldboard plow and the tandem disk had the highest after harvest soil moisture content at 16.2 and 15.9 percent dry basis. The cultivator had the lowest average soil moisture content, but was statistically similar to the chisel plow and the shovel in a row.

Plant Characteristics

Cotton plant emergence was very uniform over the entire field. No significant differences in emergence were found when counted 21 days after planting. Preharvest plant counts were also uniform over the field. A slight loss, on the average of 2 plants per 10 feet of row length, occurred during the growing season.

Contained in Appendix C and Table XI are the actual and average values of the plant parameters measured in this study. Stated in Batchelder and McLaughlin (1978), a higher low boll tends to improve harvest efficiency. The cultivator and the moldboard plow had the highest average low boll; while the shovel in a row had the lowest average low boll height. Plant width was greater for the chisel with points and the shovel in a row and least for the tandem disk.

As shown in Table XI, significant differences in plant

TABLE IX

ANALYSIS OF VARIANCE OF MEAN SOIL MOISTURE CONTENT AFTER HARVEST

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	149	115.98		
Tillage Treatments	4	15.09	7.22	0.0001
Replications	5	27.76	10.63	0.0001
Residuals (error)	140	73.14		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

TABLE X

DUNCAN'S MULTIPLE RANGE TEST FOR MEAN SOIL MOISTURE CONTENT AFTER HARVEST

Tillage Implement	Mean Soil Moisture	Grouping*
Moldboard Plow	16.23	A
		A
Tandem Disk	15.93	A B
		B
Chisel Plow	15.59	B C
		C
Shovel in a Row	15.52	C
		C
Cultivator	15.35	C

*Means with the same letter are not significantly different at an alpha level of 0.05.

TABLE XI

AVERAGE PHYSICAL PARAMETERS OF COTTON AND AVERAGE SOIL CONE INDEX AFTER TILLAGE

Tillage Implement	Cotton Yield (kg/ha)	Plant Height (cm)	Plant Width (cm)	Height of Low Boll (cm)	Cone[1] Index (kPa)
Chisel Plow	834.69	51.3	29.8	22.2	385
Cultivator	811.60	50.8	24.9	26.7	700
Moldboard Plow	811.26	54.9	22.7	25.0	326
Tandem Disk	627.10	45.7	18.2	21.3	1000
Shovel in a Row	557.92	42.8	28.9	19.5	1100

All data averaged over six blocks.
1. Cone index averaged over top 15 cm, after tillage.

height occurred during the growing season. This may have been related to differences in the soil cone index values. Using the moldboard plow as the primary tillage tool resulted in the lowest value of cone index and also the tallest average plants. The shovel in a row had little effect in reducing soil cone index and its plots had the least average plant height. There was no significant difference in plant height among the moldboard plow, chisel plow with points and the cultivator.

A comparison was made between plant height measurements and soil penetration resistance data as shown in Figure 22. The coefficient of determination (R-square) was 0.93 (significant above the 99 percent level of confidence). The best regression line was found to be:

$$H = 54.6 - 9.32 \times 10^{-6} \times CI^{2} \qquad (1)$$

where: H = plant height (cm)

CI = soil cone index (kPa) after primary tillage averaged over the top 15 cm of soil

Cotton Yield

There were significant differences in yield among tillage implement treatments. The primary tillage tools resulted in different soil strengths, different rates of water infiltration and differences in plant characteristics; these items all had an effect on yield.

A good correlation was found between yield of

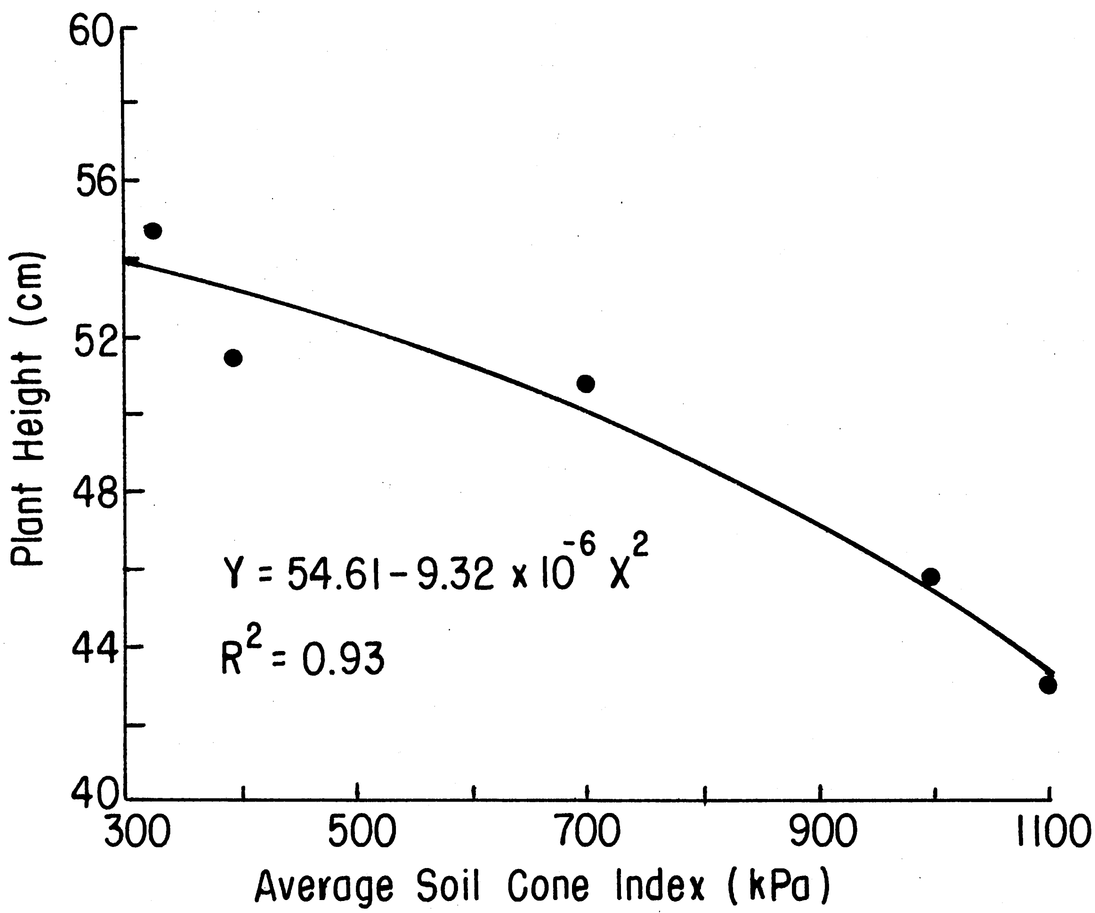

Figure 22. Plant Height Vs. Soil Cone Index

clean seed cotton and average soil cone index in the top 15 centimeters of soil. This relationship can be seen in Figure 23. The coefficient of determination (R-square) was found to be 0.92 (significant above the 99 percent level of confidence). The best regression line was found to be:

$$Y = 872.97 - 2.445 \times 10^{-4} \times CI^{2} \qquad (2)$$

where: Y = yield of clean seed cotton (kg/ha)

CI = soil cone index (kPa) after primary tillage averaged over the top 15 cm of soil

There was no apparent relationship between plant width and yield or plant population and yield. A correlation was found between yield of clean seed cotton and plant height (Figure 24). The coefficient of determination (R-square) was found to be .87 (significant above the 97 percent confidence level). The best regression line was found to be:

$$Y = -447 + 24.56 \times H \qquad (3)$$

where: Y = yield of clean seed cotton (kg/ha)

H = plant height (cm)

Shown in Table XI are the cotton yields and soil cone index values for each of the tillage tools. Table XII is the analysis of variance table for yield of clean seed cotton. Using the F test at the 5 percent significance level, there is evidence to conclude that a significant difference does exist between yields for different primary tillage implements. Through the use of Duncan's multiple

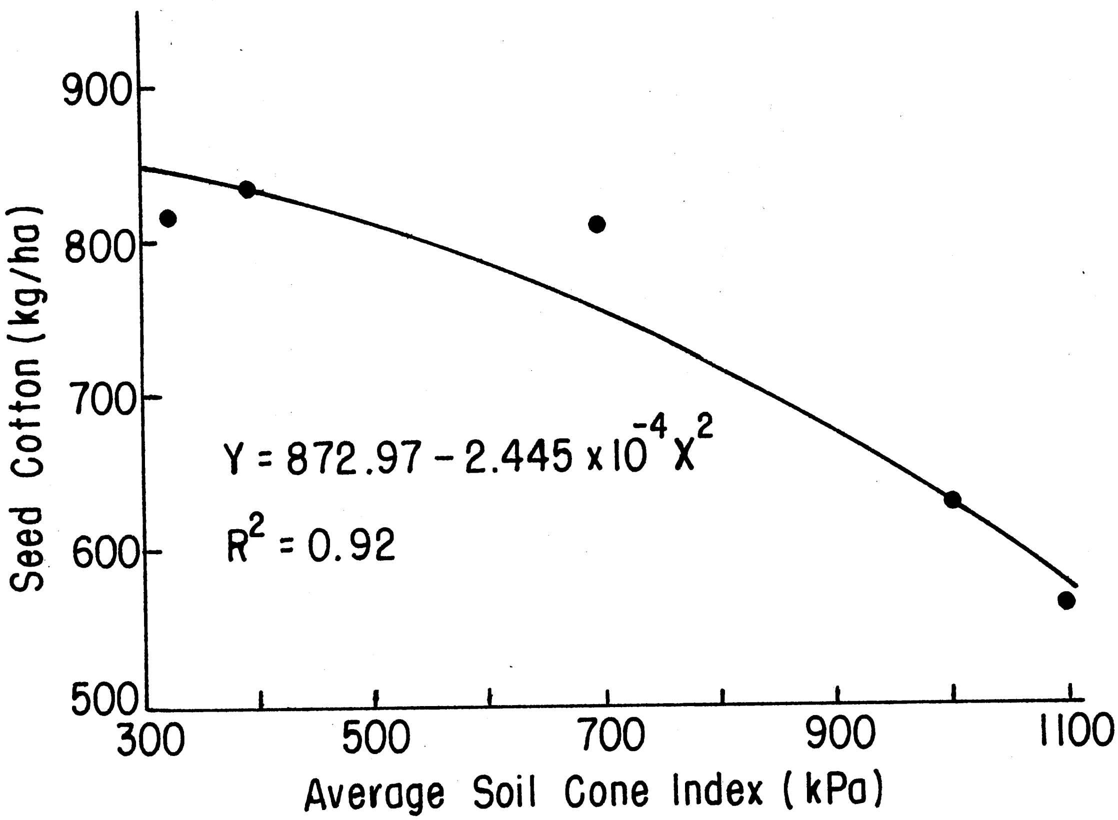

Figure 23. Yield of Clean Seed Cotton Vs. Soil Cone Index

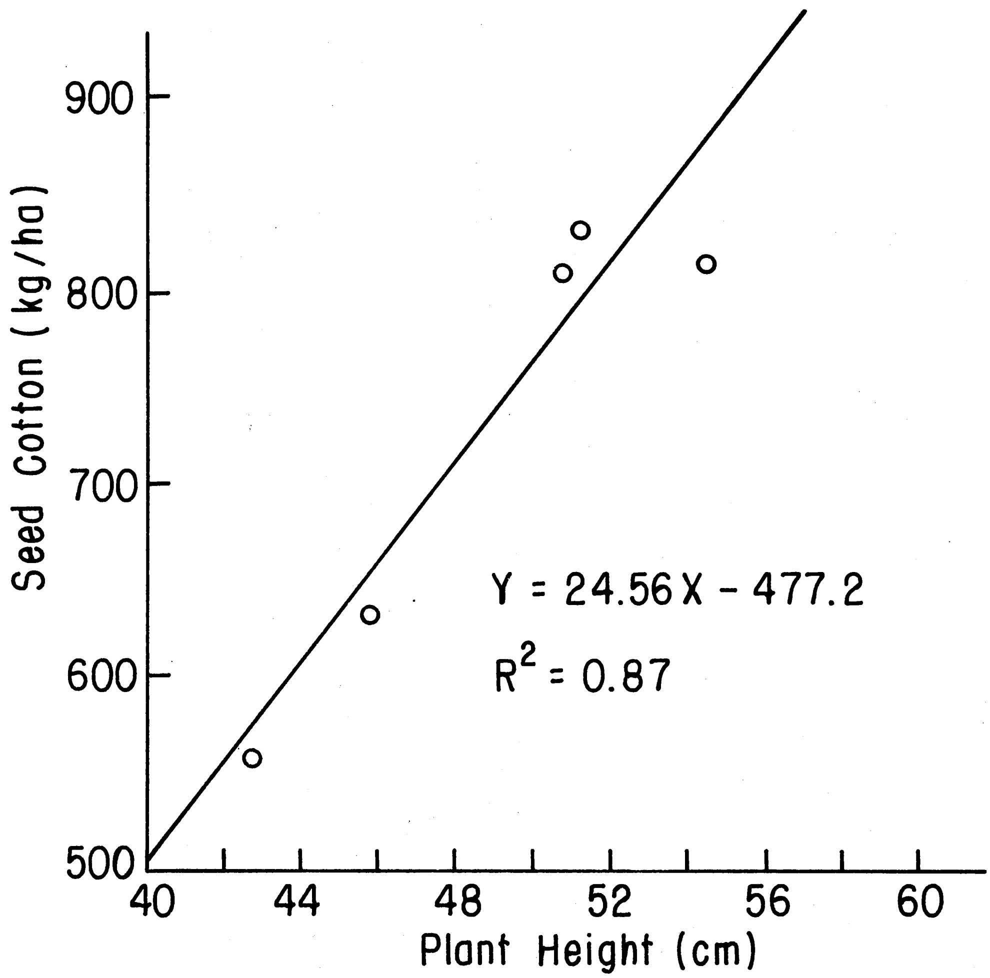

Figure 24. Yield of Clean Seed Cotton Vs. Plant Height

range test (Table XIII), it was determined that there was no significant difference in yield from the use of the moldboard plow, the chisel plow with points and the cultivator, with an average yield of 819 kg/ha. There was also no significant difference in yield from the use of the tandem disk and shovel in a row with an average yield of 592 kg/ha. Percent weight of seed cotton from harvest weight is contained in Appendix D. Actual cotton harvest weights are contained in Appendix E.

Fuel Energy Requirements

Because the tractor and primary tillage implements were not well matched, a procedure for estimating fuel requirement was developed. This procedure was outlined in Self et al. (1983) for a tractor being operated in the range of 60-70 percent of rated PTO capacity. A constant given by Bowers (1978) is used to estimate PTO horsepower from drawbar horsepower. This constant takes into consideration losses due to lack of traction and losses in the power train. On firm soil such as this field, this constant is equal to 0.64. An average fuel conversion factor of 2.70 kW-h/L was found for tractors loaded in the 60-70 percent range of maximum PTO power. This was calculated from over 300 two-wheel drive diesel tractors tested at the Nebraska tractor testing laboratory.

TABLE XII

ANALYSIS OF VARIANCE OF COTTON YIELDS

Source	D.F.	Sum of Squares	F Ratio	Significance Level*
Corrected Total	29	666857.8		
Tillage Treatments	4	307626.8	10.52	0.0001
Replications	5	213015.0	5.83	0.0018
Residuals (error)	20	146216.0		

*Probability of an error in rejecting the null hypothesis of significance of the source of variation.

TABLE XIII

DUNCAN'S MULTIPLE RANGE TEST FOR COTTON YIELDS

Tillage Implement	Mean Yield (kg/ha)	Grouping*
Chisel Plow	834.7	A
		A
Cultivator	811.6	A
		A
Moldboard Plow	811.3	A
Tandem Disk	627.1	B
		B
Shovel in a Row	557.9	B

*Means with the same letter are not significantly different at an alpha level of 0.05.

The equation for estimating fuel use for tractors utilizing 60-70 percent of rated PTO capacity is:

$$L/ha = PTO\ (kW)\ /\ [(ha/h) \times 2.70\ (kW\text{-}h/L)] \quad (4)$$

Where: PTO (kW) = drawbar kW / 0.64

Table XIV shows results for each implement along with projected fuel use in liters per hectare. The analysis of variance table for fuel requirements is given in Table XV. Using an F test at the 5 percent significance level, there is evidence to conclude significant differences do exist between different tillage tools in terms of fuel requirement. Through the use of Duncan's multiple range test (Table XVI), it was determined that all of the implements were significantly different from each other in terms of fuel requirement, with the exception of the cultivator and the tandem disk. The measured values for draft, speed, and slip for each implement and block is contained in appendix F.

Shown in Table XIV, the moldboard plow had the highest fuel requirement at 14.5 L/ha. The chisel plow with points had the next highest fuel requirement at 8.1 L/ha or 56 percent of the fuel requirement of the moldboard plow. The other implements following in terms of fuel use as a percentage of the moldboard plow were: the tandem disk required 46 percent, the cultivator required 44 percent and the shovel in a row required 23 percent of the fuel requirement of the moldboard plow in this soil type.

TABLE XIV

MEASURED DRAFT AND PROJECTED FUEL REQUIREMENT FOR EACH PRIMARY TILLAGE TOOL

Tillage Implement	Depth (cm)	Speed (km/h)	Pull (kN/m)	Drawbar (kW/m)	PROJECTED PTO[1] (kW/m)	PROJECTED Fuel[2] (L/ha)
Molboard Plow	25-28	6.8	9.0	16.9	26.4	14.5
Chisel Plow	18	5.5	5.0	7.6	12.0	8.1
Tandem Disk	13	7.7	4.2	9.1	14.2	6.7
Cultivator	10-13	7.6	3.7	7.8	12.2	6.4
Shovel in a Row	13	7.1	1.9	3.9	5.9	3.3

1. Calculated as (DB kW/m)/0.64
2. Calculated using 2.70 PTO kW-h/L

TABLE XV

ANALYSIS OF VARIANCE OF FUEL REQUIREMENTS

Source	D.F.	Sum of Squares	F Ratio	Significance At 5% level
Corrected Total	29	417.255		
Tillage Treatments	4	409.796	377.62	Yes*
Replications	5	2.033	1.50	No
Residuals (error)	20	5.426		

*Probability of an error is less than 1 percent in rejecting the null hypothesis of significance of the source of variation.

TABLE XVI

DUNCAN'S MULTIPLE RANGE TEST FOR PROJECTED FUEL REQUIREMENT

Tillage Implement	Fuel Use (L/ha)	Grouping*
Moldboard Plow	14.5	A
Chisel Plow	8.1	B
Tandem Disk	6.7	C C
Cultivator	6.4	C
Shovel in a Row	3.3	D

*Means with the same letter are not significantly different at an alpha level of 0.05.

Estimated Total Energy Requirement

Several researchers have measured the total fuel requirements in the growing of cotton for their particular soil type and equipment. Others have reported the fuel requirements of different tillage implements in a variety of soil types. Because of the wide variety and differences in how cotton fields may be prepared, cultivated and harvested, estimates from different sources will be used to evaluate the fuel requirements for each of the operations utilized in this test. The same operations were used for all five tillage implements.

The fuel requirement data given for each of the tillage implements is for 100 percent field efficiency. To determine the percentage of fuel utilized in primary tillage, an estimate of actual field efficiency will add a percentage to the total fuel requirements for each implement. According to Kepner et al. (1971) in Principles of Farm Machinery most tillage operation have typical field efficiencies of 75-90 percent. A field efficiency of 80 percent will be used for all five primary tillage implements.

Shown in Table XVII are the estimated fuel requirements for each of the operations utilized in this cotton production, along with the fuel requirements of the different primary tillage implements. Estimated fuel requirement for cutting stalks, a row crop planter and incoporating herbicides were found in Dumas and Renoll

(1982). Estimated fuel requirement for cultivation and a springtooth harrow came from Williford and Smith (1982). Estimated fuel use for cotton harvesting with a stripper was obtained from two sources, Sistler and Zimmerman (1980) and Williford and Smith (1982).

Results show large differences in terms of fuel requirements of the tillage implements as percentages of the total. The moldboard plow required the highest percentage of total fuel use at over 34 percent. The others followed as a percentage of total fuel use at 22 percent for the chisel with points, 19 percent for the tandem disk, 19 percent for the cultivator and 11 percent for the shovel in a row.

TABLE XVII

PERCENTAGE FUEL REQUIREMENT FOR EACH PRIMARY TILLAGE TOOL OF THE ESTIMATED TOTAL FUEL REQUIREMENT

Operation		Fuel Requirement (L/ha) Moldboard Plow	Chisel Plow	Cultiv	Tandem Disk	Shovel
Cut Stalks (Tandem disk)	6.5					
Primary Tillage	___	18.1*	10.1*	8.0*	8.4*	4.1*
Apply Treflan	7.2					
Springtooth 2x	8.0					
Row Crop Planter	3.2					
First Cultivation	2.6					
Second Cultivation	2.6					
Harvest (Cotton Stripper)	4.7					
Total Fuel Req.	34.9	53.0	45.0	42.9	43.3	39.0
Primary Tillage as a Percentage of Total Fuel Req.		34%	22%	19%	19%	11%

*Calculated as projected fuel requirement (Table XV) in liters per hectare divided by 0.80 (field efficiency)

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The effects of five primary tillage implements on cotton yield, soil cone index, plant characteristics and fuel requirements were studied in a replicated complete block design.

Each treatment of a tillage tool was replicated six times. The five primary tillage implements tested were a moldboard plow, a chisel plow with points, cultivator, a tandem disk and a shovel in a row.

Draft and fuel data were obtained from each replication and analyzed. Total fuel requirement to conduct primary tillage, apply herbicide, cultivate and harvest were estimated and compared in terms of liters per hectare.

Yield data and plant characteristics were obtained and analyzed for each tillage tool. Relationships between plant characteristics and yield were analyzed along with relationships between cotton yield and cone index.

Soil resistance to penetration measurements and moisture samples were taken for each replication. These values were obtained before primary tillage, after primary tillage and again after harvest. This data indicates the effects of the different primary tillage tools on soil cone index and soil moisture.

Conclusions

1. Use of the moldboard plow will require significantly more pull and fuel than the other primary tillage tools examined. The chisel plow with points will require relatively high fuel requirements, second only to the moldboard plow. The tandem disk and cultivator will be similar in terms of fuel requirement, but will require less fuel than the chisel with points. The shovel in a row will require the lowest amount of fuel of the five tillage implements tested.

2. The moldboard plow will greatly reduce the soil's resistance to penetration throughout the growing season. Soil Cone index values for the moldboard plow plots will be below restrictive levels until after harvest. The chisel plow with points and the cultivator will both reduce cone index values below restrictive levels, but can be expected to recompact during the growing season to a point similar to that before primary tillage. Use of the tandem disk and shovel in a row will result in little reduction in cone index.

3. The moldboard plow plots will be associated with higher soil moisture content compared to the other tillage implements examined in these tests. The chisel with points, the cultivator, the tandem disk and the shovel in a row will

produce similar soil moisture content in the root region of the soil.

4. No significant differences in plant emergence or preharvest plant stands will result from the use of these primary tillage implements. The moldboard plow, chisel plow and cultivator will produce a relatively taller cotton plant with higher low bolls. The shovel in a row will produce a relatively shorter cotton plant with lower low bolls. The chisel with points will produce relatively wider cotton plants compared to these other tillage implements.

5. The soil's resistance to penetration after primary tillage measured by soil cone index, is an indicator of plant height.

6. The moldboard plow, the chisel plow with points and the cultivator will produce similar yields. The tandem disk and the shovel in a row will also produce similar yields, but will be less than the other tillage tools.

7. The soil's resistance to penetration after primary tillage measured by soil cone index, is an indicator of cotton yield. Plant height measured at harvest is also an indicator of cotton yield.

8. The moldboard plow is more costly in terms of fuel requirement and pull, while producing no significant increase in yield, compared to the chisel plow and field cultivator.

9. The field cultivator is the primary tillage implement of choice for cotton production under these

conditions and soil type.

Recommendations for Future Work

A study utilizing primary tillage implements should be continued for several years. Soil moisture and soil cone index values should be taken several times on regular intervals throughout the growing season. This would provide information concerning transient effects of tillage on soil moisture and strength.

A similar study of cotton concerning the effects of primary tillage should also be done on irrigated cotton.

A more complete cost analysis of the use of different primary tillage implements should be done and it should include the effects of timeliness and equipment costs for each implement.

Finally research should be done in a number of different areas over the state on several soil types to insure that the data is applicable to other areas.

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APPENDIX A

MEASURED SOIL CONE INDEX VALUES AT VARIOUS DEPTHS BEFORE PRIMARY TILLAGE, AFTER PRIMARY TILLAGE AND AFTER HARVEST

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
MOLDBOARD PLOW	1	0	469.6	257.6	266.8
MOLDBOARD PLOW	1	20	567.4	298.2	493.0
MOLDBOARD PLOW	1	40	842.8	326.0	683.4
MOLDBOARD PLOW	1	60	1196.8	327.4	885.0
MOLDBOARD PLOW	1	80	1619.0	341.4	1298.4
MOLDBOARD PLOW	1	100	1877.2	362.4	1692.8
MOLDBOARD PLOW	1	120	2049.8	372.0	1910.6
MOLDBOARD PLOW	1	140	2111.2	369.2	2054.2
MOLDBOARD PLOW	1	160	2109.6	352.4	2043.0
MOLDBOARD PLOW	1	180	2059.6	354.0	1792.2
MOLDBOARD PLOW	1	200	2079.0	373.4	2299.6
MOLDBOARD PLOW	1	220	2234.8	462.6	1618.4
MOLDBOARD PLOW	1	240	2738.0	593.6	1800.4
MOLDBOARD PLOW	1	260	3266.2	781.8	2183.8
MOLDBOARD PLOW	1	280	3197.8	1159.4	2478.8
MOLDBOARD PLOW	1	300	2838.4	1783.6	2942.2
MOLDBOARD PLOW	2	0	238.4	253.6	214.6
MOLDBOARD PLOW	2	20	270.4	269.0	325.0
MOLDBOARD PLOW	2	40	317.8	259.4	697.2
MOLDBOARD PLOW	2	60	469.6	256.4	1149.4
MOLDBOARD PLOW	2	80	653.6	249.4	1408.8
MOLDBOARD PLOW	2	100	776.2	236.8	1532.8
MOLDBOARD PLOW	2	120	857.0	220.0	1662.4
MOLDBOARD PLOW	2	140	905.8	232.6	1632.2
MOLDBOARD PLOW	2	160	883.4	231.2	1690.2
MOLDBOARD PLOW	2	180	833.2	200.6	1698.2
MOLDBOARD PLOW	2	200	786.0	200.4	1507.8
MOLDBOARD PLOW	2	220	737.2	260.4	1519.0
MOLDBOARD PLOW	2	240	738.4	369.2	1808.6
MOLDBOARD PLOW	2	260	897.4	466.6	1841.8
MOLDBOARD PLOW	2	280	1082.6	613.0	2078.8
MOLDBOARD PLOW	2	300	1242.8	865.4	2098.2
MOLDBOARD PLOW	3	0	455.8	204.6	129.2
MOLDBOARD PLOW	3	20	710.6	249.4	236.8
MOLDBOARD PLOW	3	40	1078.6	277.2	553.8
MOLDBOARD PLOW	3	60	1451.8	291.4	898.4
MOLDBOARD PLOW	3	80	1634.6	296.8	1202.0
MOLDBOARD PLOW	3	100	1644.4	305.2	1334.2
MOLDBOARD PLOW	3	120	1617.6	314.8	1337.0
MOLDBOARD PLOW	3	140	1555.4	355.2	1270.8
MOLDBOARD PLOW	3	160	1456.2	402.6	1251.4
MOLDBOARD PLOW	3	180	1407.4	415.2	1248.8
MOLDBOARD PLOW	3	200	1430.8	401.2	1237.6
MOLDBOARD PLOW	3	220	1514.6	370.4	1188.4
MOLDBOARD PLOW	3	240	2001.0	365.2	1080.6
MOLDBOARD PLOW	3	260	1737.8	455.8	1066.8
MOLDBOARD PLOW	3	280	1660.8	681.4	1328.8
MOLDBOARD PLOW	3	300	1549.4	1054.6	1742.2
MOLDBOARD PLOW	4	0	331.6	281.4	250.6
MOLDBOARD PLOW	4	20	395.8	283.0	462.8
MOLDBOARD PLOW	4	40	483.6	319.2	680.8

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
MOLDBOARD PLOW	4	60	710.8	349.8	859.8
MOLDBOARD PLOW	4	80	1027.0	372.0	1064.0
MOLDBOARD PLOW	4	100	1449.2	402.6	1243.2
MOLDBOARD PLOW	4	120	1733.6	423.6	1425.2
MOLDBOARD PLOW	4	140	1834.8	423.6	1519.0
MOLDBOARD PLOW	4	160	1836.6	450.4	1563.0
MOLDBOARD PLOW	4	180	1797.4	455.4	1590.8
MOLDBOARD PLOW	4	200	1746.0	500.0	1601.6
MOLDBOARD PLOW	4	220	1725.0	681.2	1613.2
MOLDBOARD PLOW	4	240	1975.8	908.4	1780.8
MOLDBOARD PLOW	4	260	2502.4	1084.0	2079.0
MOLDBOARD PLOW	4	280	2984.8	1387.8	2247.2
MOLDBOARD PLOW	4	300	2824.4	1711.2	2539.6
MOLDBOARD PLOW	5	0	780.2	327.4	209.2
MOLDBOARD PLOW	5	20	1061.8	323.4	360.8
MOLDBOARD PLOW	5	40	1181.4	337.4	625.4
MOLDBOARD PLOW	5	60	1311.0	322.0	912.4
MOLDBOARD PLOW	5	80	1471.4	290.0	1053.0
MOLDBOARD PLOW	5	100	1507.6	277.2	1086.0
MOLDBOARD PLOW	5	120	1495.2	317.6	1108.2
MOLDBOARD PLOW	5	140	1489.6	331.6	1207.4
MOLDBOARD PLOW	5	160	1556.4	292.8	1226.8
MOLDBOARD PLOW	5	180	1630.4	305.2	1179.6
MOLDBOARD PLOW	5	200	1644.4	323.2	1155.0
MOLDBOARD PLOW	5	220	1761.2	359.4	1113.4
MOLDBOARD PLOW	5	240	1904.8	553.2	1317.8
MOLDBOARD PLOW	5	260	1954.8	1004.6	1772.6
MOLDBOARD PLOW	5	280	1994.0	1351.6	1998.8
MOLDBOARD PLOW	5	300	2055.2	1627.4	1996.2
MOLDBOARD PLOW	6	0	649.2	295.4	203.6
MOLDBOARD PLOW	6	20	922.2	351.2	269.8
MOLDBOARD PLOW	6	40	1157.8	397.0	501.4
MOLDBOARD PLOW	6	60	1486.8	439.0	840.6
MOLDBOARD PLOW	6	80	1708.4	458.4	1061.0
MOLDBOARD PLOW	6	100	1815.8	489.0	1207.4
MOLDBOARD PLOW	6	120	1786.4	472.4	1262.4
MOLDBOARD PLOW	6	140	1679.0	454.2	1364.4
MOLDBOARD PLOW	6	160	1577.4	409.8	1372.8
MOLDBOARD PLOW	6	180	1524.4	390.2	1414.2
MOLDBOARD PLOW	6	200	1553.6	408.2	1499.6
MOLDBOARD PLOW	6	220	1563.4	452.8	1538.4
MOLDBOARD PLOW	6	240	1674.8	540.4	1579.6
MOLDBOARD PLOW	6	260	2092.8	813.8	1615.6
MOLDBOARD PLOW	6	280	2369.0	1022.8	2040.0
MOLDBOARD PLOW	6	300	2502.4	1117.6	2410.0
CHISEL PLOW	1	0	419.4	263.0	186.8
CHISEL PLOW	1	20	596.4	294.0	385.6
CHISEL PLOW	1	40	811.0	321.8	614.4
CHISEL PLOW	1	60	1117.4	370.6	934.4
CHISEL PLOW	1	80	1553.8	443.0	1342.4
CHISEL PLOW	1	100	2052.4	512.8	1554.8

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
CHISEL PLOW	1	120	2409.2	575.6	1786.6
CHISEL PLOW	1	140	2622.6	663.2	2285.8
CHISEL PLOW	1	160	2641.8	801.0	2660.8
CHISEL PLOW	1	180	2607.0	1007.2	2774.0
CHISEL PLOW	1	200	2540.2	1153.6	2925.6
CHISEL PLOW	1	220	2498.4	1263.8	3088.2
CHISEL PLOW	1	240	2733.8	1503.4	3179.4
CHISEL PLOW	1	260	2943.0	1736.0	3353.2
CHISEL PLOW	1	280	2758.8	1879.4	3694.8
CHISEL PLOW	1	300	2470.4	1878.4	3697.6
CHISEL PLOW	2	0	259.0	295.2	231.0
CHISEL PLOW	2	20	408.2	332.8	374.6
CHISEL PLOW	2	40	558.8	407.0	705.6
CHISEL PLOW	2	60	737.2	486.4	1138.6
CHISEL PLOW	2	80	979.6	530.8	1464.0
CHISEL PLOW	2	100	1153.8	539.2	1717.8
CHISEL PLOW	2	120	1227.8	535.0	1817.0
CHISEL PLOW	2	140	1230.4	588.0	1883.0
CHISEL PLOW	2	160	1177.6	695.4	1850.0
CHISEL PLOW	2	180	1118.8	888.8	1935.4
CHISEL PLOW	2	200	1088.2	1088.4	2250.2
CHISEL PLOW	2	220	1082.6	1209.4	2536.8
CHISEL PLOW	2	240	1209.6	1476.8	2550.6
CHISEL PLOW	2	260	1371.0	1784.8	2522.8
CHISEL PLOW	2	280	1456.2	1846.2	2911.8
CHISEL PLOW	2	300	1430.8	1589.8	3030.4
CHISEL PLOW	3	0	300.8	169.8	209.4
CHISEL PLOW	3	20	528.0	218.8	460.2
CHISEL PLOW	3	40	1053.4	248.0	920.6
CHISEL PLOW	3	60	1513.0	268.8	1254.4
CHISEL PLOW	3	80	1729.2	288.4	1521.8
CHISEL PLOW	3	100	1833.8	303.4	1731.4
CHISEL PLOW	3	120	1899.2	365.0	1866.4
CHISEL PLOW	3	140	1881.0	529.4	1808.8
CHISEL PLOW	3	160	1805.8	779.0	1703.8
CHISEL PLOW	3	180	1746.0	889.0	1759.0
CHISEL PLOW	3	200	1728.0	1003.2	1882.8
CHISEL PLOW	3	220	1739.0	1091.0	2103.6
CHISEL PLOW	3	240	1896.2	1276.4	2197.6
CHISEL PLOW	3	260	1929.8	1649.8	2111.8
CHISEL PLOW	3	280	1683.4	2020.4	2043.0
CHISEL PLOW	3	300	1442.4	1999.6	2059.8
CHISEL PLOW	4	0	635.4	285.4	140.2
CHISEL PLOW	4	20	774.8	285.8	258.8
CHISEL PLOW	4	40	1050.6	291.2	523.4
CHISEL PLOW	4	60	1547.8	317.8	898.6
CHISEL PLOW	4	80	2035.8	363.4	1190.8
CHISEL PLOW	4	100	2272.6	406.8	1463.8
CHISEL PLOW	4	120	2311.8	423.4	1632.2
CHISEL PLOW	4	140	2250.4	457.0	1690.2
CHISEL PLOW	4	160	2140.4	568.6	1701.2

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
CHISEL PLOW	4	180	2122.0	804.0	1723.2
CHISEL PLOW	4	200	2072.0	1117.4	1618.2
CHISEL PLOW	4	220	2014.8	1330.8	1626.6
CHISEL PLOW	4	240	2221.0	1354.6	1593.4
CHISEL PLOW	4	260	2605.6	1453.4	1582.4
CHISEL PLOW	4	280	3062.6	1691.4	1814.2
CHISEL PLOW	4	300	3064.2	1811.6	1921.8
CHISEL PLOW	5	0	812.2	324.8	198.0
CHISEL PLOW	5	20	1109.2	381.8	366.2
CHISEL PLOW	5	40	1330.8	416.6	683.4
CHISEL PLOW	5	60	1479.6	443.0	967.4
CHISEL PLOW	5	80	1585.6	455.6	1439.0
CHISEL PLOW	5	100	1644.0	457.0	1894.0
CHISEL PLOW	5	120	1629.2	515.4	2263.4
CHISEL PLOW	5	140	1569.0	660.4	2517.4
CHISEL PLOW	5	160	1528.6	737.0	2644.4
CHISEL PLOW	5	180	1471.6	770.6	2674.6
CHISEL PLOW	5	200	1442.2	765.0	2641.4
CHISEL PLOW	5	220	1567.4	856.8	2578.2
CHISEL PLOW	5	240	2007.8	1103.6	2451.4
CHISEL PLOW	5	260	2257.4	1433.8	2407.2
CHISEL PLOW	5	280	2380.0	1642.8	2547.6
CHISEL PLOW	5	300	2522.2	1766.8	2964.2
CHISEL PLOW	6	0	468.4	172.6	206.2
CHISEL PLOW	6	20	627.0	214.6	297.4
CHISEL PLOW	6	40	988.0	262.0	462.8
CHISEL PLOW	6	60	1360.2	294.2	719.2
CHISEL PLOW	6	80	1698.2	331.4	948.2
CHISEL PLOW	6	100	1899.2	370.6	1177.0
CHISEL PLOW	6	120	1956.4	374.8	1279.4
CHISEL PLOW	6	140	1899.2	416.8	1483.2
CHISEL PLOW	6	160	1810.2	553.2	1681.8
CHISEL PLOW	6	180	1730.6	741.4	1822.4
CHISEL PLOW	6	200	1743.4	880.4	2073.4
CHISEL PLOW	6	220	1790.4	993.4	2307.8
CHISEL PLOW	6	240	1875.6	1124.4	2465.2
CHISEL PLOW	6	260	2226.8	1365.6	2296.8
CHISEL PLOW	6	280	2614.2	1573.2	2114.8
CHISEL PLOW	6	300	2533.2	1778.0	2114.8
CULTIVATOR	1	0	512.6	291.2	242.2
CULTIVATOR	1	20	744.0	426.6	471.0
CULTIVATOR	1	40	1070.4	630.0	893.2
CULTIVATOR	1	60	1454.8	981.0	1326.0
CULTIVATOR	1	80	1864.4	1561.8	1662.4
CULTIVATOR	1	100	2113.8	1952.2	2018.4
CULTIVATOR	1	120	2229.4	2127.8	2415.4
CULTIVATOR	1	140	2263.0	2118.0	2635.8
CULTIVATOR	1	160	2249.0	1982.8	2751.8
CULTIVATOR	1	180	2295.0	1847.6	2840.2
CULTIVATOR	1	200	2303.4	1715.4	2912.0
CULTIVATOR	1	220	2282.4	1626.2	2997.2

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
CULTIVATOR	1	240	2257.4	1732.0	2881.6
CULTIVATOR	1	260	2341.0	1945.0	2812.2
CULTIVATOR	1	280	2506.8	2193.4	2956.0
CULTIVATOR	1	300	2487.2	2180.4	2964.4
CULTIVATOR	2	0	278.6	303.8	256.0
CULTIVATOR	2	20	374.6	321.8	388.4
CULTIVATOR	2	40	536.4	346.8	490.2
CULTIVATOR	2	60	763.4	376.2	664.0
CULTIVATOR	2	80	943.2	402.6	1042.0
CULTIVATOR	2	100	949.0	434.8	1318.0
CULTIVATOR	2	120	939.2	676.0	1544.0
CULTIVATOR	2	140	950.2	940.6	1704.0
CULTIVATOR	2	160	914.2	1045.2	1808.6
CULTIVATOR	2	180	859.6	1068.8	1726.0
CULTIVATOR	2	200	811.0	1089.6	1717.8
CULTIVATOR	2	220	853.0	1117.4	1563.4
CULTIVATOR	2	240	955.8	1282.0	1538.4
CULTIVATOR	2	260	1055.0	1554.8	1601.8
CULTIVATOR	2	280	1191.2	1790.8	1896.8
CULTIVATOR	2	300	1190.0	1718.0	2015.6
CULTIVATOR	3	0	320.6	193.8	316.6
CULTIVATOR	3	20	508.6	249.4	553.6
CULTIVATOR	3	40	756.6	295.6	757.6
CULTIVATOR	3	60	1017.2	348.6	948.2
CULTIVATOR	3	80	1198.4	401.2	1224.0
CULTIVATOR	3	100	1310.0	441.6	1436.2
CULTIVATOR	3	120	1366.8	526.6	2018.2
CULTIVATOR	3	140	1378.0	912.6	2721.6
CULTIVATOR	3	160	1322.4	1305.6	2897.8
CULTIVATOR	3	180	1275.2	1456.0	2644.4
CULTIVATOR	3	200	1282.0	1439.4	2343.8
CULTIVATOR	3	220	1359.8	1371.0	1990.6
CULTIVATOR	3	240	1411.6	1315.4	1830.8
CULTIVATOR	3	260	1438.0	1517.6	1952.0
CULTIVATOR	3	280	1415.8	1750.2	2233.4
CULTIVATOR	3	300	1301.4	1652.2	2098.4
CULTIVATOR	4	0	884.8	241.2	222.8
CULTIVATOR	4	20	917.0	270.4	413.0
CULTIVATOR	4	40	1092.2	278.8	658.4
CULTIVATOR	4	60	1383.8	306.4	937.2
CULTIVATOR	4	80	1661.0	454.0	1168.8
CULTIVATOR	4	100	1980.2	748.2	1420.0
CULTIVATOR	4	120	2221.0	1152.4	1731.4
CULTIVATOR	4	140	2354.8	1481.2	1952.0
CULTIVATOR	4	160	2446.8	1567.6	2067.6
CULTIVATOR	4	180	2468.0	1542.6	2261.0
CULTIVATOR	4	200	2482.8	1555.0	2338.4
CULTIVATOR	4	220	2484.6	1517.2	2302.2
CULTIVATOR	4	240	2628.0	1444.8	2368.6
CULTIVATOR	4	260	2877.4	1411.8	2652.6
CULTIVATOR	4	280	3128.0	1761.6	3228.8

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
CULTIVATOR	4	300	3161.6	2023.2	3571.0
CULTIVATOR	5	0	668.8	238.2	212.0
CULTIVATOR	5	20	845.8	277.4	372.0
CULTIVATOR	5	40	1181.6	349.6	529.0
CULTIVATOR	5	60	1587.0	440.2	650.2
CULTIVATOR	5	80	1840.8	668.8	757.8
CULTIVATOR	5	100	1898.0	937.8	997.8
CULTIVATOR	5	120	1829.4	1032.6	1127.4
CULTIVATOR	5	140	1779.4	1082.4	1271.0
CULTIVATOR	5	160	1649.6	1110.6	1386.8
CULTIVATOR	5	180	1545.2	1065.8	1626.8
CULTIVATOR	5	200	1503.4	988.0	1720.4
CULTIVATOR	5	220	1513.4	1011.6	1684.6
CULTIVATOR	5	240	1730.6	1304.0	1761.6
CULTIVATOR	5	260	2203.0	1786.4	1756.4
CULTIVATOR	5	280	2353.4	2023.2	1894.4
CULTIVATOR	5	300	2183.4	1900.6	2448.4
CULTIVATOR	6	0	575.4	273.0	151.2
CULTIVATOR	6	20	794.4	344.0	281.0
CULTIVATOR	6	40	1017.2	428.0	484.8
CULTIVATOR	6	60	1355.6	604.8	708.2
CULTIVATOR	6	80	1772.6	894.6	984.0
CULTIVATOR	6	100	1967.6	1172.0	1221.2
CULTIVATOR	6	120	2013.2	1298.8	1436.4
CULTIVATOR	6	140	1960.6	1245.6	1855.4
CULTIVATOR	6	160	1900.4	1200.8	2407.0
CULTIVATOR	6	180	1807.4	1227.6	2578.2
CULTIVATOR	6	200	1780.8	1213.4	2404.4
CULTIVATOR	6	220	1747.4	1187.2	2258.0
CULTIVATOR	6	240	1684.6	1324.8	2076.0
CULTIVATOR	6	260	1641.6	1622.0	2054.0
CULTIVATOR	6	280	1925.6	1776.6	2302.2
CULTIVATOR	6	300	2188.8	1698.6	2470.6
TANDEM DISK	1	0	423.4	307.6	308.6
TANDEM DISK	1	20	565.8	381.8	471.2
TANDEM DISK	1	40	749.8	558.6	686.2
TANDEM DISK	1	60	1107.6	861.0	1069.6
TANDEM DISK	1	80	1397.6	1277.8	1624.0
TANDEM DISK	1	100	1704.0	1828.0	2095.6
TANDEM DISK	1	120	1967.6	2218.4	2685.6
TANDEM DISK	1	140	2048.2	2363.2	3099.4
TANDEM DISK	1	160	2047.0	2402.2	3121.4
TANDEM DISK	1	180	2017.4	2332.6	2920.0
TANDEM DISK	1	200	2027.4	2204.2	2638.6
TANDEM DISK	1	220	2180.8	2140.2	2437.4
TANDEM DISK	1	240	2353.6	2148.6	2421.0
TANDEM DISK	1	260	2482.8	2040.0	2492.6
TANDEM DISK	1	280	2452.6	2005.0	2547.6
TANDEM DISK	1	300	2389.8	2037.0	2801.6
TANDEM DISK	2	0	614.2	437.6	352.4
TANDEM DISK	2	20	755.2	579.6	598.0

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
TANDEM DISK	2	40	958.8	707.8	956.4
TANDEM DISK	2	60	1124.6	833.2	1375.8
TANDEM DISK	2	80	1146.8	1103.4	1601.8
TANDEM DISK	2	100	1121.6	1367.2	1753.2
TANDEM DISK	2	120	1085.2	1425.6	1864.0
TANDEM DISK	2	140	1054.8	1323.8	1858.4
TANDEM DISK	2	160	1047.8	1181.6	1814.4
TANDEM DISK	2	180	1006.0	1063.0	1745.2
TANDEM DISK	2	200	1078.4	1082.8	1773.0
TANDEM DISK	2	220	1204.0	1208.0	1668.0
TANDEM DISK	2	240	1435.2	1329.0	1715.0
TANDEM DISK	2	260	1624.8	1531.4	2169.8
TANDEM DISK	2	280	1771.0	1698.6	2589.0
TANDEM DISK	2	300	1751.4	1666.4	2945.0
TANDEM DISK	3	0	604.8	203.2	167.8
TANDEM DISK	3	20	857.0	246.6	330.4
TANDEM DISK	3	40	1085.6	329.0	490.4
TANDEM DISK	3	60	1280.4	413.8	735.8
TANDEM DISK	3	80	1396.2	571.2	1053.2
TANDEM DISK	3	100	1428.2	925.2	1499.6
TANDEM DISK	3	120	1383.8	1335.0	1993.2
TANDEM DISK	3	140	1283.4	1545.4	2523.2
TANDEM DISK	3	160	1194.2	1597.2	2707.8
TANDEM DISK	3	180	1176.2	1574.4	2798.8
TANDEM DISK	3	200	1220.8	1573.0	2589.2
TANDEM DISK	3	220	1333.6	1538.4	2332.8
TANDEM DISK	3	240	1471.4	1428.2	2040.4
TANDEM DISK	3	260	1638.8	1355.6	1908.0
TANDEM DISK	3	280	1556.4	1491.0	1866.8
TANDEM DISK	3	300	1313.8	1651.2	1935.4
TANDEM DISK	4	0	398.6	478.0	368.8
TANDEM DISK	4	20	497.2	660.4	611.8
TANDEM DISK	4	40	691.0	961.4	826.8
TANDEM DISK	4	60	1018.6	1315.4	1075.0
TANDEM DISK	4	80	1407.4	1615.2	1596.2
TANDEM DISK	4	100	1789.0	1762.6	2070.6
TANDEM DISK	4	120	2049.6	1808.6	2407.0
TANDEM DISK	4	140	2214.0	1811.4	2503.6
TANDEM DISK	4	160	2308.8	1772.2	2528.4
TANDEM DISK	4	180	2360.4	1856.2	2475.8
TANDEM DISK	4	200	2388.6	2169.6	2352.0
TANDEM DISK	4	220	2555.4	2603.0	2286.0
TANDEM DISK	4	240	2967.8	2923.4	2506.2
TANDEM DISK	4	260	3373.6	2813.2	3146.2
TANDEM DISK	4	280	3411.0	2412.0	3413.8
TANDEM DISK	4	300	3195.2	1928.4	2969.8
TANDEM DISK	5	0	668.8	336.0	214.6
TANDEM DISK	5	20	859.4	458.4	471.2
TANDEM DISK	5	40	1149.4	684.0	620.2
TANDEM DISK	5	60	1350.4	938.0	719.2
TANDEM DISK	5	80	1447.6	1183.0	893.0

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
TANDEM DISK	5	100	1490.8	1367.0	1271.2
TANDEM DISK	5	120	1554.0	1457.6	1651.4
TANDEM DISK	5	140	1517.2	1442.2	1985.2
TANDEM DISK	5	160	1453.4	1368.4	2134.2
TANDEM DISK	5	180	1494.8	1252.8	2081.4
TANDEM DISK	5	200	1634.8	1218.0	1990.6
TANDEM DISK	5	220	1861.4	1426.8	1996.0
TANDEM DISK	5	240	2088.6	1708.4	2021.0
TANDEM DISK	5	260	2123.6	1807.0	2029.4
TANDEM DISK	5	280	2166.6	1751.4	2680.2
TANDEM DISK	5	300	2276.6	1655.4	3264.8
TANDEM DISK	6	0	602.0	356.8	374.6
TANDEM DISK	6	20	744.0	419.4	496.0
TANDEM DISK	6	40	1003.2	592.0	589.4
TANDEM DISK	6	60	1443.8	982.4	945.4
TANDEM DISK	6	80	1778.0	1365.6	1406.2
TANDEM DISK	6	100	1948.0	1658.2	1797.4
TANDEM DISK	6	120	2020.2	1811.2	2288.4
TANDEM DISK	6	140	2069.2	1817.2	2487.2
TANDEM DISK	6	160	2037.2	1780.8	2453.8
TANDEM DISK	6	180	1956.2	1729.4	2410.0
TANDEM DISK	6	200	1863.0	1627.4	2263.6
TANDEM DISK	6	220	1804.4	1602.4	2247.4
TANDEM DISK	6	240	2034.4	1714.0	2285.8
TANDEM DISK	6	260	2214.0	1873.0	2404.4
TANDEM DISK	6	280	2265.6	1737.4	2716.0
TANDEM DISK	6	300	2118.0	1434.0	2903.4
SHOVEL IN A ROW	1	0	202.0	322.0	520.8
SHOVEL IN A ROW	1	20	239.6	414.0	576.0
SHOVEL IN A ROW	1	40	270.4	622.8	890.0
SHOVEL IN A ROW	1	60	390.2	965.6	1196.4
SHOVEL IN A ROW	1	80	691.2	1346.2	1356.2
SHOVEL IN A ROW	1	100	982.6	1713.8	1571.4
SHOVEL IN A ROW	1	120	1238.6	1924.4	1814.0
SHOVEL IN A ROW	1	140	1634.6	1960.4	2059.6
SHOVEL IN A ROW	1	160	2062.4	1925.8	2189.0
SHOVEL IN A ROW	1	180	2233.6	1868.8	2233.2
SHOVEL IN A ROW	1	200	2265.4	1787.6	2109.4
SHOVEL IN A ROW	1	220	2306.2	1772.4	2092.6
SHOVEL IN A ROW	1	240	2350.8	1895.0	2263.8
SHOVEL IN A ROW	1	260	2425.8	2189.0	2591.8
SHOVEL IN A ROW	1	280	2516.8	2438.4	2895.0
SHOVEL IN A ROW	1	300	2559.8	2306.2	2955.6
SHOVEL IN A ROW	2	0	412.8	387.2	302.8
SHOVEL IN A ROW	2	20	558.8	458.4	424.2
SHOVEL IN A ROW	2	40	811.0	564.4	526.2
SHOVEL IN A ROW	2	60	997.8	699.4	697.0
SHOVEL IN A ROW	2	80	1055.0	774.6	928.6
SHOVEL IN A ROW	2	100	1078.6	876.4	1130.2
SHOVEL IN A ROW	2	120	1081.4	1017.2	1290.0
SHOVEL IN A ROW	2	140	1070.2	1088.2	1428.0

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
SHOVEL IN A ROW	2	160	1028.4	1088.0	1370.0
SHOVEL IN A ROW	2	180	990.8	1132.8	1372.8
SHOVEL IN A ROW	2	200	978.2	1148.2	1543.8
SHOVEL IN A ROW	2	220	986.6	1168.8	1629.4
SHOVEL IN A ROW	2	240	1010.2	1268.0	1748.2
SHOVEL IN A ROW	2	260	1316.8	1528.6	1941.0
SHOVEL IN A ROW	2	280	1549.4	1889.4	2338.2
SHOVEL IN A ROW	2	300	1524.2	1778.0	2506.4
SHOVEL IN A ROW	3	0	337.2	564.2	338.6
SHOVEL IN A ROW	3	20	472.4	744.2	462.8
SHOVEL IN A ROW	3	40	728.6	903.2	667.0
SHOVEL IN A ROW	3	60	932.0	1219.0	950.8
SHOVEL IN A ROW	3	80	1060.4	1539.6	1425.2
SHOVEL IN A ROW	3	100	1153.6	1812.8	1908.0
SHOVEL IN A ROW	3	120	1137.2	2123.2	2203.0
SHOVEL IN A ROW	3	140	1089.6	2258.6	2225.0
SHOVEL IN A ROW	3	160	1056.0	2150.0	2054.0
SHOVEL IN A ROW	3	180	1056.2	1918.8	1869.4
SHOVEL IN A ROW	3	200	1081.2	1673.6	1814.2
SHOVEL IN A ROW	3	220	1283.4	1517.4	1736.8
SHOVEL IN A ROW	3	240	1438.0	1527.2	1728.6
SHOVEL IN A ROW	3	260	1380.8	1727.8	1960.6
SHOVEL IN A ROW	3	280	1280.4	1949.6	2260.8
SHOVEL IN A ROW	3	300	1181.4	2119.2	2382.2
SHOVEL IN A ROW	4	0	596.4	405.6	192.6
SHOVEL IN A ROW	4	20	662.0	530.8	330.2
SHOVEL IN A ROW	4	40	897.4	667.6	479.4
SHOVEL IN A ROW	4	60	1287.4	834.8	744.2
SHOVEL IN A ROW	4	80	1732.0	1205.4	1119.4
SHOVEL IN A ROW	4	100	2031.4	1513.2	1384.2
SHOVEL IN A ROW	4	120	2143.2	1637.0	1789.6
SHOVEL IN A ROW	4	140	2103.8	1674.6	2211.4
SHOVEL IN A ROW	4	160	2008.0	1680.6	2421.0
SHOVEL IN A ROW	4	180	1922.8	1665.2	2578.2
SHOVEL IN A ROW	4	200	1924.0	1608.0	2583.6
SHOVEL IN A ROW	4	220	2020.4	1559.4	2487.0
SHOVEL IN A ROW	4	240	2157.0	1566.0	2305.0
SHOVEL IN A ROW	4	260	2327.0	1775.4	2065.0
SHOVEL IN A ROW	4	280	2404.8	2156.8	1935.6
SHOVEL IN A ROW	4	300	2381.6	2353.6	2225.2
SHOVEL IN A ROW	5	0	554.4	401.2	286.2
SHOVEL IN A ROW	5	20	716.2	466.6	523.4
SHOVEL IN A ROW	5	40	926.6	549.0	857.4
SHOVEL IN A ROW	5	60	1170.4	778.8	1097.0
SHOVEL IN A ROW	5	80	1334.6	1007.2	1262.4
SHOVEL IN A ROW	5	100	1466.0	1190.0	1601.8
SHOVEL IN A ROW	5	120	1498.0	1197.0	1985.2
SHOVEL IN A ROW	5	140	1478.2	1141.4	2071.0
SHOVEL IN A ROW	5	160	1443.6	1092.4	2034.8
SHOVEL IN A ROW	5	180	1438.0	1068.8	2098.2
SHOVEL IN A ROW	5	200	1418.6	1066.0	2051.4

TILLAGE IMPLEMENT	BLOCK	DEPTH	CONE INDEX BEFORE TILLAGE	AFTER TILLAGE	AFTER HARVEST
SHOVEL IN A ROW	5	220	1429.6	1203.8	2059.4
SHOVEL IN A ROW	5	240	1577.2	1439.4	2236.0
SHOVEL IN A ROW	5	260	1842.0	1669.2	2713.2
SHOVEL IN A ROW	5	280	2120.6	1876.8	2727.2
SHOVEL IN A ROW	5	300	2070.6	1800.2	2878.8
SHOVEL IN A ROW	6	0	572.8	416.8	189.8
SHOVEL IN A ROW	6	20	865.2	541.8	465.4
SHOVEL IN A ROW	6	40	1158.0	787.2	672.4
SHOVEL IN A ROW	6	60	1537.0	1145.6	912.4
SHOVEL IN A ROW	6	80	1814.2	1495.2	1323.2
SHOVEL IN A ROW	6	100	2021.8	1677.6	2026.6
SHOVEL IN A ROW	6	120	2166.6	1858.8	2663.6
SHOVEL IN A ROW	6	140	2186.4	1952.0	2928.2
SHOVEL IN A ROW	6	160	2155.6	1970.2	3066.4
SHOVEL IN A ROW	6	180	2025.8	1936.8	3080.0
SHOVEL IN A ROW	6	200	1918.8	1892.2	3107.8
SHOVEL IN A ROW	6	220	1970.4	1915.8	2994.4
SHOVEL IN A ROW	6	240	2140.2	1971.8	2845.4
SHOVEL IN A ROW	6	260	2438.2	2137.4	2727.0
SHOVEL IN A ROW	6	280	2464.8	2042.6	2740.8
SHOVEL IN A ROW	6	300	2226.6	1771.0	2685.8

APPENDIX B

MEAN SOIL MOISTURE CONTENT BEFORE TILLAGE, AFTER TILLAGE AND AFTER HARVEST

	Depth-cm	Plow	Chisel	Cultivator	Disk	Shovel
Before	0-8	13.4	13.6	13.9	13.3	13.0
Primary	8-15	15.6	15.1	15.1	15.1	14.9
Tillage	15-23	16.0	15.3	15.4	15.4	15.9
	23-30	16.2	15.8	15.7	16.0	16.4
	30-38	16.7	16.5	16.7	16.6	17.1
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Average		15.6	15.3	15.4	15.3	15.5
One	0-8	14.2	14.5	13.7	13.7	13.5
Month	8-15	17.6	16.5	17.0	15.7	14.7
After	15-23	19.0	17.3	17.1	16.7	16.3
Primary	23-30	19.4	17.1	17.3	17.0	16.8
Tillage	30-38	19.0	17.7	18.1	17.6	17.6
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Average		17.8	16.7	16.7	16.2	15.8
One	0-8	16.1	16.1	15.9	15.8	16.1
Week	8-15	16.2	15.4	15.4	15.8	15.6
After	15-23	16.5	15.4	15.3	15.9	15.3
Harvest	23-30	16.5	15.5	15.3	16.1	15.4
	30-38	16.2	15.6	15.1	15.9	15.6
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Average		16.3	15.6	15.4	15.9	15.6

All data given as mean soil moisture content on a percent dry basis.

APPENDIX C

COTTON PLANT MEASUREMENTS

TILLAGE IMPLEMENT	BLOCK	15 DAYS	21 DAYS	BEFORE HARVEST	HEIGHT	WIDTH	LOW BOLL
MOLDBOARD PLOW	1	21	24	24	66	28	18
		25	30	28	36	10	18
MOLDBOARD PLOW	2	26	30	28	61	15	15
		28	28	25	74	30	25
MOLDBOARD PLOW	3	29	32	30	61	23	18
		22	27	25	58	43	20
MOLDBOARD PLOW	4	24	33	33	51	15	28
		23	30	23	69	15	43
MOLDBOARD PLOW	5	24	27	24	41	23	36
		31	32	32	38	20	22
MOLDBOARD PLOW	6	24	29	27	58	25	43
		28	33	32	46	23	13
CHISEL PLOW	1	21	30	31	45	41	18
		18	24	23	66	41	41
CHISEL PLOW	2	23	33	29	61	41	10
		33	33	29	58	28	13
CHISEL PLOW	3	35	39	31	53	30	20
		32	34	33	56	43	28
CHISEL PLOW	4	25	30	28	51	23	8
		28	33	14	41	15	25
CHISEL PLOW	5	26	32	31	46	28	23
		35	40	38	41	23	31
CHISEL PLOW	6	28	33	31	56	41	30
		43	43	43	41	23	15
CULTIVATOR	1	26	30	30	48	15	30
		27	32	30	61	36	13
CULTIVATOR	2	25	22	19	56	10	33
		30	30	29	36	10	25
CULTIVATOR	3	35	39	31	53	30	20
		32	34	33	56	43	38
CULTIVATOR	4	25	28	25	66	45	18
		30	37	35	66	20	28
CULTIVATOR	5	18	29	29	58	25	43
		22	28	26	41	20	15
CULTIVATOR	6	28	29	29	38	15	33
		31	32	20	56	28	23
TANDEM DISK	1	25	25	24	51	18	30
		30	35	34	58	25	13
TANDEM DISK	2	22	28	26	76	25	25
		21	31	28	43	25	18
TANDEM DISK	3	12	28	28	30	13	15
		21	28	26	64	15	36
TANDEM DISK	4	23	28	28	38	15	37
		24	25	15	36	23	25
TANDEM DISK	5	26	29	28	36	15	20
		29	29	24	45	23	10
TANDEM DISK	6	20	23	21	30	10	20
		23	26	26	41	10	18

TILLAGE IMPLEMENT	BLOCK	15 DAYS	21 DAYS	BEFORE HARVEST	HEIGHT	WIDTH	LOW BOLL
SHOVEL IN A ROW	1	19	25	24	56	36	13
		25	33	33	36	28	33
SHOVEL IN A ROW	2	28	34	34	30	25	20
		30	32	30	51	36	30
SHOVEL IN A ROW	3	28	28	24	56	30	25
		31	27	25	56	25	18
SHOVEL IN A ROW	4	14	14	12	33	28	15
		25	28	24	48	33	18
SHOVEL IN A ROW	5	21	25	25	38	30	10
		30	37	34	48	28	23
SHOVEL IN A ROW	6	25	30	28	30	20	13
		30	37	36	30	23	15

All plant count data (columns 2,3 and 4) measured as number of plants in rows 3 and 4 for 3 meters of row length.

All plant measurements data (columns 5,6 and 7) is given in centimeters and was obtained from the fifth plant from the north end of each plot on rows 3 and 4.

APPENDIX D

PERCENTAGE OF SEED COTTON IN HARVESTED COTTON

TILLAGE IMPLEMENT	BLOCK	% SEED COTTON
MOLDBOARD PLOW	1	49.9
MOLDBOARD PLOW	2	42.0
MOLDBOARD PLOW	3	41.1
MOLDBOARD PLOW	4	49.5
MOLDBOARD PLOW	5	51.1
MOLDBOARD PLOW	6	48.0
CHISEL PLOW	1	52.2
CHISEL PLOW	2	52.5
CHISEL PLOW	3	48.0
CHISEL PLOW	4	56.0
CHISEL PLOW	5	53.8
CHISEL PLOW	6	51.2
CULTIVATOR	1	52.0
CULTIVATOR	2	49.4
CULTIVATOR	3	52.3
CULTIVATOR	4	57.8
CULTIVATOR	5	56.2
CULTIVATOR	6	55.8
TANDEM DISK	1	55.4
TANDEM DISK	2	41.7
TANDEM DISK	3	44.6
TANDEM DISK	4	51.1
TANDEM DISK	5	57.1
TANDEM DISK	6	59.2
SHOVEL IN A ROW	1	54.9
SHOVEL IN A ROW	2	37.7
SHOVEL IN A ROW	3	41.6
SHOVEL IN A ROW	4	54.0
SHOVEL IN A ROW	5	53.8
SHOVEL IN A ROW	6	54.7

APPENDIX E

HARVESTED WEIGHT OF COTTON

TILLAGE IMPLEMENT	BLOCK	HARVESTED WEIGHT (kg)
MOLDBOARD PLOW	1	751.0
MOLDBOARD PLOW	2	789.0
MOLDBOARD PLOW	3	761.0
MOLDBOARD PLOW	4	560.3
MOLDBOARD PLOW	5	500.6
MOLDBOARD PLOW	6	510.7
CHISEL PLOW	1	781.0
CHISEL PLOW	2	730.9
CHISEL PLOW	3	801.0
CHISEL PLOW	4	600.8
CHISEL PLOW	5	630.8
CHISEL PLOW	6	440.6
CULTIVATOR	1	710.9
CULTIVATOR	2	721.0
CULTIVATOR	3	660.8
CULTIVATOR	4	550.7
CULTIVATOR	5	670.9
CULTIVATOR	6	560.7
TANDEM DISK	1	620.8
TANDEM DISK	2	470.6
TANDEM DISK	3	520.7
TANDEM DISK	4	380.5
TANDEM DISK	5	520.3
TANDEM DISK	6	480.6
SHOVEL IN A ROW	1	620.8
SHOVEL IN A ROW	2	360.5
SHOVEL IN A ROW	3	400.5
SHOVEL IN A ROW	4	460.6
SHOVEL IN A ROW	5	440.6
SHOVEL IN A ROW	6	380.4

APPENDIX F

MEASURED PULL, SPEED, RPM AND SLIP FOR EACH TILLAGE IMPLEMENT AND BLOCK

TILLAGE IMPLEMENT	BLOCK	PULL (kN)	SPEED (km/h)	RPM	SLIP (%)
MOLDBOARD PLOW	1	21.00	6.82	2118.6	17.62
MOLDBOARD PLOW	2	23.52	6.83	2189.4	20.13
MOLDBOARD PLOW	3	22.39	6.34	2098.8	18.79
MOLDBOARD PLOW	4	21.89	6.88	2125.8	17.13
MOLDBOARD PLOW	5	22.07	6.78	2164.8	17.71
MOLDBOARD PLOW	6	21.08	6.40	2100.6	21.83
CHISEL PLOW	1	24.39	5.71	2336.9	23.12
CHISEL PLOW	2	22.75	5.66	2346.4	23.92
CHISEL PLOW	3	26.72	5.50	2324.8	25.67
CHISEL PLOW	4	24.07	5.56	2341.1	25.29
CHISEL PLOW	5	22.52	5.56	2332.5	24.58
CHISEL PLOW	6	26.69	4.84	2315.4	34.03
CULTIVATOR	1	11.30	8.31	2385.0	11.04
CULTIVATOR	2	18.81	7.59	2320.9	16.62
CULTIVATOR	3	20.55	7.32	2265.1	17.87
CULTIVATOR	4	19.31	7.30	2290.3	19.00
CULTIVATOR	5	21.76	6.97	2239.0	20.76
CULTIVATOR	6	16.44	7.81	2348.7	15.17
TANDEM DISK	1	15.93	7.88	2365.3	15.14
TANDEM DISK	2	17.05	8.06	2367.6	13.12
TANDEM DISK	3	19.16	7.73	2350.7	16.11
TANDEM DISK	4	18.23	7.29	2338.2	20.75
TANDEM DISK	5	18.84	7.27	2344.7	20.98
TANDEM DISK	6	18.63	7.84	2352.9	15.08
SHOVEL IN A ROW	1	11.43	6.99	2157.8	15.98
SHOVEL IN A ROW	2	15.57	6.83	2141.8	16.97
SHOVEL IN A ROW	3	13.72	7.38	2220.4	13.41
SHOVEL IN A ROW	4	13.97	7.16	2215.7	16.22
SHOVEL IN A ROW	5	14.68	6.90	2147.0	16.43
SHOVEL IN A ROW	6	15.34	6.85	2155.2	17.35

VITA 2

Kelvin Paul Self

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF FIVE PRIMARY TILLAGE IMPLEMENTS ON SOIL STRENGTH, ENERGY REQUIREMENTS AND YIELD FOR COTTON PRODUCTION IN OKLAHOMA

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