This is to certify that the

thesis entitled

Evaluation of Energy Requirements for Conservation Tillage Systems in Michigan

presented by

George S N Mungai

has been accepted towards fulfillment of the requirements for

M.S. degree in Ag. Tech.&Sys. Mgt.

Thomas H Burkhardt
Major professor

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Evaluation of Energy Requirements for Conservation Tillage Systems in Michigan

by

George S N Mungai

A THESIS

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ABSTRACT

Evaluation of Energy Requirements for Conservation Tillage Systems in Michigan

by

George S N Mungai

Evaluation of three tillage systems was performed in Michigan to determine the relative performance of conventional and conservation tillage systems from the stand point of fuel and energy consumption. The three systems included: moldboard plow-based tillage system, chisel plow-based tillage system, and no-till tillage system. The tests were carried out in Owosso-Marlette sandy loam soil, Metamora-Capac sandy loam soil, Capac loam soil and Palms muck soil. Primary and secondary tillage as well as planting operations were conducted during the Summer and Fall of 1989 and 1990.

The data obtained using a microcomputer based data acquisition system showed that the moldboard plow-based conventional tillage system demanded higher fuel (L/ha and L/kWh) and energy (kWh/ha) input than the chisel plow-based conservation tillage system. However, the chisel plow required higher draft than the moldboard plow for the same width of operation. The chisel plow would therefore require a larger tractor than the moldboard plow for the same width. The no-till tillage systems using row crop planters and grain drills provided the most fuel and energy savings when compared with the conventional tillage and conservation tillage systems.

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MSU is an Affirmative Action/Equal Opportunity Institution

To my beloved wife Anne

and daughters, Catherine, Caroline,

Lilian and Pauline.

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CHAPTER 1

INTRODUCTION

For about two decades, research efforts in tillage have been directed to either using renewable energy resources or increasing the efficiency of using fossil fuels to reduce crop production costs. Developing new fuel resources for farm machinery has not been technically or economically successful; therefore, diesel fuel may continue as the dominant fuel for many years. Much work in tillage energy research has been done using fuel consumption and draft requirement as the indicators of performance. While these measurements give a valid indication of energy used for a particular combination of equipment and soil conditions, they are limited to a regional application. It is difficult to transfer the results to the general case (Smith and Barker, 1982) and therefore, it is necessary to conduct experiments in various areas to establish the local tillage energy needs.

Tillage has been considered as one of the major energy and power consumers at the farm level. Farmers often use the drawbar power requirement of tillage to determine the size of the largest tractor for the farm. The moldboard plow has traditionally been used as the basic implement for primary tillage followed by several secondary tillage operations. Moldboard plow-based tillage systems have generally been considered to have a high energy consumption level. This has lead to research efforts being directed to collecting energy data to verify this assumption. These efforts are aimed at formulating alternative energy-saving systems. Conservation tillage systems, which have the potential to reduce tillage energy requirements, field time, labor input, soil compaction, degradation of environment, and soil and water loss have been considered as an alternative approach to conventional tillage. The research conducted for this project was designed to evaluate conventional, conservation, and no-till tillage systems from the perspective of energy and power demand.

Many factors contribute to the energy used in tillage. The soil type and condition, depth of tillage, speed of operation, and hitch geometry are some of the important factors (Kepner et al., 1980). Draft and energy requirements of tillage tools are an important consideration in selecting optimal tillage systems (Khalilian et al., 1988). The research conducted during the last two summers by the Department of Agricultural Engineering at Michigan State University (MSU) and near St. Johns in Clinton County, Michigan, compared the energy and power requirements of a moldboard plow-based, chisel plow-based and no-till tillage systems. Tractor fuel consumption and implement draft were the primary data collected using an in-field microcomputer data acquisition system.

CHAPTER 2

LITERATURE REVIEW

2.1 Conventional versus Conservation Tillage Systems

The amount of energy expended in preparing a suitable seedbed depends on the tillage system used. Field operations can be achieved with various combinations of machines which result in different basic energy requirements. (Frisby and Summers, 1978). In conventional tillage practices, the farmer usually plows, disks twice, spring tooth harrows, plants the crop and cultivates at least twice (Hansen et al., 1958). This amounts to about 6 to 10 trips across the field resulting in excessive soil compaction and high cost in time and money. This system of tillage has evolved over the years since human beings first opened the soil to plant seeds, without a sound scientific basis to justify it. Bowers and Bateman (1960) in their research studies on minimum tillage questioned the necessity of each additional tillage on the basis of its contribution to weed control, soil and wind erosion, crop yield and production cost.

Stone and Heslop (1986) compared three tillage systems; they observed that the use of moldboard plow-based tillage systems resulted in gradual deterioration of soil structure.

Cook et al. (1958) in their research on minimum tillage conducted since 1946 showed that secondary tillage was not necessary as plow-planting or wheel-track planting were successful in establishing crop stands that needed only two weed control cultivations after planting. With the advent of chemical weed control, experiments with no-till planting (direct drilling) have shown that mechanical manipulation of the soil can be eliminated under some field conditions without adversely affecting the crop yield. No-till planting also offers other generally obtainable advantages: improved water conservation, reduced soil erosion, reduced machinery cost, lower labor input and in some instances increased yields (Smith and Fornstrom, 1980). Erbach (1982) concluded that tillage systems did not significantly affect yields of either corn or soybeans in a corn soybean rotation research study.

Zhengping et al. (1986) conducted research on machine width for time and fuel efficiency and concluded that conservation tillage systems reduced machinery cost. This view is further supported by Kushwaha et al. (1986) who asserted that minimum tillage systems have considerable potential for saving energy and time as well as controlling wind and water erosion. In his research on a comparison of the energy input in some tillage tools, Reid (1978) found out that no-till or reduced tillage is often promoted because these methods usually require about one-third to one-half of the fuel used in conventional tillage.

Bolton and Booster (1980) carried out research on strip-till planting system from which they concluded that grain yields compared favorably with those obtained using conventional bare fallow and stubble mulch tillage systems, each of which involved four times as many field operations.

Due to the changing trends of energy cost and availability during the last two decades, the need for reviewing energy input in agricultural production has become an important issue. Rotz et al. (1982) developed a multiple crop machinery selection algorithm through which they concluded that the cost per hectare for conservation tillage was always less than that of conventional tillage. It was also shown that due to less competition for time, conservation tillage implements were often smaller and thus better matched to the farm.

Conservation tillage systems have been experimented with to establish methods that are less energy demanding and more environmentally sound while providing agronomically acceptable seedbeds. Smith et al. (1980) assert that though there are many areas where today's farmer could conserve energy, a very important one is energy consumed in field operations. The availability of more efficient herbicides as well as the rising fuel and labor costs have given conservation tillage systems a big boost during the last few years (Khalilian et al., 1988). Hamlett et al. (1983) in their research on the economic potential of conservation tillage in Iowa concluded that conservation tillage practices in crop production save soil, lower energy consumption, and reduce machinery investment.

The moldboard plow is the most widely used primary tillage implement. Various researchers have carried out field tests to compare the energy requirements of moldboard plow-based tillage systems with conservation tillage systems. Michel et al. (1985) used the hypothesis that the chisel plow requires less time and energy per unit area than does the moldboard plow when they were comparing the performance of the two plows. They took this premise because the chisel plow does not move and invert the soil as the moldboard plow does. They concluded that the chisel plow-based system produced equal yields with approximately 40 per cent less fuel and less time for pre-plant tillage operations when working in irrigated sugarbeets, dry beans and corn. Similar experiments conducted by Smith et al. (1989) showed that reduced tillage systems can substantially reduce the total fuel and energy requirements for field operations as compared to the conventional moldboard plow tillage system. They found that a minimum tillage system which was designed to have minimal preplant field operations, used almost 70 percent less fuel and energy than the moldboard plow system.

Heavy duty tandem disk harrows have recently been tested for use as primary tillage implements because of the reduced labor and energy requirements and the high work rate associated with the disk harrow systems (Krishnan et al. 1988; Singh Jai, 1978).

2.2 Alternative Energy Sources

According to Stout (1990) the energy required for production agriculture is about 3 per cent and 5 to 6 per cent of the national energy needs in developed and developing countries, respectively. Stout (1977) has also shown that about 20 per cent of this energy is used in field operations. The energy used on farms is predominantly petroleum based. Although testing ethanol use in spark-ignition engines has shown positive results, a majority of farms are equipped with diesel powered farm machinery and this trend is increasing (Shannon, 1982; Yahya and Goering, 1977).

Efforts to find effective renewable sources of energy to replace diesel fuel for farm machinery have not met with much success (Boruff et al., 1980). Shropshire et al. (1982) performed research on the injection of anhydrous ethanol into a diesel engine. The experiment resulted in degradation of qualities of diesel fuel such as cetane number, viscosity, and volumetric energy content. Although up to 20 per cent of ethanol could be tolerated, the major problem was one of water tolerance as small amounts of water caused ethanol and petroleum fractions to separate. They also observed that the use of diesel engines is not likely to change quickly since diesel fuel is presently available and is cheaper than ethanol. Marcio Cruz et al. (1981) in their research on dual-fueling turbocharged diesels with ethanol concluded that ethanol can be used successfully to displace a portion of the normal fuel requirements for a diesel tractor. Their findings were not without reservations as they recommended that further testing was required to determine the long term effect on engine wear and durability. Fumigation is another method of blending ethanol with diesel fuel resulting in diesohol. This involves keeping the ethanol in a separate tank on the tractor and injecting it into the airstream of the engine (Goering and Wood 1982). This approach implies major changes in the design of the tractor fuel system.

Shannon et al. (1982) experimented with butanediol, a biomass-derived alcohol, to determine the possibility of complete displacement of No. 2 diesel fuel in tractors. Their results showed that a large portion of energy escaped through the exhaust as unburned fuel. In conclusion, butanediol was found to be an unacceptable substitute for diesel fuel for various reasons which included reduction in engine power.

The feasibility of replacing fossil fuels in agricultural production in order to reduce energy cost appears to be a distant solution which requires more research work. The use of diesel fuel in farm machinery may continue for many years to come. Therefore, the most viable proposition in curtailing energy use in field operations is to reduce the number of field trips by using conservation tillage systems to obtain high energy-use efficiency. This approach is supported by Summer et al. (1986) who observed that recent escalation of fuel prices and reduction of farm income has stimulated renewed interest in proper selection and operation of tractor implement systems that provide maximum energy efficiency.

2.3 Energy and Power Consumption in Tillage

Energy consumption for crop production takes many forms. A complete catalogue of energy used in crop production includes: labor, machinery manufacturing, fuel, nitrogen, phosphorus, potassium, seed, irrigation (if required), insecticides, herbicides, grain drying, electricity, and transportation (Clark and Johnson 1974). Clark and Johnson (1974) emphasized that evaluation of crop production systems should be based on energy use and power consumption among other factors. The direct consumption of petroleum based fuels by farm machinery has been the subject of considerable study. This has been done through instrumenting a tractor to measure draft, fuel flow, and other parameters under controlled conditions (Schrock et al. 1984).

The design of this research was to compare conventional, conservation and no-till tillage systems from the point of view of energy and power requirements. Some of the early research work in this area conducted by Hansen et al. (1958) showed that the fuel and power consumption in conventional tillage practice required 55 per cent more fuel and 58 per cent more drawbar energy per unit area than the minimum tillage practice of the day. Plow-planting required 31 per cent less fuel and 27 per cent less drawbar energy than minimum tillage.

Selection of a tillage system should take into account the draft and energy requirements of the tillage tools. Summers et al. (1986) emphasized this fact and further stated that the determination of a tractor size is better when good draft and power requirement data exists for desired implements in the specific soil types. In their experiments on draft relationships for primary tillage in Oklahoma soils, they measured draft and ground speed in four different soil types.

In earlier experiments Summers et al. (1985) developed a method for estimating implement power requirements from engine fuel consumption. Output measurements of the system during field operation were engine speed, elapsed time, accumulated fuel consumption, fuel temperature, and machine forward velocity. According to Stephens et al. (1981) the use of implement energy to compare different implements is valuable because it is not influenced by the tractor i.e. power train, rolling resistance and slip.

2.4 Fuel and Draft Measurements

Experiments on energy and power measurement for field machinery require that the fuel flow and the draft force generated by the implements be monitored. Conflicting results have been reported by previous researchers on the energy used by moldboard plow-based and chisel plow-based tillage systems. Chaplin et al. (1988) conducted research on drawbar energy use for tillage operations on loamy sand. Draft force and speed of three tillage systems were measured. These systems included:

1. Moldboard plowing and planting
2. Chisel plowing and planting and
3. No-till planting

They concluded that the reduced tillage systems involving chisel plowing as the primary tillage, used 62 per cent more drawbar energy per acre than the conventional tillage system.

Grevis-James and Bloome (1982) measured drawbar power, wheelslip, drawbar pull and ground speed with a tractor power monitor. They disregarded fuel measurement and regretted doing so after they realized its significance later.

Similar tests were conducted by Michel (1985) in which a chisel plow required one half of the fuel used by a moldboard plow and covered almost three times the area in the same amount of time. Vaughan (1977) also documented savings of 13 and 38 liters of diesel fuel per hectare for reduced tillage and no-till systems, respectively, when compared to a conventional tillage system. Experiments done by Zwilling and Hummel (1988) have shown that the fuel requirements (L/ha) were greater for moldboard plowing than for chisel plowing. Disking after moldboard plowing required more fuel than after chisel plowing. Fuel requirements for conventional tillage systems ranged from 25.8 to 45.7 L/ha and minimum tillage systems ranged from 17.2 to 25.3 L/ha. Other researchers have documented that a moldboard plow requires more fuel and time per hectare than any other tillage implement (Bowers et al. 1986, Summers et al. 1986).

Various fuel flow meters have been used to monitor fuel consumption. Lin et al. (1980) used a volumetric paddle wheel flow meter; a 2-terminal integrated circuit (IC) temperature transducer was used to monitor temperature. Both measuring devices were inserted between the fuel filter and injection pump. A 3-way valve was used in the return fuel line to bring the surplus fuel back to the injection pump. Smith, et al. (1981) used a Fluidyne model 1250 fuel meter which uses a positive displacement sensing device to measure fuel consumption to the nearest cubic centimeter. Fuel temperature, fuel pressure and time were measured separately.

In determining the energy and power required for tillage implements, operating parameters that are frequently monitored include:

1. Fuel consumption
2. Draft force
3. Engine speed
4. Actual ground speed
5. Drive wheel speed

From these measurements, drawbar power (kW), fuel consumption (L/ha), specific fuel consumption (L/kWh), drawbar energy (kWh/ha), draft/unit width (kN/m), draft/tool (kN/row; kN/shank) and wheel slip (per cent) can be analytically determined (Tompkins et al. 1982, Grogan et al. 1987 and Zwilling et al. 1988).

2.5 Instrumentation

The standard tractor is usually equipped with only a tachometer as a guide in operation of the tractor and implement. The need to monitor various parameters that affect the performance of a tractor and implement combination requires extra instrumentation. Various instrumentation systems have been developed. These vary in complexity and sophistication from measuring one or two parameters and recording display readings by hand (Williford, 1981) to on-board microcomputer-based monitoring of several operating parameters (Adsit and Clark, 1981; Wendte and Rozeboom, 1981). Luth et al. (1978) documented that recent advances in instrumentation, radio telemetry and digital computers now allow engineers to collect and analyze large amounts of data in order to monitor tractor/implement energy needs. The instrumentation package which they developed was capable of collecting data on 31 channels, transmitted it up to 8 km to a "powered" receiving station where the data were conditioned and sampled by a computer.

The need for collecting data to determine energy requirements has resulted in several complex on-board microprocessors and Data Acquisition Systems (Summers et al., 1986). The current state of the art in in-field data collection enables collection of large amounts of data on-board without using remote support equipment. Advances in technology have revolutionized methods for collecting data on mobile equipment in agricultural research (Upchurch et al., 1987). The ability to record and display several channels of data on the computer monitor enables immediate checking of the performance of the transducers (Marshall and Buckley, 1984). Lin et al. (1980) designed a microprocessor-based instrumentation system to measure field data. The system was based on a Heath H8 8080-A based microcomputer. An Analog Devices RTI-1200-016 board was used in the computer to interface the analog signals for each parameter to the microcomputer bus. Other computer configurations have been used to measure tractor related parameters. Stange et al. (1982) used a Hewlett Packard (HP) data acquisition system, HP Microcomputer, HP 3455A digital voltmeter and HP 34590A scanner to collect data on tractor work. Bandy et al. (1985) developed a Motorola 6800 microprocessor-based data acquisition system to monitor the performance of a tractor in the field.

Vandoren (1982) defines data acquisition system (DAS) as an electronic instrument or group of interconnected hardware items, dedicated to the measurement and quantization of analog signals for digital analysis or processing. The DAS functions as an analog interface to the digital domain. Green et al. (1984) assert that research emphasis in recent years has been in the development of performance monitors and computer-based data acquisition systems.

Various DAS's have been developed to monitor energy related field data. Harter et al. (1979) used a MOS TECHNOLOGY'S 6502 microprocessor capable of addressing 64 Kilobytes of memory with an Analog Devices model DAS1128 consisting of analog input multiplexer, sample and hold amplifier and a 12 bit Analog to Digital (A/D) converter. The system was designed for experiments on tractor tillage.

Carnegie et al. (1983) used an Apple IIe microcomputer for collecting tractor performance data. The system was operated by a 12V tractor battery system. Their report confirmed that the computer operated well. Recent literature shows work by other researchers that have used highly sophisticated DAS's. McLaughlin et al. (1989) conducted field data collection for energy requirements using a tractor equipped with factory installed transducers for measuring engine speed, wheel and ground speeds and three-point hitch height and draft as part of an electronic monitor and control system. The 110V power for the system was supplied by a 4.0 kVA generator. Operation of the set-up required two other persons besides the driver, one to coordinate the experiment and the second to operate the data logger. Accommodation of the instrumentation equipment and the operators on the tractor required an extension of the left hand side of the tractor cab.

Tembo (1986) performed field research using an Apple IIe microcomputer-based instrumentation system at MSU. He used six transducers for force measurement and four transducers for speed measurement. Experiments were also conducted by Mah (1990) using the same instrumentation package. The two researchers collected the field data successfully.

2.6 Summary

The literature available on research for tillage energy requirements indicates that fuel requirement is an important consideration. Given that renewable sources of energy for field machinery are not feasible yet, energy-use efficiency needs to be pursued using the current fossil fuels. The current method of data collection involves on-board microcomputer-based DAS's which have been found to withstand harsh field conditions. The systems are capable of collecting large data sets at time intervals which can be varied to meet particular research needs.

The results of tractor/implement performance experiments that have been done elsewhere are applicable to specific geographic areas, conditions and implement combinations. The energy related research cited shows that the parameters monitored in field data collection include draft, ground speed, wheel speed, engine speed and fuel flow. The microcomputer-based DAS that was used for experiments at MSU by preceding researchers included all of the above parameters except the fuel flow and drawbar draft measurement which were incorporated into the present research.

CHAPTER 3

OBJECTIVES

The energy and power requirements for tillage operations are useful in evaluating the efficiency of tractor fuel consumption. In order to reduce fuel consumption in tillage, efficient management of field equipment is a primary consideration. Minimal implement usage, combining of operations, regulating ground speeds to match implement size and keeping tillage depth to an allowable minimum are some of the avenues through which fuel costs can be curtailed.

The available literature documents research that has been carried out in this area of energy and power utilization in tillage. However, the results of this work have been limited to application in the specific geographic areas of research. It was desirable, therefore, to conduct similar experiments in Michigan in order to establish the energy and power needs of various combinations of conventional and conservation tillage implements.

The specific objectives of this study were to:

1. Instrument a tractor for use in determining energy and power required for conventional and conservation tillage systems.

2. Determine the relationship between fuel consumption and the energy requirement of tillage systems.

3. Compare the energy and power requirement of conventional, conservation and no-till tillage systems.

The following parameters were monitored in the experiments:

1. Engine speed
2. Operational ground speed
3. Wheel speeds
4. Fuel consumption
5. Implement draft.
6. Tillage depth
7. Soil moisture content
8. Soil cone penetrometer index

CHAPTER 4

EQUIPMENT

4.1 Specifications

The experiments were conducted using the same tractor for all tests. A total of 14 implements including two moldboard plows, two chisel plows, one field cultivator, four disk harrows, one row crop planter and four grain drills were experimented with at two field sites. Detailed specifications for the tractor and the field implements are provided in Appendices A and B, respectively. A brief description of each machine used, instrumentation set up, the data acquisition system and the transducers is presented in this chapter.

4.2 Tractor

The tractor utilized for all tests for this research project was a 65kW (86HP) Ford[1], model 7610 that was used previously for other similar research at MSU. The tractor was equipped with front wheel assist and with a standard fully enclosed cab that protected the instrumentation system from bad weather and dusty conditions.

The transmission of the tractor consisted of 16 forward and 8 reverse gear combinations giving a range of 2.2 to 30.6 Km/h forward ground speeds in four wheel drive mode. This

[1]Trade names are used in this thesis solely to provide specific information. Mention of a product name does not constitute an endorsement of the product by the author to the exclusion of other products not mentioned.

range of speed was achieved using 18.4 by 34 tires on the rear wheels and 13.6 by 24 tires on the front wheels.

4.3 Conventional Tillage Implements

For the conventional tillage system, the moldboard plow was used for the primary tillage operations. Disk harrows and conventional grain drills followed the conventional primary tillage operation both at St. Johns and MSU sites. The field cultivator was used only at the MSU field as there was none available with the farmers at St. Johns.

4.3.1 Moldboard Plows

Traditionally the moldboard plow has been used for primary tillage. Secondary tillage implements including disk harrows and field cultivators among others, are used to refine the seedbeds. This research was designed to test a moldboard plow-based tillage system and to compare it with a chisel plow-based conservation tillage system and a no-till system. The experiments performed near St. Johns were conducted with a 0.4 m six-bottom pull type moldboard plow covering a theoretical width of 2.4 m. The implement had two hydraulic remote controlled transport wheels.

The MSU experiments were done with a fully mounted three point linkage moldboard plow which had three 0.4 m bottoms with an overall theoretical width of 1.2 m. Since the instrumentation was designed for pull type implements, the data collected with this plow was limited to the fuel consumption, and engine, ground and wheel speeds. Draft measurements were not monitored.

4.3.2 Disk Harrows

Four sizes of tandem disk harrows measuring 4.3 m, 3.9 m, 3.0 m and 3.2 m were used for the secondary tillage trials. The first one was used at the MSU farm while the others were used in St. Johns fields. All four had hydraulic remote controlled transport wheels. The size of the disk blades varied between 0.50 m and 0.60 m in diameter.

4.4 Conservation Tillage Implements

Implements used for conservation tillage included a chisel plow for primary tillage, disk harrow for shallow primary tillage and disk harrow following chisel plow as reduced tillage tools. No-till experiments were performed with a no-till row crop planter and no-till grain drills. The no-till row crop planter used near St. Johns was a conventional one that the farmer improvised for no-till system.

4.4.1 Chisel Plows

Two chisel plows were used, one in each experimental site. At St. Johns the chisel plow had 7 spring loaded tines with 3 tines in the front row and 4 tines in the back row with a spacing of 38 cm between them along the row. It was provided with four transport wheels operated through a remote hydraulic control. The overall theoretical width of the implement was 2.5 m.

The chisel plow used at MSU had 8 tines mounted on three rows of 2, 3, and 3 tines each for the front, middle, and rear rows, respectively. The overall theoretical width of the plow was 2.2 m.

4.5 Field Cultivator

The field cultivator tested had three rows of tools. The rows had 8 tines in the front row, 8 tines in the second row and 9 tines in the third row. The cultivator sweeps had a width of 15 cm across the widest section and were spaced 50 cm apart. This gave a theoretical width of 4.3 m. The shanks were spring loaded. Transporting the implement was facilitated by two hydraulically operated wheels which were also used for depth regulation. The implement was also provided with spraying equipment which included a plastic chemical tank and a sprayer boom mounted at the front.

4.6 Planting Implements

The planting implements experimented with at both sites included conventional, conservation and no-till grain drills. The no-till row crop planter was used at St. Johns only. Conventional row crop planters were not available for testing.

4.6.1 Row Crop Planter

The improvised row crop planter used near St. Johns was equipped with seed and fertilizer hoppers as well as two drums for liquid ballast needed during no-till planting. The planter had six rows (78 cm apart) that covered a width of 3.8 m. A furrow opener placed fertilizer ahead and about 5 cm to the side of the seed. The knife edge furrow opener for fertilizer placement had a corrugated disk coulter that cut a strip into the ground ahead of the knife furrow opener to reduce draft. The coulter also cut plant residue to reduce clogging. Similarly the furrow opener for the seeds had a fluted disk coulter ahead of a double disk furrow opener which was also used for minimizing implement draft (See Fig. 4.1).

4.6.2 Grain Drills

Four grain drills were tested in various conditions, two at each experimental site. The smallest grain drill which had 10 rows spaced 20 cm apart with an overall width of 1.83 m was tested near St. Johns. An 18 row grain drill with a row spacing of 18 cm and an overall width of 3 m was the second grain drill used near St. Johns.

One of the grain drills used at MSU had 15 rows spaced 23 cm apart and had 2.84 m overall width. It was equipped with spring loaded wavy disk coulters at the front of the double disk furrow openers. Two liquid ballast drums were provided for use in direct drilling operations. The second grain drill

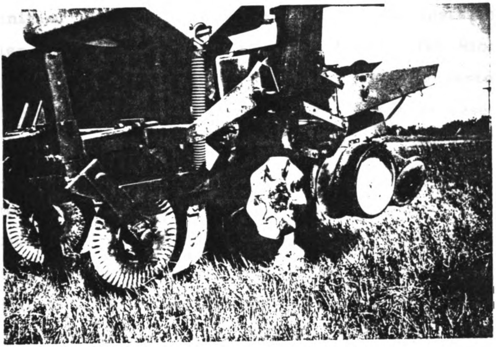

Figure 4.1 The modified no-till row planter on field 1.

had 21 rows spaced 18 cm apart to give an overall width of 3.56 m.

4.7 <u>The Instrumentation System</u>

The initial instrumentation of the tractor was installed by earlier researchers (Tembo, S. 1986 and Mah, M. 1990: Michigan State University). Elaborate description of the system is available from both the above authors. For this research, however, the system had to be reassembled and the fuel measurement meter incorporated to meet the stated objectives. The modified instrumentation package and the transducers will be described in this section. The specifications of the transducers were well documented by Tembo (1986). The specifications have been reproduced in Appendix C.

The instrumentation was reassembled in the summer and fall of 1989. The system consisted of a Dickey john Tractor Performance Monitor II (DjTPMII), Fluidyne PDP1 piston fuel flow meter, signal conditioner rack, DC to AC voltage converter, analog to digital (A/D) converter, microcomputer-based data acquisition system and an accessory battery. The signal conditioner rack, voltage converter and the A/D converter were secured in a foam padded wooden box that was attached to the right hand side of the tractor cab. A similar wooden box was fastened to the left hand side of the cab to accommodate the microcomputer and the monitor. The computer and monitor were secured to the box with rubber fasteners for ease of removal (See Fig. 4.2 and 4.3).

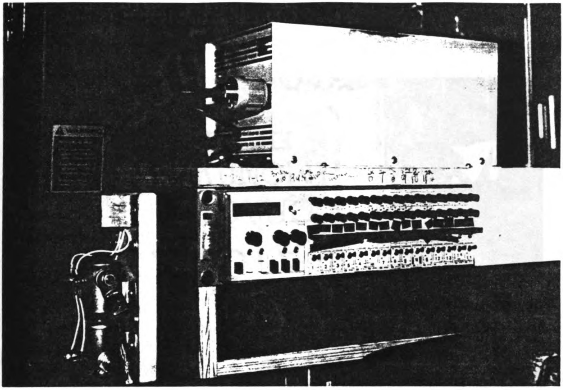

Figure 4.2 The signal conditioner rack and the voltage converter in the tractor cab.

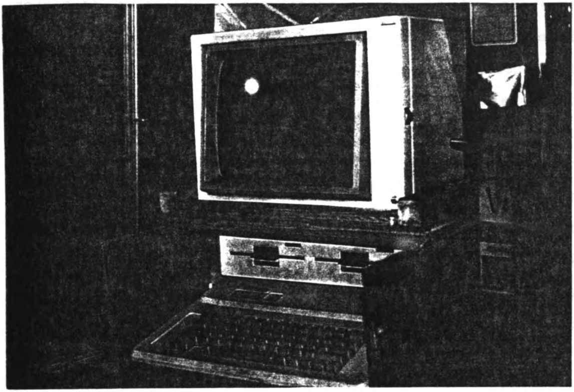

Figure 4.3 The Apple IIe computer and monitor in the tractor cab.

The accessory battery was fastened to the tractor at the rear side of the cab, behind the driver's seat. It was connected to the tractor battery terminals via a double pole, double throw switch to facilitate recharging when the system was not collecting data. The tractor cab side windows were removed and replaced by transparent plastic sheets because the wooden boxes required extra space. The computerized console of the DjTPMII and the fuel flow meter calibration/run switch were mounted on the tractor dash board. Only three components of the system were mounted outside the tractor cab, i.e. the fuel flow meter box, the radar speed detector unit, and the strain gages on the drawbar. The fuel flow meter box was secured on the right hand side of the tractor below the fuel filters and the radar unit was attached at the same side but on the underside of the tractor.

Each transducer was calibrated in order to derive regression equations (Appendix C). Preliminary field tests were conducted on the MSU farm during October 1989 to verify the accuracy of the transducers and to develop the procedures for operating the DAS. The instrumented tractor was then stored indoors until summer 1990 when the actual experiments were conducted.

4.8 Data Acquisition System

The central feature of the in-field DAS was an Apple IIe microcomputer that was capable of operating at high speeds in rugged field conditions. The system consisted of an AI13 A/D converter (Interactive Structures Inc) and a 65C02 microprocessor based microcomputer (Apple IIe, Apple Computer Co.). Six of the 16 channels of the DAS were utilized to collect data sequentially from six transducers and to store the data in the Random-Access-Memory (RAM) of the microcomputer in ASCII form. Data were transmitted through M1000 series (Data Capture Technology) signal conditioners which conditioned the analog signals prior to conversion by the A/D converter which provided the interface between each analog signal and the microcomputer as shown in Figure 4.4. The AC power required for the system was provided by the extra battery connected to a 12VDC-120Vac, 60Hz, 500 Watt sinusoidal voltage converter (model 20-500, Venner Corporation, Ohio).

The conversion of the continuous data obtained from the transducers to discrete values was performed by the DAS. The transfer function for the 12-bit Binary (4096-level) quantisizer was of the following form:

$$\alpha = \frac{V_{FS}}{2^n}$$

where:

α = Quantum interval

V_{fs} = Fullscale voltage input

2 = Number base for binary

n = Number of bits (binary digits)

2^n = Number of quantisizing intervals.

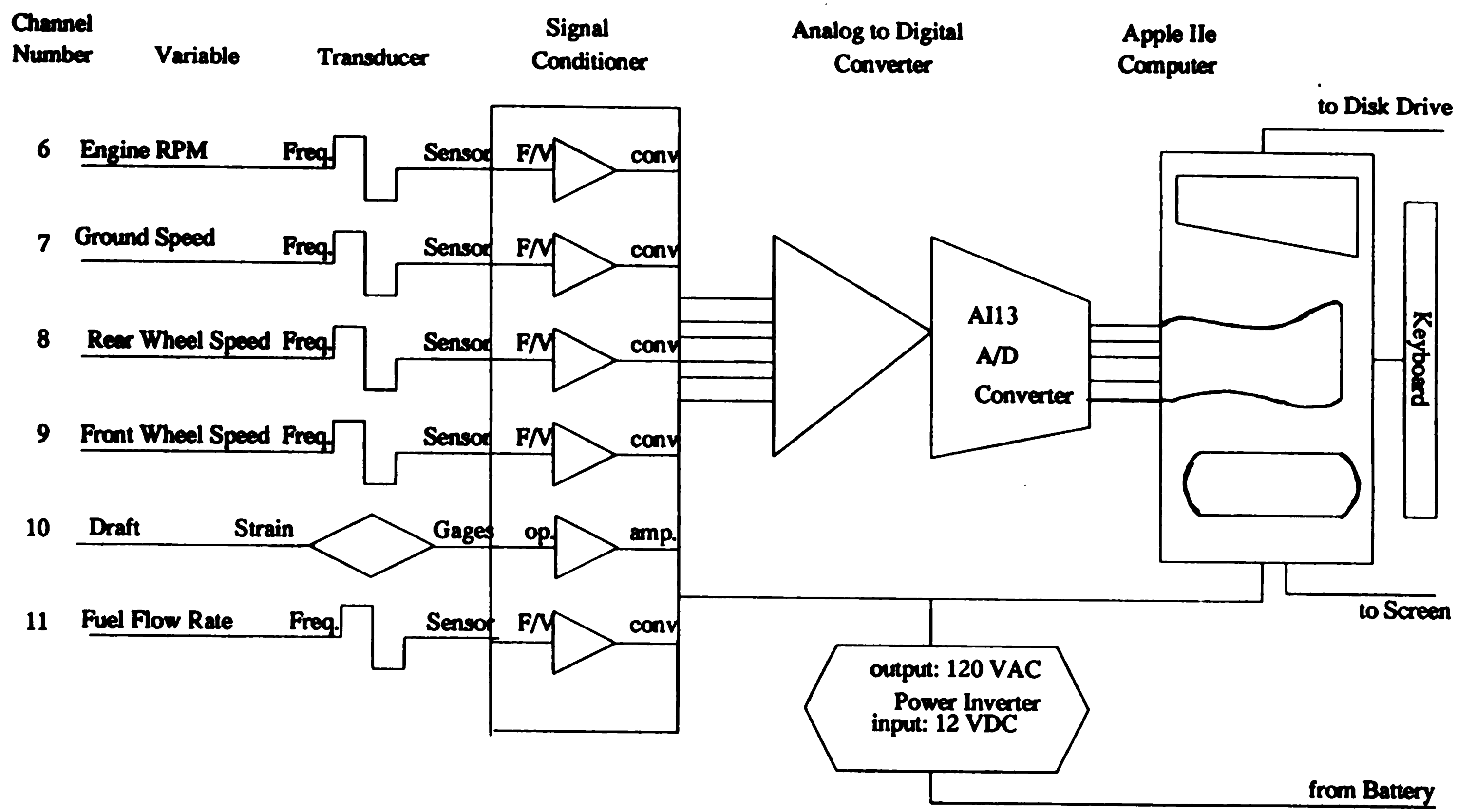

Figure 4.4 Block Diagram of the Data Acquisition System Hardware

The experiment's DAS had the following transfer function:

$$\alpha = 5V\,x\,\frac{1000}{2^{12}}$$
$$= 1.22\ mV$$

(After Vandoren, 1982)

Each step of the digital system represented 1.22 mV.

4.9 <u>The Signal Sensors</u>

4.9.1 <u>DjTPMII</u>

The DjTPMII is a commercial computerized system that is used to monitor various tractor and implement in-field parameters. The system consists of a computerized control console, engine RPM sensor, radar ground speed sensor, implement status switch and a wheel speed sensor. Information on the engine speed, ground speed, percentage wheel slip, distance travelled and area covered can be selectively displayed on the console. This enables an on-the-run checking of these parameters. For this experiment the ground, wheel and engine speeds were monitored through the DjTPMII console during the field tests.

4.9.2 <u>Ground Speed Measurement</u>

The radar unit used for ground speed measurement was mounted on the underside of the tractor at an inclination toward the rear of the tractor. The measurement of the ground speed was through frequency generated by a sensor which emitted a beam of microwave energy onto the ground surface. The microwave energy was reflected back to the sensor. The comparison of the reflected frequency to that emitted to the ground would give a measure of the ground speed. Movement by the sensor caused a shift of the comparative frequencies which was proportional to the speed of the tractor.

The DjTPMII console received the frequency output from the radar unit and channelled it through an M1080 10KHz frequency to voltage (F/V) converter and hence to the AI13 analog to digital converter. The digital value was subsequently transmitted to the microcomputer through the digital multiplexer.

4.9.3 Engine Speed Measurement

The engine speed sensor was mounted between the existing mechanical drive sender and the tachometer cable, and then routed to the DjTPMII console on the dashboard. The rotation of the sensor generated a frequency proportional to the engine speed. The frequency signal was sent through an M1080, 10KHz F/V converter prior to transmission through the AI13 A/D converter for conversion to the digital domain.

4.9.4 Front Wheel Speed Measurement

The tractor was used in four wheel drive mode throughout the experiments. Determination of the front wheel rotational speed was necessary in order to calculate the slippage of the wheels. This measurement was accomplished by using magnetic (inductive) pickups that generated voltage pulses. A 60 tooth sprocket accurately machined and mounted on the external diameter of the innerside of the right front wheel hub, was used to generate the pulse signals. A cylindrical pole magnet pickup (model 60-0198"G"--2.5 inches threaded reach) mounted perpendicular to the sprocket teeth counted the number of teeth passing as the wheel rotated. The analog signal in frequency form was transmitted to the F/V converter of the signal conditioner and hence to the A/D converter.

4.9.5 <u>Rear Wheel Speed Measurement</u>

The rear wheel rotational speed was also useful in the determination of the wheel slippage. The set-up for measuring rear wheel speed was similar to that used to determine the front wheel speed. The rear wheel sprocket had 80 teeth and was mounted on the right hand side of rear axle housing in a manner similar to the front wheel one. The magnetic pick-up was identical to the one for the front wheel one and was mounted in a like manner.

After the conversion of the frequency signal to voltage value by the F/V converter, the A/D converter transformed it to a digital form for the DAS to sample and enter into the RAM of the computer.

4.9.6 <u>Implement Draft Measurement</u>

The measurement of the implement draft was of primary concern in the experiments as it was used to determine the energy and power requirement of the various implements. All of the implements used except the moldboard plow at MSU were pull type. The tractor drawbar was therefore instrumented with strain gauges to measure the longitudinal pull force generated by the implements. The strain gages were mounted on the right and left hand sides of the drawbar. Lateral movement of the drawbar was checked by an improvised stopper on which the far end of the drawbar rested to prevent the gauges from contacting the drawbar mounting bracket as it swung sideways.

4.9.7 Fuel Consumption Measurement

In order to accomplish the primary objectives of this project, a dependable fuel consumption measuring meter was a crucial requirement. The meter selected for this important aspect of the experiment was a Fluidyne positive displacement Piston Flowmeter, model PDP1 obtained from Emco Engineering Measurements Company, Colorado. The primary features of this device include:

1. High accuracy and repeatability.
2. Extreme low flow capability.
3. Wide liquid flow range.
4. Wide liquid viscosity range.
5. High pressure and temperature rating.
6. Explosion proof housing for safe operation in hostile environment.

The meter's linearity deviation from average ranges between -0.59 per cent to +0.28 per cent depending on the nominal flow rate which varies between 1 cc/min to 1200 cc/min (See Appendix D). The flowmeter was mounted vertically in a sealed weatherproof metal box which was attached to the tractor on the right hand side below the fuel filters

(Fig. 4.5). Three access holes were drilled into the side of the box for in and out fuel flow lines and the signal transmission wiring. Two three-way valves were installed to provide metering and bypass mode possibilities. Overflow from the metering system was channelled back to the injection low pressure fuel line (between the meter and the injection pump) to ensure that all metered fuel was consumed by the tractor. The connection of the meter to the tractor fuel system was done using quick couplers for ease of removal at the end of the research.

The positive displacement piston flowmeter utilizes four pistons, driven by the flow of the liquid to be measured, which in turn drive a crankshaft through connecting rods in a fashion similar to a radial internal-combustion engine. The rotational velocity of the crankshaft is proportional to the volumetric flowrate through the flowmeter. The crankshaft is equipped with a magnetic element which in turn causes an external transmitter magnet disk to rotate with the same angular velocity. This rotational velocity is then converted to pulses using an optical encoder.

The output from the transmitter is a 12 $V_{p\text{-}p}$ square wave with a frequency range of 0-2500 Hz. The square wave output of the transmitter is converted to a sine wave by the signal conditioner. The frequency generated by the piston flowmeter and the associated electronic signal are proportional to the flow rate of the fluid according to the following equation:

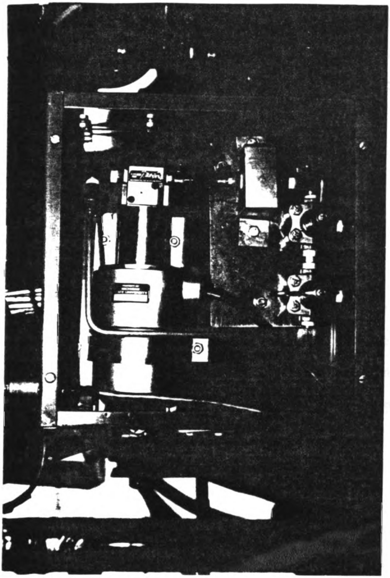

Figure 4.5 Fluidyne PDP1 fuel flow meter mounted on the tractor.

$$Q = (F/K_f) \times 60$$

where Q = Flow rate in cubic centimeters per minute

F = Frequency output in pulses per second (Hz)

K_f = Meter calibration factor in pulses per cc

The Kf factor for this meter which was provided by the factory is 119.87.

4.9.7.1 Calibrator/Run Simulator

A calibrator/run device (frequency simulator) was designed and fabricated for the flow meter. This device was used for calibration of the meter in the calibrator mode and to transmit signals to the signal conditioner in the run mode. Its purpose was to expand the narrow signal obtained from the sensor to one that the signal conditioner could read. It consisted of a preamplifier through which the flow meter signal was directed in order to increase its resolution to the 0 to 5 volts range. The simulator had four preset levels of frequency (100, 250, 500 and 1000 Hz) that were used for the calibration of the DAS.

4.9.7.2 Fuel Meter Verification

In order to ascertain that the values of the fuel consumption obtained from the PDP1 meter were accurate, the system was tested manually in the laboratory using a gravity fuel feed system that was devised to measure the rate of fuel consumption with the tractor at a stationary position. The fuel consumption rate was measured at various engine speeds and the data were manually recorded. A graduated cylinder was filled with fuel and the time taken by the tractor to consume 100 or 200 cc of fuel, depending on engine speed, was recorded. Simultaneous monitoring of the fuel consumption was done with the PDP1 using the DAS for a direct comparison.

The tractor was then connected to a PTO dynamometer and the tests were repeated for loads ranging between 7 kW and 65 kW (full load). The fuel consumption rates measured by the manual system and the PDP1 were compared with values calculated using the ASAE standard fuel consumption formula. The PDP1 registered lower values by a constant factor of 1.1296 as compared to the manual values (see Fig. 4.6). Figure 4.7 shows the comparison of the manual fuel measurement and the regression line of the corrected fuel measurement. This indicates that the regression line can be used to estimate the fuel consumption of the tractor using the equation:

$$Y = 0.215168 * X + 3.776305$$

$$R^2 = 0.9987$$

4.10 Calibration of the Signal Conditioners

The signal conditioners were M1000 series (Data Capture Technology). Each of them was calibrated prior to the calibration of the transducers. The signal conditioners used for the five frequency generating sensors were the M-1080s. The strain gage transducer used the M-1060 signal conditioner which is designed to sense forces.

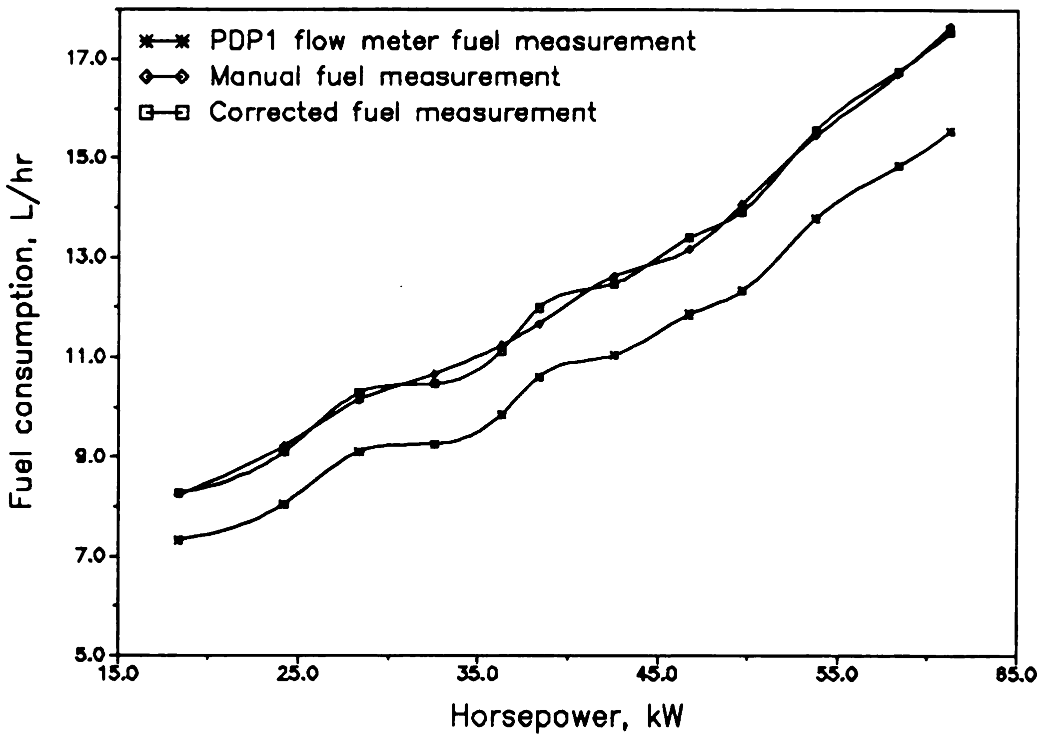

Figure 4.6 Correction of PDP1 fuel measurement.

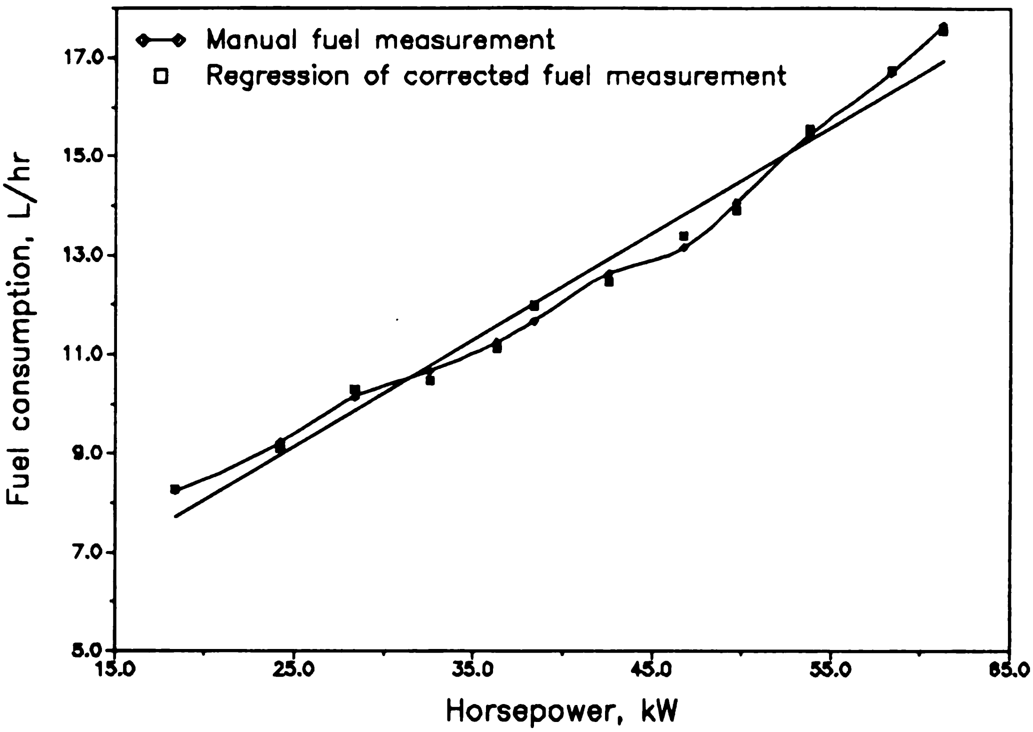

Figure 4.7 Regression of corrected fuel measurement.

4.11 Calibration of Transducers

Calibrations of the transducers were carried out prior to the preliminary field experiments conducted in summer 1989. The strain gages on the drawbar were calibrated using a Universal Tension Machine with a maximum load of 44,927 N (details in Appendix C). The DAS channels were calibrated in the laboratory to receive data from the speed measurement transducers. The calibration was done using a frequency generator, and an oscilloscope. The frequency generated was directed through the DAS for the computer to develop a regression equation. The calibration of the fuel meter DAS channel was done using the calibrator/run simulator to provide the signal in calibration mode instead of the frequency generator. The calibrator was capable of emulating the transducer signals and hence providing the required frequency for calibration.

The frequency generator was connected to the appropriate channel of the signal conditioner using cables that had a provision for intercepting the signal and directing it to the oscilloscope for an accurate frequency count. The dials on the frequency generator were not accurate enough for obtaining the actual frequency. The signal conditioner converted the signal to voltage before sending it to the DAS. The gain code of each transducer was determined and logged into the computer program together with the respective channel number.

The maximum loads expected from respective transducers were determined (i.e. rpm, ground speed, etc.) and converted to frequencies. The frequency generator was set to provide the maximum frequency for a particular transducer. This was directed to the signal conditioner to obtain an analogous voltage. The maximum voltage obtained was used to determine the gain code of the sensors. The range of all six transducers was 0 to 5 volts. The gain code was therefore set at 0 for all of them.

The calibration subroutine of the AI13 program was used to receive the signal generated by the frequency generator directly from the signal conditioner. The frequency generator was used to generate 10 to 12 frequencies depending on the determined range. The oscilloscope was set to provide a suitable sine wave on the screen to determine the accurate frequency settings. The actual frequency was logged into the computer for each of the frequencies. The computer then provided the slope and intercept for a regression equation to calculate the load (frequency) that would be used to convert the DAS output to the analog frequency. The equations for each of the transducers are provided in Table 4.1. Details of the calibration procedure are provided in Appendix C.

The transducer loads (frequencies) were converted to the respective parameters using the factors provided by the supplier of each device. The factors are shown below. The only exception was the draft load whose calibration equation converted the load to units of force (N).

Table 4.1 Calibration Response Equations.

Channel Number	Gain Code	Variable	Calibration Response Equation	R^2
6	0	Engine Speed	Hz = mV x 0.089 + 1.694	0.9998
7	0	Ground Speed	Hz = mV x 0.098 + 2.277	0.9992
8	0	Rear Wheel Speed	Hz = mV x 0.083 + 2.757	0.9988
9	0	Front Wheel Speed	Hz = mV x 0.090 + 1.110	0.9986
10	0	Draft Force	N = (mV x 24000.664/1000) - 12.587	0.9991
11	0	Fuel Flow	Hz = mV x 0.204 + 0.880	0.9999

1. Engine speed (RPM):

The engine speed transducer registers 4 pulses per engine revolution. The conversion equation of the load (Hz) to engine speed was:

$$RPM = \frac{Load(Hz)}{4pulses} x \frac{60 sec}{min}$$

2. Ground speed (Km/h):

The conversion factor used for the radar ground speed sensor was 100Hz/m/sec. The conversion equation of the load (Hz) to ground speed (Km/h) was:

$$Km/h = \frac{Load(Hz)}{100Hz} x \frac{m}{sec} x\ 3.6$$

3. Rear wheel speed (Km/h):

The rear wheel sprocket had 80 teeth. Hence 80 pulses were equivalent to one revolution of the wheel. The load (Hz) was converted to wheel revolutions per minute (RPM) and then to peripheral speed (Km/h) as follows:

$$RPM = Load(Hz)\ x \frac{1 rev.}{80 pulses} x \frac{60 sec}{min}$$

$$Km/h = RPM \ x \ \frac{Circ.(m)}{rev} \ x \ \frac{1\,Km}{1000\,m} \ x \ \frac{60\,min}{1\,Hr}$$

4. Front wheel speed (Km/h):

The front wheel sprocket had 60 teeth and therefore 60 pulses were equivalent to one wheel revolution. The equations for converting the load (Hz) to the peripheral speed were as follows:

$$RPM = Load(Hz) \ x \ \frac{1\,rev}{60\,pulses} \ x \ \frac{60\,sec}{1\,min}$$

$$Kph = RPM \ x \ \frac{Circ.(m)}{1\,rev.} \ x \ \frac{1\,Km}{1000\,m} \ x \ \frac{60\,min}{1\,Hr}$$

The rolling radius of each wheel was used to compute the circumference.

5. Fuel flow measurement:

The conversion factor provided by the suppliers of PDP1 was 119.87 pulses per cc of fuel flow.

$$L/hr = Load(Hz) \ x \ \frac{1\,cc}{119.87\,pulses} \ x \ 3.6$$

CHAPTER 5

EXPERIMENTAL PROCEDURE

5.1 Verification of Instruments

This research was carried out jointly with Wan Ismail (1991) who was working on a machinery selection simulation model. Prior to the collection of data in the field, preliminary data collection was conducted to verify the accuracy of the instrumentation and the transducers.

5.1.1 Verification of the Engine Speed

The engine speed was verified using a photo-tachometer, the DjTMPII and the tractor's tachometer. The engine was operated at various speeds and measurement by the photo-tachometer carried out at the cooling system sheave off the crankshaft. The data from the two measuring devices were compared for accuracy. The data measured by the DjTMPII was found to be accurate and satisfactory within 3 per cent.

5.1.2 Verification of Wheel Speeds

Verification of the wheel speeds was performed by first elevating the tractor off the ground. The tractor was operated at several speeds and the wheel revolutions for the rear and front wheels counted. A count of 10 revolutions of the rear and 15 of the front wheel were noted and the time taken measured. Meanwhile the DAS was receiving and recording the data generated by the magnetic pick-up transducers. A comparison of the wheel speeds using the two methods of wheel speed measurement verified that the transducers were performing with an accuracy of 2 per cent.

5.1.3 Verification of the Ground Speed

The ground speed was verified by measuring the actual distance covered on a concrete surface at various speed settings . The time taken was recorded and the speed computed. Simultaneous ground speed data was recorded by the DAS for comparison with the manual measurements. The transducer ground speed measurement was compared with the manual measurement. The transducer data was accurate within 1 per cent of the manual data.

5.1.4 Verification of the Fuel Flow Measurement

The fuel flow meter was tested for accuracy as discussed in section 4.9.7.2 of chapter four. The test showed that the fuel flow meter had a discrepancy of 12.96 per cent as compared with the manual measurement. This factor was used to correct the fuel flow measurements. The variation could have been due to the difference between the liquid used for the initial calibration of the meter and the fuel used by the tractor. The specification of the liquid used was:

Liquid spec: SAE 967d
Visc. (100F): 2.5-3.5
Sp. Gr.: 0.820-0.830

5.2 Test Sites and Description of Experiments

The experiments were conducted on two sites between the months of May and September 1990. The selection of the first site which consisted of three farmers' fields was done in collaboration with the local district conservationist in Clinton County, Michigan. Efforts were made to obtain two soil types, course and fine texture. The three fields used were located near St. Johns. The second experimental site was on the MSU farm located south of the campus at the northwest corner of College and Jolly roads.

The experiments performed on each field are described in this section. Altogether, 210 field runs were conducted; 148 at St. Johns and 62 at MSU. The summary statistics for some of the files have been reproduced in Appendix F. The characteristics and other information of the soils are provided in Appendix D.

5.2.1 Field 1

Field 1 was located at the southeast corner of Price and Chandler roads about 8 kilometers southeast of St. Johns. The field had alfalfa and rye grass for a continuous three year period. The soil type was predominantly Capac loam (CaA 0-4 per cent slope). The remnant of the preceding sod stubble was sprayed with Roundup beforehand as a weed control measure. The field tests on this site were conducted on May 29, 1990.

Six tests were done with a modified six row conventional row crop planter to achieve no-till planting which was done at three speeds: 4.8, 6.4 and 8 Km/h replicated twice.

5.2.2 Field 2

Field 2 had two sections, one on either side of Townsend road, about 8 kilometers north of field 1. The field on the northern side of the road was designated as 2a. The soil type was Granby loamy sand (Gr) and was relatively flat. It was not cultivated the preceding year and had grass stubble. A section of the field was moldboard plowed before the tests. Five experiments were replicated twice and were conducted on this field as shown in Table 5.1.

The field on the south side of Townsend road was designated as field 2b. The soil was predominantly Palms muck (Pa, 0-2 per cent slope). The soil had high organic matter content and was dark in color. Six experiments, replicated twice, were performed on this field as shown in Table 5.2.

5.2.3 Field 3

Field 3 was located between the first two at the southeast corner of Taft and Watson roads about one kilometer from Chandler road. The field had two soil types: Owosso-Marlette sandy loam (2-6 per cent slope) and Metamora-Capac sandy loam (0-4 per cent slope) separated in the middle by a grass drainage waterway grown with grass.

Table 5.1 Experiments Performed on Field 2a near St Johns.

Implement	Width-m (Rows)-#	Tillage System	Preceding Implements
Disk harrow	3.9	Conventional	Moldboard plow
Disk harrow	3.0	Conventional	Moldboard plow
Grain drill	1.8(10)	Conventional	Moldboard plow Disk harrow
Grain drill	3.0(18)	Conventional	Moldboard plow Disk harrow
Grain drill	1.8(10)	No-Till	None

Table 5.2 Experiments Performed on Field 2b near St Johns.

Implement	Width-m (Rows)- #	Tillage System	Preceding Implements
Disk harrow	3.9	Conventional	Moldboard plow
Disk harrow	3.0	Conventional	Moldboard plow
Row crop planter	3.8(6)	Conventional	Moldboard plow Disk harrow
Grain drill	1.8(10)	Conventional	Moldboard plow Disk harrow
Row crop planter	3.8(6)	No-Till	None
Grain drill	3.0(18)	No-Till	None

The tests in this field were done after the harvesting of winter wheat. The parts of the field that had a significant gradient were avoided to minimize the effects of slope on draft. The field had been used for no-till crop production for eight years continuously. The crop preceding wheat was soybeans that followed corn grown the year before. A section of the harvested wheat crop had been planted by aerial seeding. The field tests were done on 13, 15 and 16 August, 1990. Six conventional and conservation tillage experiments were conducted in each soil type as shown in Table 5.3 below. The tests were replicated two times at the same speed.

5.2.4 MSU Field

The MSU field tests were performed on 28 and 29 August and 1st and 4 September 1990 after the July wheat harvest. The experiments were restricted to the flat sections of the field. The field had predominantly Capac loam soil with a slope of 0-4 per cent. Ten experiments were performed for the conventional and conservation tillage systems as shown in Tables 5.4 and 5.5. Each experiment was replicated twice. No-till tillage experiments were performed with the no-till grain drills.

Table 5.3 Experiments Performed on Field 3 near St Johns.

Implement	Width-m Tools/Rows-#	Tillage System	Preceding Implements
Moldboard plow	2.4(6)	Conventional	None
Chisel plow	2.5(7)	Conservation	None
Disk harrow	3.2	Conventional	Moldboard plow
Disk harrow	3.2	Conservation	Chisel plow
Grain drill	1.8(10)	Conventional	Moldboard plow Disk harrow
Grain drill	1.8(10)	Conservation	Chisel plow Disk harrow

Table 5.4 Conservation Tillage Experiments Performed at MSU.

Implement	Width-m Tools/Rows-#	Preceding Implements
Chisel plow	2.2(8)	None
Disk harrow	4.3	Chisel plow
Field cultivator	4.3(25)	Chisel plow
Grain drill	2.8(21)	Field cultivator
Grain drill	3.6(21)	Chisel plow Disk harrow

Table 5.5 Conventional Tillage Experiments Performed at MSU.

Implement	Width-m Tools/Rows-#	Preceding Implement
Moldboard plow	1.2(3)	None
Disk harrow	4.3	Moldboard plow
Field cultivator	4.3(25)	Moldboard plow
Grain drill	2.8(15)	Moldboard plow Disk harrow
Grain drill	3.6(21)	Moldboard plow Field cultivator Disk harrow

5.3 <u>Data Collection Procedure</u>

5.3.1 <u>Soils Data</u>

In each of the fields, soil moisture and soil strength data were collected before the implements were tested. At least ten soil samples each with three depth levels were obtained for each field. The sampling points were randomly selected over the whole field. The sampling depths were at the surface, 10 cm and 20 cm into the ground. The soil auger used (Fig. 5.1)

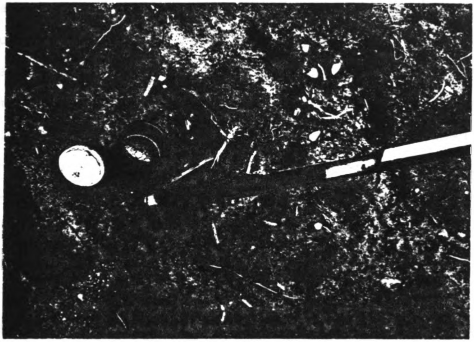

Figure 5.1 Soil auger and soil sample can.

was suitable for obtaining the three soil levels in one penetration. The soil samples were oven dried at 105 degrees Celsius for twenty-four hours and the moisture content (dry basis) determined.

The soil shear strength measurement was done with a manual proving ring cone penetrometer (Fig 5.2). This is a suitable tool for rapid determination of the penetration resistance of soils. The cone point had a base area of 6.34 cm^2. About ten readings were obtained randomly across the field at each test site. These readings were used to obtain the cone index values from the calibration chart provided by the manufacturer of the instrument.

5.3.2 Field Experimental Methodology

The experiments performed near St. Johns were conducted as the farmers did their regular land preparation and planting. All the experiments were, however, done with the instrumented tractor driven by the research personnel. The implements used were not in any way tampered with to suit the research. Instead, the farmers carried out all the required adjustments to suit their seedbed and planting requirements.

The initial calibration of the data acquisition system was done in the laboratory and preliminary tests were conducted to verify the accuracy of each of the transducers. The preliminary experimental tests were conducted in the summer and fall of 1989. During the field tests, the field runs were conducted on the longest and flattest side of the

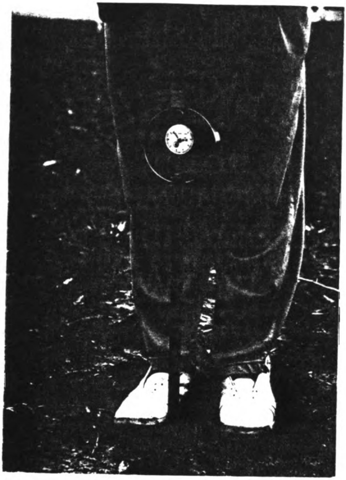

Figure 5.2 Manual proving ring cone penetrometer.

field. This enabled either 500 or 1000 data sets to be collected. The rate of data sampling was 20 data sets per second. Each data set contained one measurement for each of the six channels. Hence for a run performed at 8 Km/h, 6000 data points were collected in 50 seconds over a distance of about 110 m. When the field length was limiting, the tractor was stopped at the end of the field before full data was collected. This was the case particularly at the higher range of ground speeds (above 9.6 Km/h). However, in all cases at least 500 data sets were obtained.

The preparation for data collection in the field included adjustment of all signal conditioners to an initial zero. This was done with all transducers at no load, tractor engine off, and the implement disconnected from the drawbar. The AI13 program was initiated for data acquisition by entering the number of data sets to be collected and the rate of collection. The program was then ready to receive data. Before engaging the implement, the engine speed was set at 2100 rpm and the appropriate transmission gear selected. The tractor was engaged to work. The ground speed and the draft force were allowed to stabilize before the DAS was started. When the steady state condition was achieved, data collection was started by striking the "Return" key on the computer keyboard. Meanwhile the accessory battery was disconnected from the charging circuit to isolate it from the tractor's electrical system to avoid current flow through the strain gages to ground.

When the DAS completed taking the required data sets (or at the end of the field), the tractor was stopped while the data were transferred from the RAM to a file on floppy disk for storage. Checking of the data for the first few runs of the day prior to transfer from RAM was done on the computer monitor to ensure that all the transducers were functioning as expected. During the data dumping process, the tractor engine was left running and the recharging circuit for the accessory battery was switched on. The process of data transfer took about five minutes (compared with between 25 and 50 seconds required to collect it).

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Field Conditions

The weather during the period of the experiments was ideal. There were no extreme cold or hot conditions that would have affected the performance of the transducers or the DAS. Dusty conditions were also limited. The tractor cab was sealed well with plastic sheets to keep the dust out. The field at MSU and field 3 near St. Johns had some straw on the surface. The straw did not inhibit the performance of the tractor or the implements.

6.2 Equipment and Instrumentation Performance

The experiments were performed with implements that were available from farmers near St. Johns and with implements that were available from the MSU farms. None of the implements were specially designed or adapted for test purposes. In all of the operations, the experiments were conducted as part of the farmers' field work as they prepared the seedbeds and later planted. In all cases, the testing operations were performed with the instrumented tractor.

The success of the experiments was dependent on the accuracy of the transducers and the reliability of the DAS. The ground speed, front and rear wheel speeds and the engine speed were verified in the field to assess the consistency of the calibration equations. In all cases it was established that the system was working accurately.

The data were sampled by copying from the computer monitor for checking the accuracy and performance of the transducers and the DAS. After each day's experiments a block of twenty data sets from each experiment was read from the computer monitor. Subsequent preliminary analysis provided an indication of how the system was running. In each case the system was found to be performing satisfactorily.

After the first phase of the experiments, all of the data were retrieved into an IBM compatible computer system for further preliminary analysis. This was necessary to establish if there was need for repeating any of the tests before proceeding to the next phase. None of the tests was repeated.

6.3 Data Retrieval

In order to facilitate data processing and analysis, transferring the data to an IBM compatible computer system was desirable. This process was done by using two programs, one for each of the computer systems. The Apple IIe used an ASCII Express program that communicated with a Modem 7 PC IBM compatible communications package. This process was possible because the data were stored in ASCII form. The physical connection between the two computers was done with a crossover cable-RS232 that was connected through the serial ports of the two computers. The detailed data transfer procedure is available in Appendix E.

The initial processing of the data was performed with the Lotus 123 program. All data were then converted to the respective values using the regression equations and the conversion factors for each transducer. Basic statistics of each data file were computed and summarized as in Appendix F. These statistics consisted of the maximum value, minimum value, average and standard deviation for each variable.

Appendix G lists a complete printout of one typical raw data file. The list includes all of the 500 data sets consisting of 3,000 data points for the 6 transducers. The units of the data are in millivolts (mV). The first column shows the time intervals as the DAS sampled the data at the rate of 20 data sets per second.

6.4 Parameter Calculations

The average value of each transducer output was used to compute the various parameters used for the experimental analysis. Details of the calculations performed for each tillage system are provided here. Table 6.1 provides a summary of the mean values of the soils data (cone index and moisture content) for each of the fields. The mean engine speed, mean wheel slip and the mean effective field capacity for each of the implements used in the tillage systems are also shown in the table according to the soils worked on. The mean fuel and energy consumption values (derived from the primary data) are summarized here too.

Table 6.1 Summary of the Tillage Data.

Soil Type	Tillage System	Implement	Cone Index kPa	Soil M.C. %	Eng. Speed rpm	Ground Speed Km/h	Wheel Slip %	EFC ha/h	Fuel L/ha	Consumption L/kWh	Draft kN	Drawbar Power kW	Implement Energy kWh/ha	Field Used	TE %
Capac Loam	Conv.	Field cultivator	1560	12.5	1673	6.7	12	2.5	5.2	0.59	11.6	21.9	8.8	MSU	74
		Moldboard plow	1943	12.3	1652	6.7	16	0.6	21.2	-	-	-	-	MSU	-
		Disk harrow	1600	12.3	1617	5.2	21	1.8	6.4	0.57	13.7	19.7	11.2	MSU	69
		Grain drill (15)*	1465	11.2	1838	7.6	5	1.5	6.5	0.87	5.4	11.3	7.5	MSU	68
		Grain drill (21)	1465	11.2	1954	7.9	4	1.9	4.4	1.40	2.7	5.9	3.0	MSU	63
	Conser.	Field cultivator	1560	12.5	1736	6.9	15	2.5	2.9	0.61	7.7	18.4	7.4	MSU	72
		Chisel plow	1943	19.7	1803	6.8	22	1.3	12.7	0.47	18.4	34.8	27.3	MSU	70
		Disk harrow	1600	12.3	1656	5.4	15	1.8	5.4	0.55	12.1	17.9	9.8	MSU	73
		Grain drill (15)	1560	11.2	1888	7.8	7	1.5	8.5	1.22	5.0	10.8	6.9	MSU	72
		Grain drill (21)	1560	11.2	2054	7.8	9	1.9	4.6	1.60	2.5	5.5	2.8	MSU	70
		Disk harrow (Minimum tillage)	1943	12.3	1635	5.8	10	1.9	4.9	0.55	11.0	17.8	8.9	MSU	76
	No-till	Grain drill (15)	1943	12.2	1735	7.8	2	1.6	5.1	1.01	3.3	7.2	4.6	MSU	70
		Grain drill (21)	1943												
		Row planter (6)	888	12.2	1800	4.8	10	1.2	8.8	0.81	9.9	13.3	11.1	1	64
Owosso-Marlette sandy loam	Conv.	Moldboard plow	1695	14.9	1707	6.9	15	1.3	13.5	0.58	16.1	30.8	23.0	3	71
		Disk harrow	1191	-	1850	6.8	13	2.1	4.7	0.70	8	15	7		75
		Grain drill (10)	589	12.5	1784	5.8	-	0.7	8.6	0.91	4.4	7.0	9.5	3	-
	Conser.	Chisel plow	1787	14.9	1800	6.6	27	1.4	13.8	0.55	19.2	35.1	25.2	3	66
		Disk harrow		missing											
		Grain drill (10)	589	12.5	1750	5.6	-	0.7	6.8	0.95	3.3	5.1	7.1	3	-
Metamora Capac	Conv.	Moldboard plow	1666	14.5	1658	6.9	16	1.4	9.3	0.50	12.9	25.1	18.5	3	74
		Disk harrow	348	13.5	1650	7.9	8	2.5	4.5	0.59	8.7	19.1	7.6	2a	54
		Grain drill		12.5	1800	5.8	12	0.8	8.6	1.00	4.4	7.0	8.3	3	60
	Conser.	Chisel plow	1839	14.5	1850	7.8	18	1.7	7.8	0.50	12.1	26.3	15.9	3	62
		Disk harrow	348	13.5	1650	8.1	10	2.1	5.9	0.73	7.5	16.9	8.2	3	53
		Grain drill (10)		12.5	1750	5.6	11	0.8	6.7	1.00	3.2	5.1	6.2	3	58
	No-till	Grain drill (10)	658	14.5	1850	6.9	15	1.5	5.8	1.58	2.9	5.7	3.8	3	60
Granby loamy sand	Conv.	Moldboard plow													
		Disk harrow	581	17.5	1800	7.2	26	1.8	5.6	0.56	8.6	17.3	9.8	2a	55
		Grain drill (18)	581	17.5	1849	6.0	10	1.3	6.1	1.05	4.5	7.4	5.7	2a	48
		Grain drill (10)	581	17.5	1780	5.6	12	0.7	10.3	1.00	4.7	7.3	10.1	2a	76
	No-till	Grain drill (10)	1513	20.3	1850	5.9	7	0.8	7.3	0.91	3.6	6.1	7.9	2a	76
Palms muck	Conv.	Disk harrow	531	19.3	1620	8.0	25	1.9	6.1	0.81	6.5	14.5	7.4	2b	53
		Grain drill (18)	581	17.5	1759	6.0	17	1.3	5.3	1.00	3.6	6.2	4.7	2b	72
	No-till	Row planter (6)	1513	20.3	1567	5.6	19	1.4	6.2	0.81	6.7	10.4	7.5	2b	71
		Grain drill (10)	1513	20.3	1574	5.7	15	0.7	8.1	1.10	1.1	1.8	2.5	2b	64
		Grain drill (18)	1513	20.3	1850	5.7	17	1.2	5.8	0.95	4.8	7.6	6.2	2b	58

* Number of rows

The chisel plow registered the highest wheel slip (27 per cent) in Owosso-Marlette sandy loam soil when operating at 6.6 Km/h and demanded the highest mean drawbar power (35.1 kW). The grain drill recorded the lowest wheel slip in Capac loam soil (2 per cent). The field cultivator, operating in Capac loam soil, had the highest tractive efficiency of 74 per cent. The moldboard plow fuel consumption in Capac loam soil was rather high at 21.2 L/ha. This could have been caused by the dry field condition as the mean moisture content was 12.3 per cent. The computations of the parameters summarized in Table 6.1 are described as follows:

(i) The effective field capacity (EFC) for each implement was calculated using the optimum field efficiency as provided by the ASAE D497, Standards (1990), the implement width (W) and the operational speed (S). Table 6.2 shows the values of field efficiency used for the computation of EFC.

$$EFC = \frac{S(Km/h) \times W(m)}{10} \times Eff.(dec.)$$

Table 6.2 Implement Field Efficiency

Implement	Field Efficiency (per cent)
Moldboard plow	80
Chisel plow	85
Field cultivator	85
Disk harrow (Tandem)	85
Row crop planter (No-till)	65
Grain drill	70

(ii) The implement energy requirement (kWh/ha) was calculated using the drawbar power and the EFC as shown here:

Implement energy, kWh/ha:

$$\frac{kWh}{ha} = kW \times \frac{1}{EFC}$$

(iii) The fuel consumption was computed using two methods based on the EFC, the measured fuel consumption per hour and the drawbar power, thus:

Liters per hectare, L/ha:

$$\frac{L}{ha} = \frac{L}{hr} \times \frac{1}{EFC}$$

Specific fuel consumption, L/kWh:

$$\frac{L}{kWh} = \frac{ha}{kWh} \times \frac{L}{ha}$$

(iv) Calculation of the tractive efficiency (TE) for each implement and field condition was performed using the cone index (CI) values, the wheel slip, draft force and the dynamic weight on each tractor axle. The dynamic weight was computed using the draft force of the implement, the tractor's static weight, the tractor's hitch geometry and the height of the drawbar.

This calculation was done for the respective axles. The mean of the two was used as the overall TE. The calculation was done using the ASAE D497 Standards (1990) equation shown below. The tractor data used in computing the TE is provided in table 6.3.

$$TE = (1-s)\left(1 - \frac{\frac{1.2}{C_n} + 0.04}{0.75(1-e^{-0.3C_{ns}})}\right)$$

where:

s = slip (decimal)

$$C_n = \frac{CI \times b \times d}{W}$$

CI = Cone index, N/cm^2
b = Unloaded tire section width, cm.
d = Unloaded overall tire diameter, cm.
W = Axle dynamic weight, N.

The static weight of the tractor was 44,200 N.

Table 6.3 Specifications of Tractor Tire Size.

	Unloaded b (cm)	Tire Size d (cm)	Drawbar Height cm
Rear	34.5	131	30
Front	36.0	100	--

6.5 Comparative Performance of Tillage Systems

The data on the different soil types used for experiments were analyzed to determine the variation of the energy and fuel consumption and the power demand for various tillage systems and implement combinations. Three of the soils that had complete data for comparison are shown in Table 6.4 with the summary of fuel and energy requirement data. This summary provides the total fuel and energy needs for the three tillage systems including planting. The fuel and energy requirements for the conventional tillage system were higher than that of the conservation tillage system for all the three soil types.

6.5.1 Owosso-Marlette Sandy Loam Soil

The data summary in Table 6.4 shows that the fuel consumption for the conventional tillage system required 4.7 liters of fuel per hectare more than the conservation tillage system. Similarly 40 per cent more implement energy (kWh/ha) was required by the conventional tillage system as compared to the conservation tillage system. Specific fuel requirements also indicated 22.9 per cent more L/kWh for the moldboard plow-based system as compared to the chisel plow-based tillage system. The row crop planter required 5.1 L/ha of fuel and 4.6 kWh/ha of energy for the single field operation of no-till planting. The fuel and energy required for weed control was not accounted for in any of the three tillage systems.

A 2.5 m chisel plow required about 18 per cent more drawbar power than a 2.4 m moldboard plow. The chisel plow

Table 6.4 Fuel and Energy Requirements for Tillage Implements.

Implement	Fuel Consumption			Energy Consumption			Speed Km/h	Depth cm	EFC ha/hr
	L/hr	L/ha	L/kWh	kN	kW	kWh/ha			
Owosso-Marlette sandy loam									
Conventional:									
M/Board plow	17.9	13.5	0.58	16.1	30.8	33.2	6.9	13	0.77
Disk harrow	9.4	6.3	1.30	5.4	10.5	5.3	7.0	---	1.80
Grain drill	8.6	8.6	0.96	4.4	7.0	9.5	5.8	---	0.74
TOTAL:	35.9	28.4	2.84			48.0			
Conservation:									
Chisel plow	19.9	10.9	0.55	15.4	36.5	20.1	8.5	15	1.82
Disk harrow	9.8	6.0	0.81	6.0	12.3	6.9	7.0	---	1.82
Grain Drill	6.8	6.8	0.95	3.3	5.1	7.1	5.6	---	0.72
TOTAL:	36.5	23.7	2.31			34.1			
No-Till:									
Row planter	10.5	8.8	0.81	9.9	13.3	11.1	4.8	---	1.20
Grain drill	7.9	5.1	1.09	3.3	7.2	4.6	7.8	---	1.56
Metamora-Capac loam									
Conventional:									
M/Board plow	11.8	11.8	0.55	14.8	21.2	21.1	5.2	13	1.00
Disk harrow	9.2	5.2	1.10	4.4	8.4	4.8	6.9	---	1.76

Table 6.4 (Cont'd).

Grain drill	7.8	8.5	0.90	4.6	7.1	9.7	6.0	---	0.69
TOTAL:	28.8	25.5	2.55			35.6			
Conservation:									
Chisel plow	12.3	10.7	0.55	14.8	22.3	19.3	5.4	15	1.15
Disk harrow	9.9	5.6	0.79	6.4	12.5	7.1	7.0	---	1.78
Grain drill	7.2	7.0	0.85	3.9	6.1	7.3	5.7	---	0.80
TOTAL:	29.4	23.3	2.19			33.7			
No-Till:									
Grain drill	6.1	11.1	2.47	2.2	2.7	4.9	4.3	---	0.55
Capac Loam									
Conventional:									
Field c'vator	11.7	4.7	0.61	7.7	18.4	7.4	6.9	---	0.61
M/Board plow	8.9	15.9	---	---	---	---	5.8	13	0.56
Disk harrow	11.3	1.8	0.57	13.7	19.7	11.2	5.2	---	1.80
Grain drill	9.8	6.5	0.87	5.4	11.3	7.5	7.6	---	1.50
TOTAL:	41.7	28.9	2.05			26.1			
Conservation:									
Chisel plow	16.3	16.9	0.53	20.6	30.8	30.5	5.4	---	1.01
Disk harrow	9.9	5.4	0.55	12.1	17.9	9.8	5.4	---	1.83
Grain drill	8.5	8.5	1.22	5.00	10.8	6.9	7.8	---	1.54
TOTAL:	34.7	30.8	2.30			47.2			

Table 6.4 (Cont'd)

No-till:									
Row planter	10.5	8.8	0.81	9.9	13.3	11.1	4.8	---	1.20
Grain drill	7.9	5.1	1.09	3.3	7.2	4.6	7.8	---	1.56
Palms muck									
Conventional:									
Disk harrow	11.9	6.1	0.82	6.5	14.5	7.4	8.1	---	1.95
Grain drill	7.2	5.8	0.95	4.8	7.6	6.2	5.7	---	1.23
Row planter	8.4	6.4	0.79	6.7	10.7	8.2	5.7	---	1.31
TOTAL:	27.5	18.3	2.56			21.8			
No-Till									
Row planter	8.7	6.23	0.84	6.7	10.4	7.5	5.6	---	1.39
Grain drill	5.9	8.12	3.35	1.1	1.8	2.5	5.7	---	0.73

was operated at 15 cm depth while the moldboard plow was working at 13 cm depth. These results are shown in Figure 6.1.

From the data on ground speed and fuel consumption, prediction equations for estimating the fuel and energy consumption for both moldboard and chisel plows in the Owosso-Marlette soil type were derived using PLOTIT regression analysis. The prediction graphs and their equations are shown in Figures 6.2 through 6.5. Figures 6.2 and 6.3 are used to determine the fuel requirement (L/hr) for the moldboard and chisel plow respectively using the ground speed as the independent variable.

The energy prediction for the same implements are shown in Figures 6.4 and 6.5. The energy consumption (kWh/ha) is correlated against the fuel consumption (L/ha). The coefficient of correlation in the two sets of predictions ranged between 0.999 and 0.989. This implies that there are other factors that affected the relationships that were not taken into account and hence the variation of the coefficient. For instance the soil moisture content, the soil shear strength and the wheel slip were variables that could have influenced the results. The mean moisture content was 14.9 per cent while the mean cone index value was 1695 kPa and 1787 kPa for the moldboard and chisel plow respectively. The mean wheel slip for the moldboard plow was 15 per cent while that of the chisel plow was 27 per cent (Table 6.1).

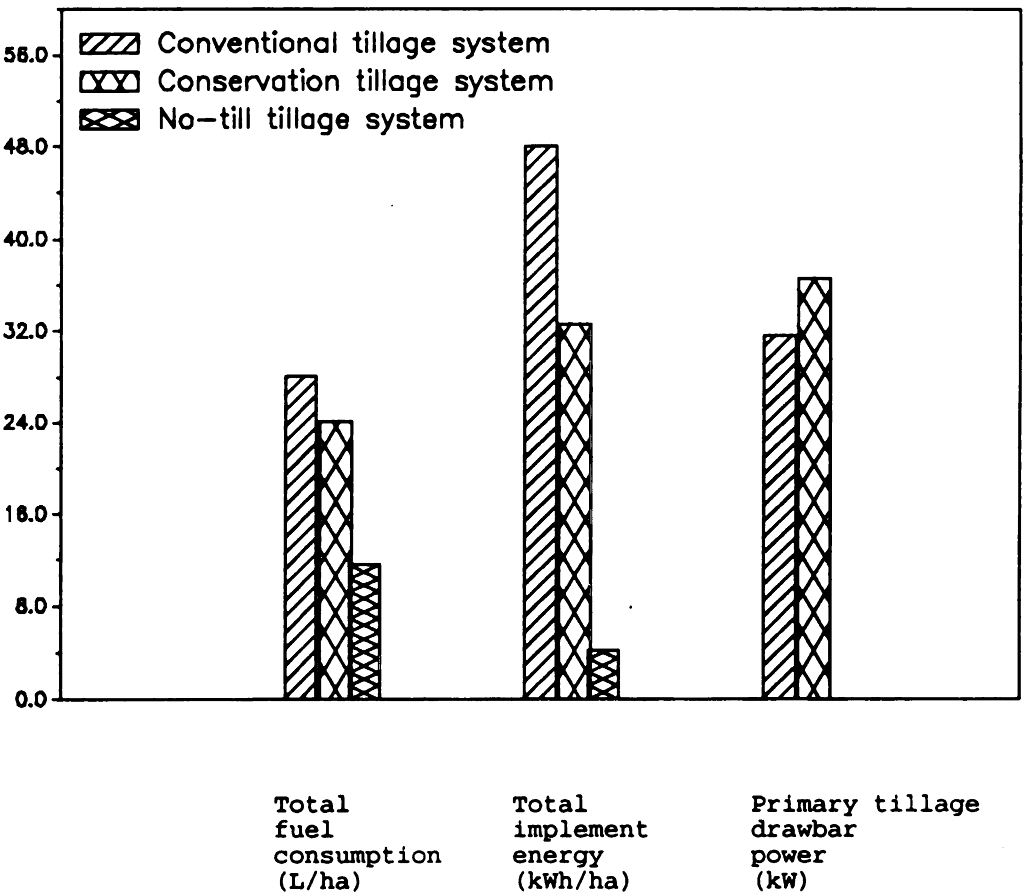

Figure 6.1 Comparative fuel and energy consumption in Owosso-Marlette sandy loam soil.

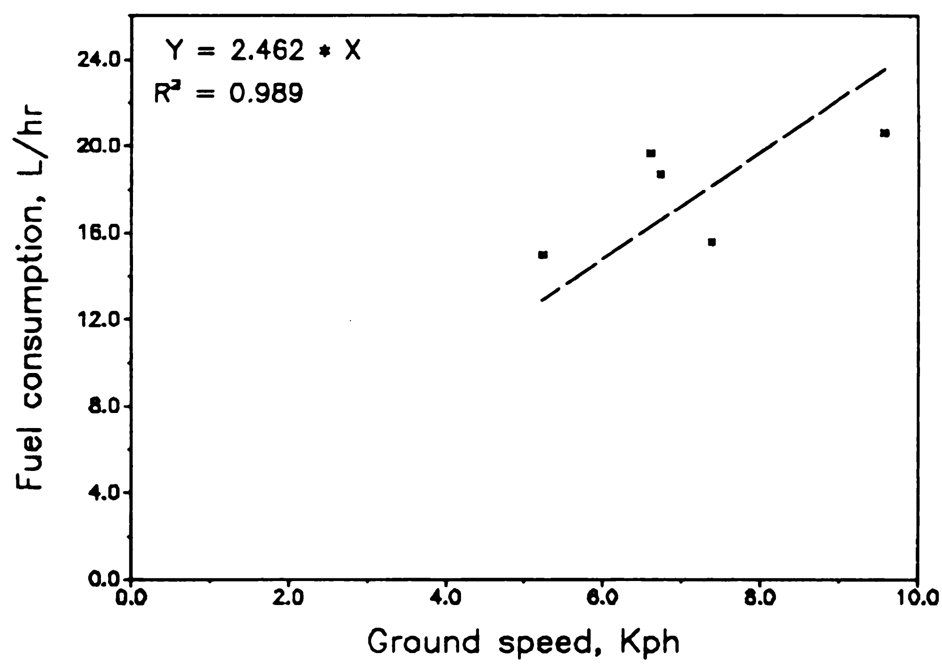

Figure 6.2 Estimation of fuel consumption for moldboard plow in Owosso-Marlette sandy loam soil.

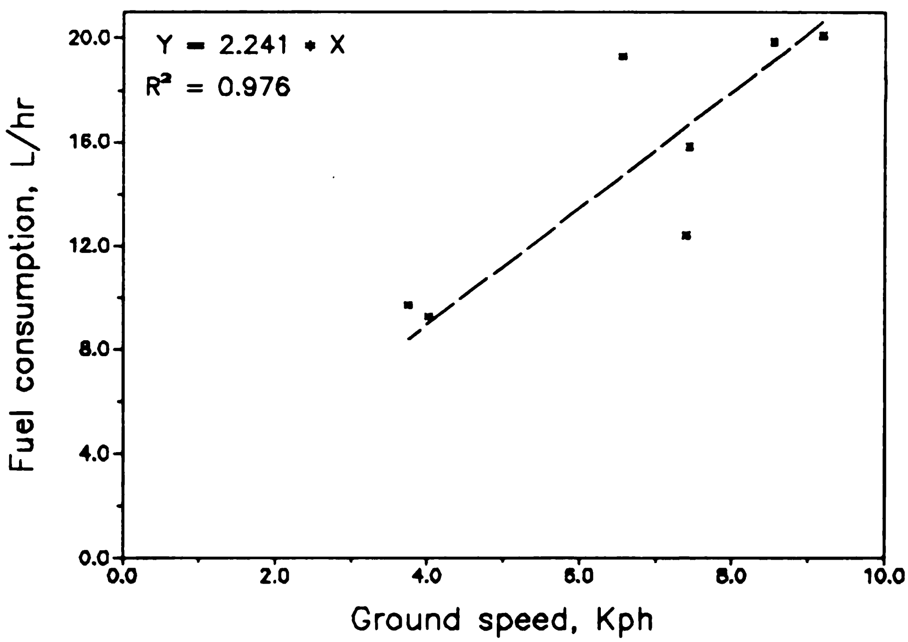

Figure 6.3 Estimation of fuel consumption for chisel plow in Owosso-Marlette sandy loam soil.

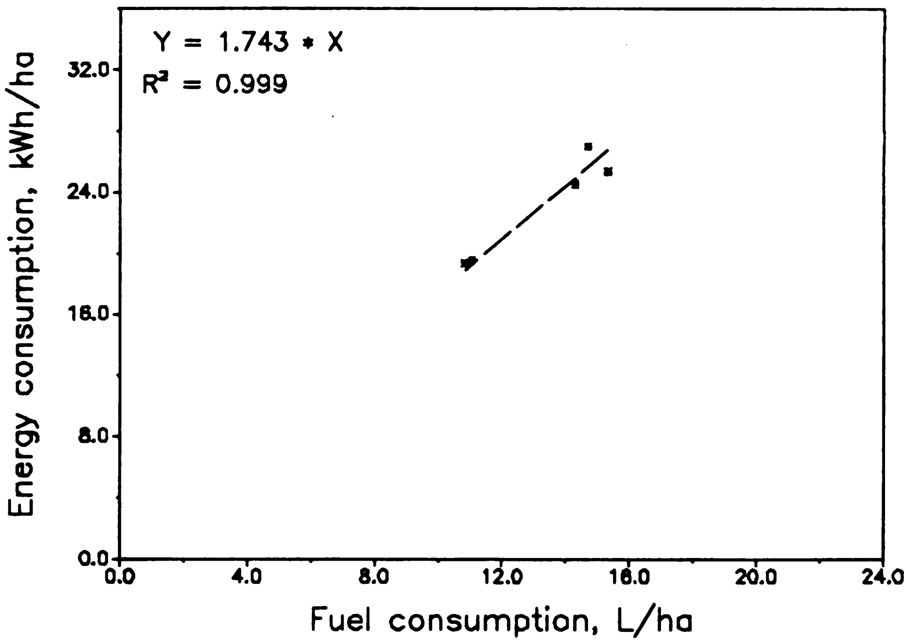

Figure 6.4 Estimation of energy consumption for moldboard plow in Owosso-Marlette sandy loam soil.

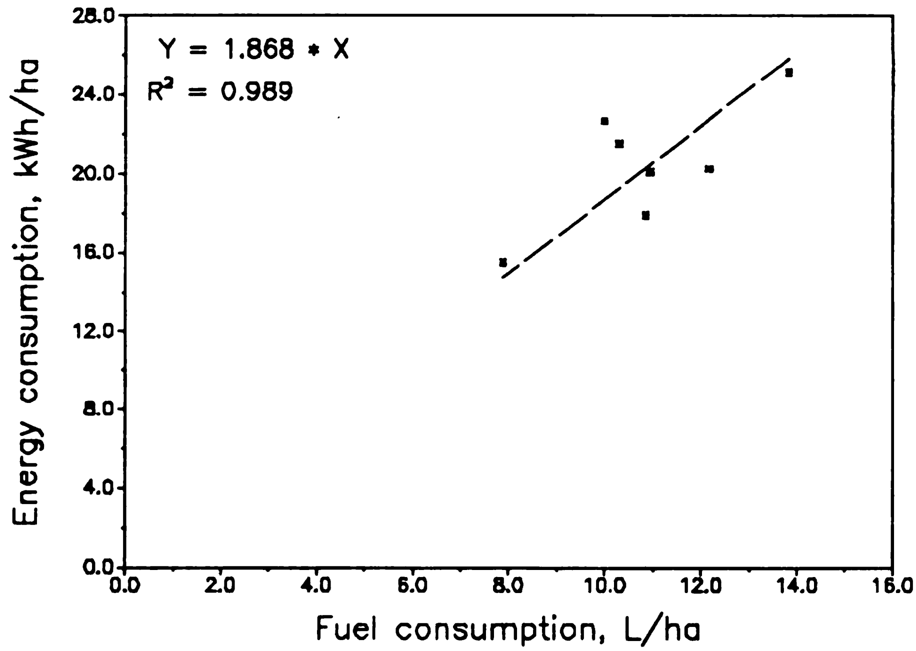

Figure 6.5 Estimation of energy consumption for chisel plow in Owosso-Marlette sandy loam soil.

6.5.2 Metamora-Capac Sandy Loam

A similar trend was observed in the Metamora-Capac sandy loam soil. The conventional moldboard plow-based tillage system required about 5 per cent more implement energy per hectare (kWh/ha) and 2.2 L/ha more fuel than the chisel plow-based conservation tillage system. The results of the demand of the specific energy requirements also showed about 16 per cent more fuel per kilowatt-hour (L/kWh) for the conventional tillage system.

The no-till grain drill required 12.2 L/ha less fuel than the conservation tillage system for the planting operation only. Fuel and energy used for the weed control was not accounted for. The power demand showed that the chisel plow demanded 0.9 kW more than the moldboard plow operating at the same depths as in the Owosso-Marlette sandy loam soil. These comparative results are shown in Figure 6.6.

Figure 6.7 represents the regression analysis of the fuel consumption for the chisel plow-based tillage system based on the ground speed as the independent variable. The coefficient of correlation was 0.990. The regression of the energy consumption for the moldboard plow is shown in Figure 6.8 with a coefficient of correlation value of 0.985. The mean moisture content for the soil was 14.5 per cent while the mean one index was 1666 kPa and 1839 kPa for the conventional and conservation tillage system respectively (Table 6.1). Figure 6.9 shows the prediction for the fuel consumption for the 18 row no-till grain drill using the ground speed as the

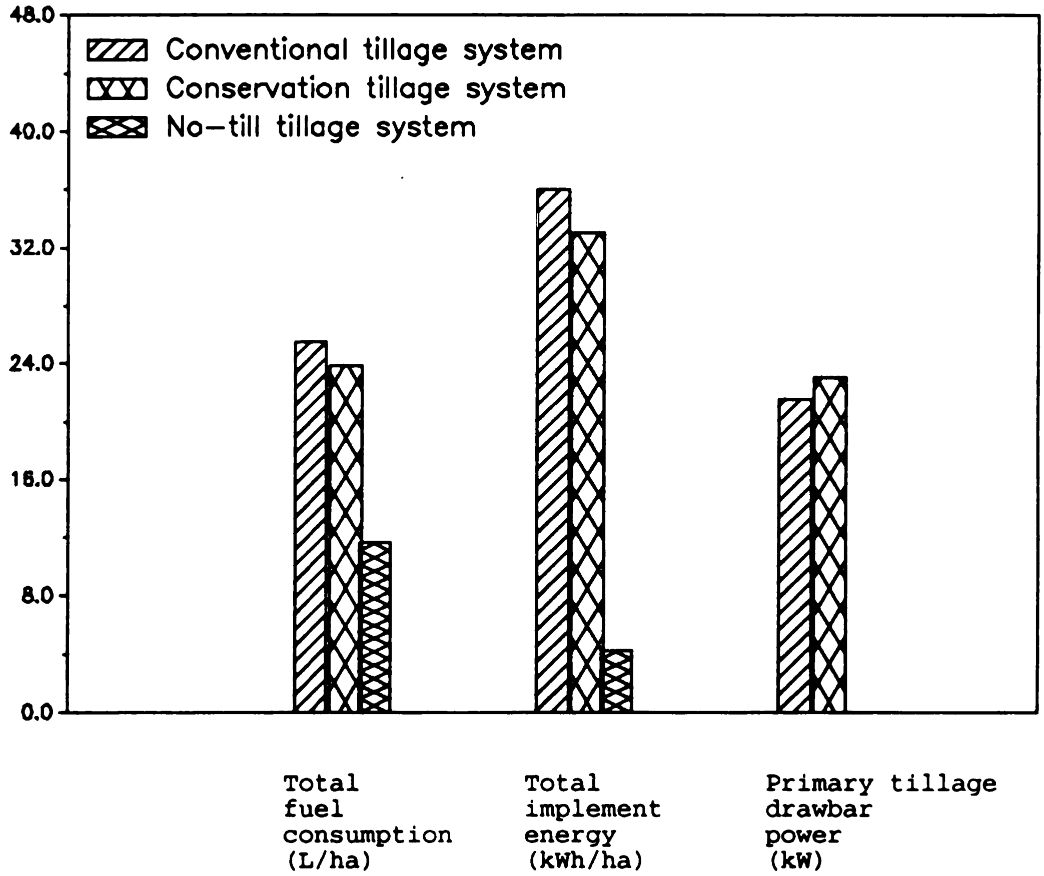

Figure 6.6 Comparative fuel and energy consumption in Metamora-Capac sandy loam soil.

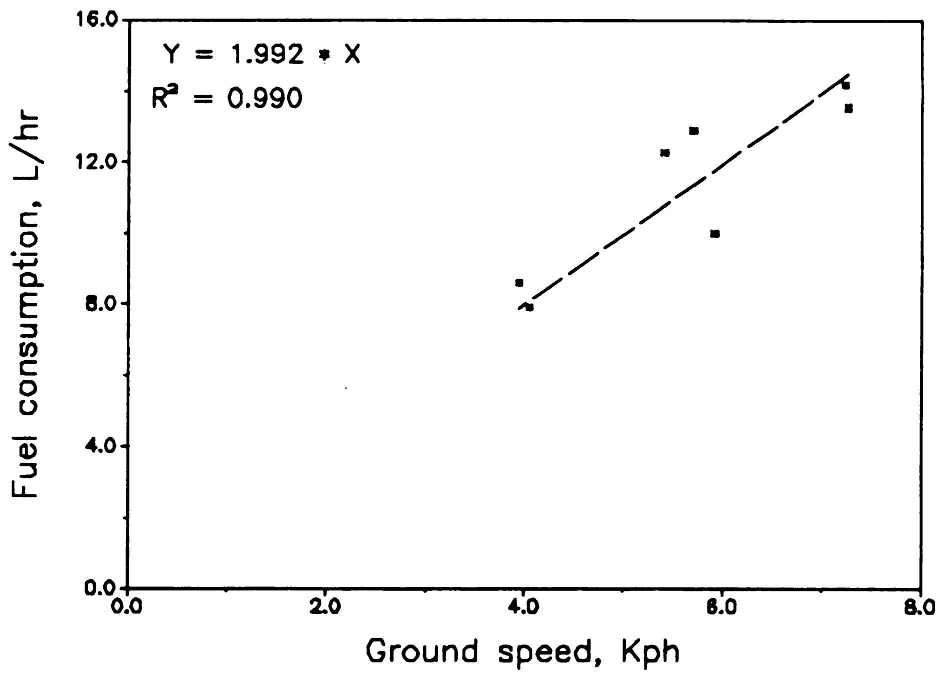

Figure 6.7 Estimation of fuel consumption for chisel plow in Metamora-Capac sandy loam soil.

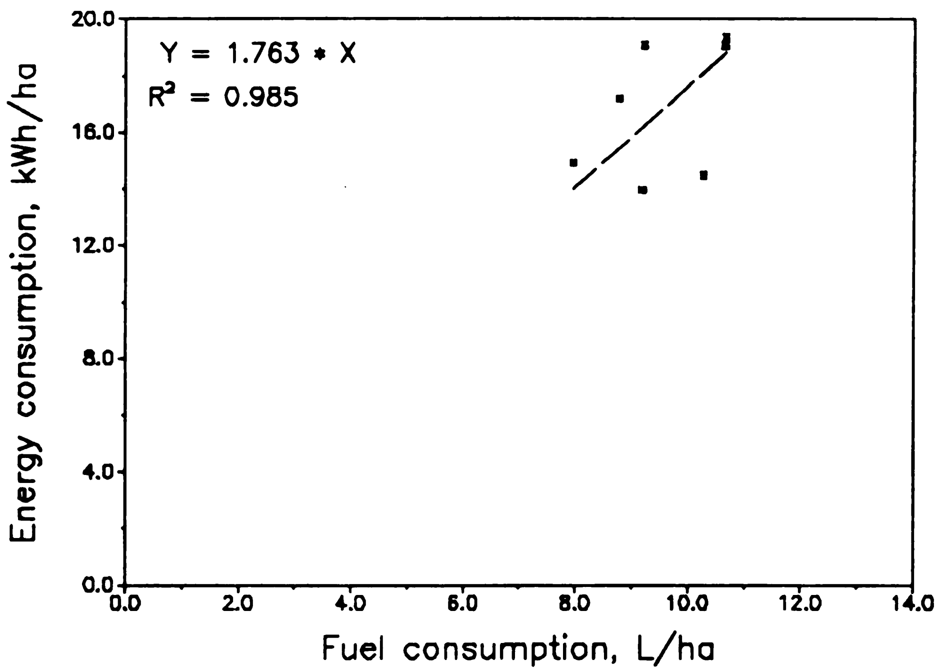

Figure 6.8 Estimation of energy consumption for chisel plow in Metamora-Capac sandy loam soil.

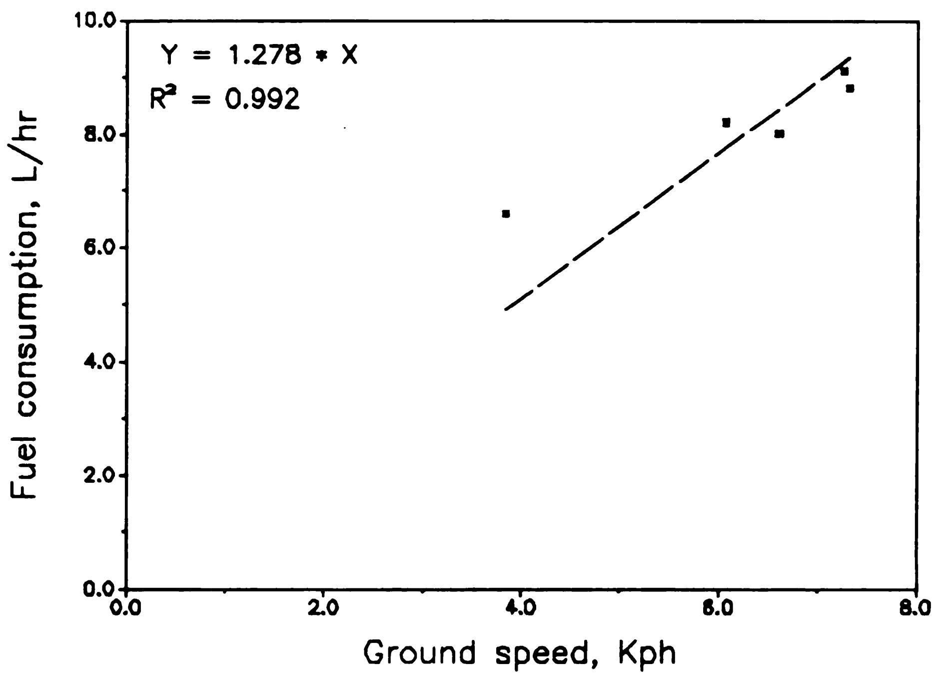

Figure 6.9 Estimation of fuel consumption for the 18 row no-till grain drill in Metamora-Capac sandy loam soil.

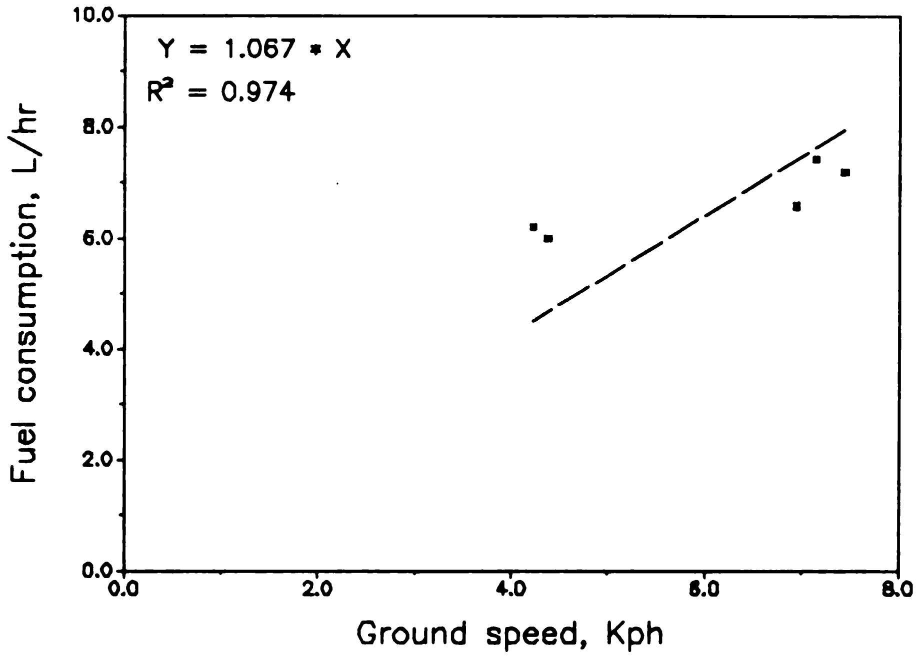

Figure 6.10 Estimation of fuel consumption for the 10 row no-till grain drill in Metamora-Capac sandy loam soil.

independent variable. The value of the coefficient of correlation was 0.992 for a mean soil moisture content of 14.5 per cent and a mean cone index value of 658 kPa. Figures 6.9 and 6.10 represent the prediction of fuel consumption for an 18 row and a 10 row no-till grain drills operated in the same soil. The coefficient of correlation for the 18 row grain drill was 0.992 whereas that of the 10 row grain drill was 0.974.

The variability of the coefficients of correlation for the regression analysis were due to other variables affecting the fuel and energy consumption. These variables which included the soil moisture content, soil shear strength, and tractor wheel slip were measured but not accounted for in the regression analysis.

6.5.3 Capac Loam Soil

The experiments performed in the Capac loam soil did not include the draft measurement for the moldboard plow. The results showed that the conservation tillage system demanded about 56 per cent more implement energy than the conventional tillage system without the moldboard plow. Similarly the fuel requirement for the conservation tillage was 1.9 L/ha more than that of the conventional tillage system. The specific fuel consumption showed 0.25 L/kWh more was demanded by the conservation tillage system as compared to the conventional tillage system. These results are shown in Table 6.4 referred to earlier.

Table 6.5 was extracted form Table 6.4 and it provides a summary of the specific fuel and energy requirements for the three soil types. In two of the soils (Owosso-Marlette and Metamora-Capac sandy loam) the conventional tillage system resulted with higher values of the fuel and energy requirement than the conservation tillage system. The Capac loam soil showed contradicting results due to lack of draft force data.

6.6 Discussion

The results obtained from the data collected show consistently that the fuel and energy requirements for the conventional tillage system were higher than those of the conservation tillage systems. These observations are in agreement with what was documented in the literature cited. In the experiments performed by Zwilling and Hummel (1988), the conclusions drawn were that the conventional tillage system requirements ranged from 25.8 to 45.7 L/ha as compared to minimum tillage requirement that was between 17.2 and 25.3 L/ha.

On average the no-till tillage system used for the experiments provided a saving of 23.7 L/ha in comparison with conventional tillage system. Conservation tillage system also provided a saving of 4.7 L/ha as compared to the conventional tillage system. Vaughan (1977) documented similar savings. In his experiments on tillage systems he obtained savings of 13 L/ha for the reduced tillage and 38 L/ha for the no-till tillage system.

Table 6.5 Specific Fuel and Energy Requirements.

Tillage System	Soil Type		
	Owosso-Marlette	Metamora-Capac	Capac
	(kWh/ha)		
Conventional	48.0	35.6	26.1
Conservation	34.1	33.7	47.2
No-Till:			
Row planter	11.1	---	4.8
Grain drill	4.6	4.9	7.8
	(L/ha)		
Conventional	28.4	25.5	30.8
Conservation	23.7	23.3	28.9
No-Till:			
Row planter	8.8	---	8.8
Grain drill	5.1	11.1	5.1
	(L/kWh)		
Conventional	2.84	2.55	2.05
Conservation	2.31	2.19	2.30
No-Till:			
Row planter	0.81	---	0.81
Grain drill	1.09	2.47	1.09

The implement combinations determine the amount of energy used for tillage. In the summary of energy and fuel use data shown in Table 6.4, only one disk harrow operation was taken into account. If the farmer chose to perform several disk harrow operations, it is expected that the energy used for the subsequent disking would not differ significantly from that used in the first disking. In both conventional and conservation tillage systems, the first disk harrow operations required about the same amount of fuel in Owosso-Marlette and Metamora-Capac soils as shown in Table 6.4

CHAPTER 7

CONCLUSIONS

The field experiments performed on three tillage systems in three soil types were analyzed and the results showed that the following conclusions could be made with regard to the fuel and energy consumption:

1. The fuel consumption measurements done with the PDP1 fuel flow meter and the draft force measured with the drawbar instrumentation can be used to predict the energy requirement of implements for various ground speeds.

2. The fuel and energy requirement per hectare basis for the moldboard plow-based tillage system was found to be consistently higher than for the chisel plow-based tillage system. This implies that moldboard plow-based tillage system would require a higher energy level input than the chisel plow-based tillage system.

3. The drawbar power requirement for the chisel plow was higher than that of the moldboard plow in Owosso-Marlette and Metamora-Capac soils for the same width of implement. This was for a depth of 13 cm for the moldboard plow and 15 cm for the chisle plow.

4. The specific energy requirement (kWh/ha) for the conventional tillage system was higher than that of the conservation tillage system.

5. The chisel plow has a higher effective field capacity (EFC) than the moldboard plow. Hence, though the chisel plow would require a larger tractor to operate than the moldboard plow, the rate of work would be higher and the overall energy demand to operate it would be less.

CHAPTER 8

RECOMMENDATIONS FOR FURTHER RESEARCH

During the course of the experiments, some observations that would improve future research in this area were made. The following are some useful recommendations to be noted in conducting similar experiments:

1. There is need to establish the fuel equivalent value for the chemical energy used in the weed control for the tillage systems. This would enable a comprehensive comparison of the total fuel and energy use to be made.
2. Measurement of the left hand wheel speeds was not done. This could be computed by using the known speed of the right hand wheels. The gear ratio of the transmission, differential and the final drive would provide the required relationship given that the differential speed is the mean of the final drive speeds. The overall wheel slip for the respective axles in front wheel assist mode would then be the mean of the right and left hand wheel slip.
3. The depth of tillage was not used as a variable in the experiments. Varying this factor would enable comparison of the tillage systems to be made at various ground speeds and depths.

APPENDICES

APPENDIX A

APPENDIX A

TRACTOR SPECIFICATIONS

Item	Specification
Make and model	Ford 7610
Power rating	65 kW (PTO)
Engine	Cylinders : 6 Displacement: 4393 cc
Rated engine speed	2100 rpm
High idle speed	2600 rpm
Transmission	Ranges: 2 Gears : 8
Rear tires	18.4 x 34
Front tires	13.6 x 24
Static weight	44200 N
Wheel base	2.25 m

APPENDIX B

IMPLEMENT SPECIFICATIONS

A total of six implement types were used for the experiments. These consisted of two moldboard plows, two chisel plows, one field cultivator, four disk harrows, one row crop planter and six grain drills. The specifications for each of these is provided here.

APPENDIX B

IMPLEMENT SPECIFICATIONS

Implement	Make and Model	Width m	# of Tools Rows	Field Used	Comments
Moldboard plow	Melroe 900 Series	2.4	6	3	Pull type 40 cm bottoms
Moldboard plow	International 450	1.2	3	MSU	Fully mounted 40 cm bottoms
Chisel plow	FEMA	2.5	7	3	Tines 38 cm apart
Chisel plow	White Farm Equipment	2.2	8	MSU	Tines 40 cm apart
Field cultivator	Glencoe 300	4.3	25	MSU	Sweeps 15 cm wide
Disk harrow	Allis Chalmers	3.9	-	2a, 2b	Tandem, 8 plain disks
Disk harrow	John Deere	3.0	-	2a, 2b	Tandem, 8 plain disks
Disk harrow	No name	3.2	-	3	Tandem, 9 plain disks
Disk harrow	John Deere Dura Cushion	4.3	-	MSU	Tandem, 8 plain disks
Row crop	John Deere 700	3.8	6	1	Modified for No-till

Appendix B (cont'd)

Grain drill	Tye Pasture Pleaser	1.8	10	2a, 2b, 3	20 cm row spacing
Grain drill	Vermeer 107	3.0	18	2b	17.8 cm row spacing
Grain drill	John Deere	3.6	21	MSU	17.7 cm row spacing
Grain drill	Tye	2.8	15	MSU	23 cm row spacing

APPENDIX C

SPECIFICATIONS AND CALIBRATION OF TRANSDUCERS

The specifications of the transducers used for obtaining the signals from the six data sources are provided here. The trade names and the sources from which they were obtained are also provided. The six transducers included the following:

1. Radar ground speed sensor
2. Engine RPM sensor
3. Front wheel speed sensor
4. Rear wheel speed sensor
5. Draft force strain gages
6. Fuel flow meter sensor

APPENDIX C

SPECIFICATIONS AND CALIBRATION OF TRANSDUCERS

Appendix C.1: Radar ground speed sensor

Sensor Origin:	Dickey john Corporation.
Velocity range:	0 to 80 Km/h
Accuracy (Typical):	±1% at 35 degrees mounting angle.
Recommended mounting angle:	Beam center to plane of earth. should be 35 degrees ±2 degrees.
Supply Voltage:	Unregulated battery voltage, 11 to 18 VDC.
Supply Current:	300 mA.
Output Signal:	Output frequency 100 Hz/m/sec (44.7 Hz/mph). Output voltage amplitude maximum low level 6 volts, minimum high level 7 volts.

Calibration procedure:

1. Determine the maximum ground speed of operation:

$$\frac{12.8Km}{hr} x \frac{1000m}{Km} x \frac{1hr}{3600sec} x \frac{100Hz}{m} x \ sec = 355.56Hz$$

2. Connect the transducer to the signal conditioner and the frequency generator.
3. Select the ground speed channel on the signal conditioner.
4. Select the calibration mode on the signal conditioner.
5. Boot the computer and run AI13 software for calibration.
6. Determine the gain code for the transducer depending on the signal conditioner output in mV.
7. Generate at least ten frequencies with the frequency generator within the above maximum level of 355.56 Hz.
8. For each frequency, compute the accurate reading from the signal conditioner and log the reading into the computer.
9. After logging ten or more frequency readings, run the calibration program for the calculation of the regression formula.

Calibration response equation:

$$Hz = mV \ x \ 0.098 + 2.278$$

Appendix C.2: Engine RPM sensor

Sensor Origin: Dickey john Corporation.
Specifications: 30 to 4000 Hz.
$3\ V_{p-p}$
4 pulses per engine revolution.

Calibration procedure:

1. Determine maximum rotational engine speed:

$$\frac{2100\ rev}{min} \times \frac{1}{60} = \frac{35\ rev}{sec}$$

2. Determine frequency at maximum engine speed:

$$\frac{2100 engrev}{1 min} \times \frac{4 pulse}{1 engrev} \times \frac{1 min}{60 sec} = 140 Hz$$

3. Connect the transducer to the signal conditioner and the frequency generator.
4. Select the engine speed channel on the signal conditioner.
5. Select the calibration mode on the signal conditioner.
6. Boot the computer and run AI13 software for calibration.
7. Determine the gain code for the transducer depending on the signal conditioner output in mV.
8. Generate at least ten frequencies with the frequency generator within the above maximum level of 140.00 Hz. preferably in steps of 10 or 20 Hz.
9. For each frequency, compute the accurate reading from the signal conditioner and log it into the computer.
10. After logging ten or more frequency readings, run the calibration program for the calculation of the regression formula.

Calibration response equation:

$$Hz = mV \times 0.089 + 1.694$$

<u>Appendix C.3: Front and rear wheel rotational speed.</u>

Sensor Origin: Wabash Inc.
Type and Model: Magnetic pick up (cylindrical pole piece 60-0198"G", 2.5 inches reach).
Specification: 14 V p-p at 30 inches per second. 0.050" air gap.

<u>Calibration procedure:</u>

1. Establish desired resolution: 12.8 km/hr.
2. Determine the front and rear wheel rolling radii:
   - -front wheel rolling radius, $R_f = 0.55$ m.
   - -rear wheel rolling radius, $R_r = 0.70$ m.
3. Gear/sprocket size:
   - -front wheel sprocket = 60 teeth
   - -rear wheel sprocket = 80 teeth
4. Determine wheel rotational circumference:

-front wheel circumference, $C_f = 2 * 0.55 \text{ m} * \pi = 3.46$ m / rev.

-rear wheel circumference, $C_r = 2 * 0.70 \text{ m} * \pi = 4.39$ m / rev.

Velocity, $V = C * N$ (N = wheel speed)

Wheel rotational speed, $N = V/C$

$$N = \frac{12.8\,Km}{1\,hr} \times \frac{1000\,m}{1\,Km} \times \frac{1\,hr}{3600\,sec} \times \frac{1\,rev}{C(m)}$$

N_f = 1.028 rev/sec.

N_r = 0.809 rev/sec.

Frequency output, F_f = No. of teeth * N_f / 60
= 60 * 1.028 rev/sec
= 61.68 Hz.

F_r = 80 * 0.809 rev/sec
= 64. 72 Hz.

5. Connect the transducer to the signal conditioner and the frequency generator.
6. For each of the wheels select the signal conditioner channel.
7. Select the calibration mode on the signal conditioner.
8. Boot the computer and run AI13 software for calibration.
9. Determine the gain code for the transducer depending on the signal conditioner output in mV.
10. Generate at least ten frequencies with the frequency generator within the above maximum level.
11. For each frequency, compute the accurate reading from the signal conditioner and log it into the computer.
12. After logging ten or more frequency readings, run the calibration program for the calculation of the regression formula.

Calibration response equations:
Front wheel:

$$Hz = mV \times 0.090 + 1\ 110$$

Rear wheel:

$$Hz = mV \times 0.083 + 2.757$$

Appendix C.4: Draft force.

Sensor Origin: Micromeasurements Inc.
Specifications: Four arm 350 ohm full bridge assembly, bonded onto the sides of the drawbar.

Calibration procedure:

Calibration of the drawbar was done using the following equipment:
- -Instron Testing Machine for the loading.
- -Oscilloscope for reading the voltage
- -Signal conditioner
- -DAS

1. Ensure that the load selector is in neutral.
2. Ensure that the speed selector is set to a minimum.
3. Select the desired loading range (50 kN)
4. Turn on the power and allow to warm up for 5 to 10 minutes.
5. Turn the speed selector to LOW loading speed.
6. Connect the drawbar to the Instron Testing Machine.
7. Connect the strain gages cables to both the signal conditioner.
8. Prepare the computer for the calibration.
9. Load the drawbar by using the loading switch.
10. Read the load during the loading and relaxing of the drawbar.
11. Enter the readings in the computer for the calculation of the regression equation.

Calibration response equation:

$$N = (mV \times 24000.664/1000) - 12.587$$

Appendix C.5:Fuel flow meter

Sensor Origin: Emco Engineering Measurements Company.
Make and Model: Piston Flowmeter, PDP1
Meter Type: Positive Displacement.
Size: 1/8" NPTF

Piston Operating Ranges:

Flow rate:	1-1,200 cc/min
Max Pressure:	Standard: 1000 psig Optional: 3000 psig
Max Temperature:	500 deg F
Max Pressure drop:	20 psid
Nominal k-factor:	111 pulses/cc 420,181 pulses/gallon
Filtration:	10 micron.

Calibration procedure:

1. Determine the maximum fuel consumption expected.
2. Switch "Run/Cal" to "Run" and set "Range" to handle maximum frequency on the signal conditioner.
3. Connect the pulse calibrator to rear DIN socket.
4. Adjust "Fine" to display analog voltage equivalent to the calibrator setting. e.g 1v for 1 Khz.
5. Adjust "Tape" in a clockwise direction to obtain a larger voltage on LED display. Switch display to 19.99v range if necessary.
6. Switch "Run/Cal" to "Cal" momentarily and note voltage.

Appendix C.6: Strain Gage amplifier

Origin:	Data Capture Technology Inc.
Specifications:	
Input Configuration:	High Gain Differential
Input Impedance:	1 Megaohm Differential
Input Mode:	Resistive bridge in 1,2 or 4 arm connection with internal bridge completion.
Input Range:	Up to 500 mV
Maximum Input:	30 v DC
CMR:	90 dB (DC to 60 Hz)
Noise:	Less than 5 microvolts r.m.s. at max gain.
Drift:	Less than 2 microvolts/C at max. gain.
Bandwidth:	DC - 10 KHz.
Gain:	20 - 5000 in switched steps with interpole control.
Output (voltage):	Up to ±2 V DC
Output Impedance (voltage):	0.5 Ohms
Output (current):	±10 mA into 120 Ohms
Ouput Impedance (current):	250 Ohms

Appendix C.7: AI13 Analog to Digital Converter.

Origin:	Interactive Structures Inc.
Analog Specifications:	Input Full Scale Ranges

Available (millivolts):

Gain Code	Size of Range	Amplification Used
0	0 to 5000	None
1	0 to 1000	5 to 1
2	0 to 500	10 to 1
3	0 to 100	5 to 1 and 10 to 1

Extended to negative values as:

4	-5000 to +5000
5	-1000 to +1000
6	-500 to +500
7	-100 to +100

Input Impedance:	10 Megaohms
Crosstalk from unselected channel:	-95dB

<u>Conversion Specifications:</u>

Resolution:	12 Bits, 4096 steps
Coding:	Binary, 0 to 4095 full scale.
Overrange Processing:	Values greater than max. will appear as 4095. Values less than min. will appear as 0.
Deviation from the ideal step size:	0.024% max.
Deviation from the ideal straight line:	0.024% typical.

<u>Conversion Timing:</u>

Selection and sampling:	6 microseconds
Hold and conversion:	13 microseconds
Total Conversion Time:	20 microseconds
Sampling aperture:	125 nanoseconds
Setting Time Delays:	
Channel switch, 5V or 1V scales:	None
Range switch, 5V or 1V scales:	None
Channel switch, 0.5V or 0.1V scales:	45 microseconds
Range switch, 0.5v or 0.1v scales:	45 microseconds

<u>Electrical Requirements:</u>

Internal Power:	Drawn from Apple Supply, 5V at 45mA, 12V at 19mA, -12V at 16mA.
External Power:	None required.
External Trigger:	Positive or Negative Edge TTL.

APPENDIX D

SOIL CHARACTERISTICS

Five soil types were used for the experiments. These included:

1. Capac loam
2. Granby loamy sand
3. Owosso-Marlette sandy loam
4. Metamora-Capac sandy loam
5. Palms muck

The characteristics of these soils are specified here. The details include the depth of the soil, the USDA texture classification and the suitability of the soil for cropping.

APPENDIX D

SOIL CHARACTERISTICS

Field #	Soil Type	USDA Texture Classified United	Description
1 and MSU	CaA	0-9" Loam (ML or CL) 9-31" Clay Loam (CL) 31-60" Loam (ML or CL)	Capac loam, 0-4% slope Erosion is a hazard in gently sloping areas. Well suited for cropping.
2a	Gr	0-14" Loamy sand (SM) 14-22" Sand (SM) 22-26" Loamy sand (SM) 26-60" Sand (SM)	Granby loamy sand. Easily blown by wind when dry and exposed. Moderately suited for farming.
2b	Pa	0-41" Muck (sapric) pit 41-60" Silt loam (CL-ML)	Palms muck, 0-2% slope Poor stability of organic material.
3a	OwB	0-23" Sandy loam (SM-SC) 23-26" Heavy sandy loam (SC-SM) 26-34" Clay-loam (CL) 34-60" Heavy loam (CL or CL-ML)	Owosso-Marlette sandy loam, 2-6% slope 55% Owosso-sandy loam and 40 % Marlette sandy. Erosion is the main problem.
3b	MeA	0-25" Sandy loam and loamy sand (SM or SC). 25-32" Heavy sandy loam (CL or ML) 32-40" Light clay loam (CL or ML) 40-60" Loam (ML or CL)	Metamora-Capac sandy loam, 0-4% slope Seasonal wetting is the main problem. Drainage required for cropping.

Source: USDA, Soil Conservation Service.

APPENDIX E

DATA TRANSFER PROCEDURE

The method described here was used to transfer the field data to an IBM compatible computer. The Apple IIe computer and an IBM compatible computer were physically connected together using the RS232 crossover cable. As the transfer proceeded from one computer to another, the data was displayed on both monitors. After completion of the transfer the data was saved on a floppy using the same file name as that used in the field.

APPENDIX E

DATA TRANSFER PROCEDURE

1. Connect the crossover cable-RS232 to the serial ports of the Apple and IBM compatible computers.

2. Boot the two computers.

3. With ASCII Express disk in drive 1 and the data disk in drive 2:
   - 3.1 Press <Ctrl> <Q> <1>
   - 3.2 Press <Ctrl> <Q> <2>. This opens menu 2.
   - 3.3 Type <N> <1> to change delay from 0 to 1.
   - 3.4 Type <K> to make terminal chat ON.
   - 3.5 Press <Ctrl> <Q> <1> to go to menu 1.
   - 3.6 Type <S> and press <RETURN KEY>.
   - 3.7 Type filename to be transferred. Before pressing <RETURN KEY> following prompt ensure that IBM is set to receive incoming file.

4. Using Modem 7PC program in the IBM:
   - 4.1 Type <Ctr B>. Type <4800> to change the baudrate.
   - 4.2 Type <T B> and "name of incoming file".
   - 4.3 Type <Ctr Y> to turn the save option on. No change in display.
   - 4.4 The transfer procedure is ready.
   - 4.5 Initiate the process on the Apple by pressing the <RETURN KEY>.
   - 4.6 The data should appear on both screens as it is being transferred.
   - 4.7 After the file is transferred save the file thus:
     - 4.7.1 Press <Ctr Y>.
     - 4.7.2 Type <Ctr E>.
     - 4.7.3 Type <WRT>.
     - 4.7.4 Press <RETURN KEY>.
   - 4.8 After the file is saved repeat the process from 3.5 and 4.2 for the Apple and IBM computers respectively to transfer other files.
   - 4.9 Type <E> to exit the program.

APPENDIX F

SAMPLE OF DATA STATISTICS SUMMARY

A sample of the data statistics summary is provided here. The calculations were performed using Lotus spreadsheet program and then imported into WordPerfect. The data file coding represented:

CPMSU3A:

CP = Chisel plow
MSU = Field
3 = Ground speed (Mph)
A = Replication

APPENDIX F

SAMPLE OF DATA STATISTICS SUMMARY

		VARIABLE					
File Name	Statistic	Engine Speed (Rpm)	Ground Speed (Km/h)	R/Wheel Speed (Km/h)	F/Wheel Speed (Km/h)	Draft Force (kN)	Fuel Cons. (L/hr)
CPMSU3A	Maximum	2089.08	4.440	7.479	7.445	23.172	11.544
	Minimum	1766.25	3.607	3.743	3.656	14.388	8.438
	Average	1942.02	4.045	5.602	5.647	18.361	9.869
	Std Dev	60.747	0.035	1.649	1.023	1.226	0.371
CPMSU3B	Maximum	2094.23	4.852	6.787	7.066	31.812	13.219
	Minimum	1797.16	2.744	2.982	3.254	17.244	10.444
	Average	1918.68	3.675	4.712	4.849	22.059	11.796
	Std Dev	57.887	0.298	1.726	1.076	1.679	0.579
CPMSU4A	Maximum	1570.49	5.740	8.494	8.748	27.132	13.464
	Minimum	1141.19	3.964	3.974	4.201	11.580	7.045
	Average	1405.40	5.258	6.668	6.708	16.367	9.673
	Std Dev	44.475	0.160	1.779	1.181	2.638	1.201
CPMSU4B	Maximum	2023.83	6.203	9.140	8.748	26.172	16.942
	Minimum	1714.73	4.452	4.873	4.769	15.636	12.455
	Average	1872.76	5.388	6.970	6.969	20.557	14.451
	Std Dev	54.037	0.205	1.745	1.076	1.877	1.284

APPENDIX F (cont'd)

CPMSU7A	Maximum	2023.83	6.203	9.140	8.748	26.172	16.942
	Minimum	1714.73	4.452	4.873	4.769	15.636	12.455
	Average	1872.76	5.388	6.970	6.969	20.557	14.451
	Std Dev	54.037	0.205	1.745	1.076	1.877	1.284
CPMSU64	Maximum	1874.43	9.089	11.261	11.731	25.476	13.818
	Minimum	1596.25	6.337	8.079	8.203	6.972	9.380
	Average	1736.78	8.437	9.651	9.770	11.387	11.371
	Std Dev	63.805	0.235	1.649	1.012	1.708	0.920
CPMSU6A	Maximum	2861.82	10.704	23.645	22.956	21.108	17.847
	Minimum	1951.71	8.100	12.299	10.808	8.028	11.385
	Average	2210.69	8.925	16.038	14.590	15.546	14.814
	Std Dev	15.316	0.227	2.499	1.852	1.689	1.266
CPMSU5A	Maximum	713.614	1.596	12.414	10.642	12.420	1.005
	Minimum	141.788	0.477	5.657	4.106	2.579	0.295
	Average	436.806	0.960	8.438	6.875	6.875	0.611
	Std Dev	11.826	0.023	2.318	1.680	1.610	0.149

APPENDIX F (cont'd)

CPMSU5B	Maximum	1893.32	7.423	11.031	10.429	23.124	16.594
	Minimum	1589.38	6.177	6.465	6.569	12.324	11.911
	Average	1759.03	6.823	8.679	8.773	18.380	14.375
	Std Dev	55.846	0.049	1.740	1.083	1.916	1.062
CPMU75	Maximum	2243.63	11.962	15.504	14.928	20.484	19.210
	Minimum	1761.10	9.715	10.223	10.642	9.876	14.637
	Average	2033.44	10.899	12.610	12.825	14.929	17.675
	Std Dev	19.255	0.299	1.889	1.246	1.955	0.837
CPMU4CA	Maximum	2243.63	11.962	15.504	14.928	20.484	19.210
	Minimum	1761.10	9.715	10.223	10.642	9.876	14.637
	Average	2033.44	10.899	12.610	12.825	14.929	17.675
	Std Dev	19.255	0.299	1.889	1.246	1.955	0.837
CPMU4CB	Maximum	1570.49	5.740	8.494	8.748	27.132	13.464
	Minimum	881.900	3.085	3.651	3.514	11.580	7.045
	Average	1356.20	5.011	6.412	6.439	16.921	9.769
	Std Dev	26.405	0.489	1.995	1.397	2.950	1.255

APPENDIX G

RAW DATA PRINTOUT

This printout shows the raw field data in millivolts for the six channels used to collect the data. The file number printed out was CPMU75 which had 500 data sets. Each data set was saved in a separate file which was imported to *Lotus 123R3* for analysis. This printout was subsequently imported to *WordPerfect 5.1* which converted it to the present grid tabular form. The analysis of the data was done by calculating the mean and the standard deviation for each channel. The means were converted to hertz (Hz) using the calibration response equations. The individual transducer's load conversion factor was used to obtain the value of the reading in the appropriate units (e.g L/hr for fuel flow).

APPENDIX G
RAW DATA PRINTOUT

Time (mSec)	TRANSDUCER OUTPUT (mV)					
	Engine Speed	Ground Speed	R/Wheel Speed	F/Wheel Speed	Draft	Fuel Flow
0	1204	2381	498	530	622	3006
50	1201	2384	480	531	660	3009
100	1177	2355	458	492	538	3020
150	1187	2381	469	504	545	3033
200	1176	2404	461	465	526	3042
250	1178	2370	490	483	524	3036
300	1142	2369	469	519	505	3007
350	1147	2409	436	456	602	2970
400	1177	2374	441	462	601	3002
450	1221	2414	446	472	523	3037
500	1185	2395	454	485	544	3072
550	1242	2453	482	519	620	3101
600	1212	2426	489	526	579	3069
650	1201	2499	508	508	550	3051
700	1233	2480	478	532	687	3011
750	1249	2483	493	510	513	2971
800	1234	2491	489	515	513	2993
850	1239	2510	503	513	436	3021
900	1269	2525	478	510	498	3073
950	1229	2508	449	528	456	3092
1000	1250	2561	508	508	427	3083
1050	1239	2545	483	527	496	3086
1100	1240	2530	460	484	576	3014
1150	1246	2559	486	542	555	2991
1200	1260	2583	502	530	742	2966
1250	1238	2547	482	501	478	2938
1300	1322	2632	567	562	522	3020

1350	1292	2599	500	517	506	3032
1400	1257	2591	487	505	492	3056
1450	1313	2641	520	542	553	3075
1500	1281	2620	551	545	630	3057
1550	1270	2652	517	542	624	3022
1600	1266	2637	508	568	558	2983
1650	1284	2659	511	611	616	2968
1700	1233	2664	516	539	572	2938
1750	1247	2652	505	505	531	2955
1800	1272	2681	536	553	556	2999
1850	1272	2665	498	498	551	3036
1900	1257	2662	511	583	543	3078
1950	1221	2687	512	507	742	3030
2000	1286	2686	511	558	770	3011
2050	1270	2670	496	538	737	3012
2100	1267	2685	505	530	682	2982
2150	1287	2712	512	537	752	3019
2200	1277	2686	537	511	698	3019
2250	1287	2701	510	534	656	3041
2300	1279	2693	500	495	731	3053
2350	1299	2727	543	579	810	3052
2400	1329	2750	526	556	746	3052
2450	1241	2672	474	511	816	3076
2500	1300	2763	568	584	810	3135
2550	1294	2716	549	590	624	3138
2600	1288	2700	494	548	590	3123
2650	1272	2704	506	525	694	3049
2700	1292	2704	524	551	667	3023
2750	1300	2702	521	542	606	3075
2800	1244	2693	508	513	676	3099
2850	1234	2645	486	521	588	3043
2900	1191	2606	434	480	707	2987

2950	1266	2648	485	524	698	2982
3000	1209	2652	478	497	629	2984
3050	1244	2645	496	510	732	3057
3100	1185	2591	423	504	775	3050
3150	1290	2650	487	513	658	3036
3200	1191	2592	438	451	551	2987
3250	1267	2649	497	529	578	3071
3300	1210	2608	444	466	550	3059
3350	1209	2641	485	492	542	3095
3400	1252	2561	490	515	547	3007
3450	1181	2581	449	502	624	2958
3500	1246	2625	467	493	576	2950
3550	1174	2590	456	464	572	2990
3600	1249	2623	462	486	459	3013
3650	1289	2672	534	569	460	3043
3700	1233	2619	498	516	452	2974
3750	1235	2620	477	524	504	2941
3800	1261	2639	522	527	598	2972
3850	1285	2671	552	575	649	3036
3900	1234	2633	509	531	686	3049
3950	1302	2648	498	526	580	3058
4000	1228	2596	504	527	537	3039
4050	1244	2609	505	503	504	3025
4100	1232	2621	525	492	546	3030
4150	1236	2615	478	504	476	3079
4200	1235	2601	474	484	564	3098
4250	1241	2612	469	505	652	3137
4300	1249	2610	460	485	593	3123
4350	1212	2600	480	496	582	3079
4400	1232	2615	468	492	529	3043
4450	1254	2639	496	510	561	3044
4500	1248	2625	470	504	425	3047

4550	1217	2623	487	508	482	3110
4600	1243	2608	455	515	523	3108
4650	1194	2611	491	510	583	3135
4700	1241	2626	483	531	616	3118
4750	1274	2637	497	550	575	3103
4800	1235	2608	463	514	578	3089
4850	1238	2621	467	533	614	3086
4900	1310	2654	511	527	574	3071
4950	1293	2652	480	530	574	3128
5000	1253	2645	482	519	606	3113
5050	1273	2659	497	492	582	3112
5100	1287	2665	509	529	551	3087
5150	1264	2651	481	499	552	3032
5200	1274	2654	520	510	615	3038
5250	1240	2654	461	539	586	3008
5300	1242	2651	455	515	673	2968
5350	1309	2735	490	519	518	2971
5400	1246	2698	480	516	455	2972
5450	1253	2761	494	522	611	3026
5500	1272	2763	526	538	659	3001
5550	1279	2759	519	537	583	2937
5600	1288	2770	507	556	454	2901
5650	1302	2775	517	543	450	2884
5700	1297	2784	518	534	440	2828
5750	1267	2771	503	538	446	2835
5800	1297	2817	519	547	571	2822
5850	1326	2837	528	558	644	2859
5900	1246	2780	472	547	600	2852
5950	1321	2842	536	571	661	2876
6000	1303	2837	517	544	657	2800
6050	1265	2810	515	522	704	2718
6100	1323	2849	540	559	705	2646

6150	1298	2838	516	552	608	2583
6200	1303	2839	517	581	476	2593
6250	1345	2855	522	537	497	2603
6300	1273	2835	529	553	638	2679
6350	1342	2866	561	593	678	2725
6400	1298	2840	520	536	673	2756
6450	1338	2876	549	601	671	2769
6500	1298	2839	504	523	639	2655
6550	1359	2889	551	575	584	2629
6600	1321	2867	536	552	438	2574
6650	1347	2881	548	609	463	2638
6700	1335	2880	555	598	550	2693
6750	1260	2811	491	510	696	2733
6800	1333	2877	551	605	662	2806
6850	1310	2831	534	568	673	2788
6900	1311	2878	524	548	631	2738
6950	1299	2827	585	572	614	2736
7000	1299	2846	527	564	524	2676
7050	1319	2825	521	532	518	2657
7100	1370	2883	626	607	590	2723
7150	1329	2853	549	580	733	2691
7200	1368	2866	608	582	707	2643
7250	1368	2862	570	595	744	2625
7300	1319	2832	536	552	799	2583
7350	1345	2850	555	594	656	2553
7400	1304	2806	537	563	585	2522
7450	1340	2849	542	564	613	2617
7500	1250	2798	522	526	693	2616
7550	1305	2822	508	531	764	2541
7600	1294	2810	506	552	632	2445
7650	1297	2814	562	553	640	2406
7700	1327	2842	538	568	627	2390

7750	1268	2775	497	519	734	2464
7800	1279	2784	487	515	700	2520
7850	1268	2795	530	524	774	2561
7900	1335	2830	551	581	710	2597
7950	1283	2772	506	528	548	2585
8000	1324	2816	541	566	614	2639
8050	1272	2765	510	537	606	2663
8100	1295	2797	527	523	683	2760
8150	1281	2809	561	583	713	2799
8200	1290	2791	542	555	551	2809
8250	1338	2785	515	545	620	2789
8300	1262	2751	494	505	624	2762
8350	1266	2783	567	562	582	2854
8400	1271	2733	475	486	627	2840
8450	1305	2785	530	530	657	2891
8500	1233	2727	486	510	703	2884
8550	1367	2786	533	544	708	2922
8600	1262	2742	490	527	618	2903
8650	1297	2787	530	540	540	2931
8700	1278	2786	546	550	664	2977
8750	1304	2773	525	561	752	3021
8800	1307	2771	545	579	844	3011
8850	1334	2786	554	572	828	2936
8900	1318	2787	574	582	854	2847
8950	1289	2748	516	546	679	2787
9000	1289	2777	521	521	614	2785
9050	1326	2789	555	587	736	2883
9100	1334	2790	565	562	625	2930
9150	1326	2775	528	548	612	2941
9200	1311	2744	531	536	608	2886
9250	1283	2743	521	543	574	2885
9300	1283	2736	519	523	653	2841

9350	1311	2750	559	592	825	2890
9400	1353	2789	590	613	817	2926
9450	1296	2730	550	562	747	2866
9500	1312	2737	532	600	721	2863
9550	1296	2763	545	547	796	2830
9600	1262	2700	496	531	689	2822
9650	1276	2794	542	524	679	2908
9700	1335	2731	534	568	576	2942
9750	1264	2687	550	554	700	2955
9800	1248	2697	546	560	711	2910
9850	1338	2741	546	568	707	2878
9900	1264	2706	529	550	710	2870
9950	1298	2717	551	553	568	2910
10000	1265	2686	510	546	642	2959
10050	1299	2703	530	558	543	2983
10100	1248	2705	524	510	625	2955
10150	1326	2725	560	568	654	2929
10200	1216	2640	508	526	721	2933
10250	1275	2674	492	524	638	2941
10300	1268	2643	494	506	664	3029
10350	1225	2630	461	550	632	3081
10400	1261	2661	510	515	697	3040
10450	1272	2682	480	512	528	2998
10500	1290	2681	545	550	528	2943
10550	1265	2648	485	518	624	2936
10600	1238	2631	488	506	774	2919
10650	1265	2700	480	549	755	2967
10700	1237	2659	513	518	734	2939
10750	1298	2663	500	514	663	2949
10800	1219	2606	470	522	672	2919
10850	1288	2646	513	530	658	2873
10900	1238	2671	563	564	634	2885

10950	1241	2612	468	498	646	2837
11000	1242	2613	481	496	742	2858
11050	1234	2616	477	538	760	2847
11100	1239	2623	494	564	815	2793
11150	1255	2662	506	528	770	2728
11200	1246	2615	537	527	547	2734
11250	1299	2687	543	570	531	2744
11300	1261	2623	480	504	569	2813
11350	1262	2662	510	536	611	2851
11400	1225	2624	486	506	622	2835
11450	1273	2667	533	588	628	2761
11500	1281	2657	515	518	516	2718
11550	1297	2689	526	538	575	2727
11600	1223	2611	457	473	622	2767
11650	1318	2681	527	538	636	2839
11700	1254	2659	511	535	604	2871
11750	1237	2701	505	528	639	2838
11800	1239	2655	474	486	728	2815
11850	1241	2651	441	474	637	2755
11900	1242	2717	465	478	768	2761
11950	1228	2654	460	490	745	2807
12000	1248	2710	531	529	720	2809
12050	1281	2750	504	520	701	2845
12100	1233	2656	480	535	547	2822
12150	1313	2707	508	524	609	2796
12200	1255	2703	475	514	592	2769
12250	1265	2714	492	506	636	2808
12300	1274	2691	479	515	699	2793
12350	1283	2712	529	540	719	2846
12400	1274	2724	529	565	741	2774
12450	1273	2691	508	521	767	2723
12500	1254	2693	483	541	654	2755

12550	1353	2734	533	540	554	2818
12600	1276	2696	504	552	578	2882
12650	1304	2765	543	571	625	2924
12700	1268	2710	522	542	695	2892
12750	1262	2769	555	558	678	2833
12800	1322	2702	524	544	771	2790
12850	1321	2738	554	577	762	2850
12900	1256	2682	508	560	658	2895
12950	1297	2716	511	532	688	2919
13000	1268	2705	561	569	662	2957
13050	1220	2665	486	554	610	2943
13100	1294	2689	496	537	694	2908
13150	1289	2691	526	548	735	2901
13200	1244	2663	481	582	764	2994
13250	1240	2647	457	480	755	2921
13300	1282	2718	545	560	720	2946
13350	1257	2675	511	521	641	2899
13400	1292	2711	524	542	595	2902
13450	1244	2625	476	497	654	2969
13500	1255	2686	584	574	670	3041
13550	1229	2629	476	496	677	3055
13600	1225	2629	462	584	673	3057
13650	1255	2643	502	521	726	2981
13700	1340	2703	537	555	676	2962
13750	1296	2695	566	579	647	2981
13800	1319	2717	556	574	619	3014
13850	1285	2675	550	559	648	3041
13900	1272	2661	488	518	617	3059
13950	1261	2672	519	511	583	3042
14000	1262	2748	562	566	647	2972
14050	1274	2683	530	569	726	2929
14100	1293	2697	537	584	658	2921

14150	1270	2658	539	544	670	2908
14200	1264	2662	528	564	729	2961
14250	1238	2654	520	547	619	2898
14300	1254	2646	492	546	605	2928
14350	1277	2687	547	558	588	2829
14400	1264	2658	486	519	576	2798
14450	1262	2649	490	502	638	2769
14500	1240	2645	490	531	718	2786
14550	1244	2642	504	515	660	2762
14600	1246	2654	479	504	734	2801
14650	1223	2636	458	478	600	2712
14700	1289	2697	509	562	602	2686
14750	1223	2646	466	516	547	2621
14800	1274	2686	502	526	608	2668
14850	1215	2653	470	490	598	2659
14900	1211	2670	532	546	718	2722
14950	1222	2631	454	465	644	2677
15000	1252	2674	478	496	643	2649
15050	1231	2654	476	494	606	2608
15100	1291	2692	462	496	568	2642
15150	1230	2657	484	478	617	2672
15200	1194	2637	427	462	622	2732
15250	1258	2687	508	540	659	2782
15300	1272	2695	490	502	598	2725
15350	1230	2673	481	499	566	2686
15400	1207	2707	444	540	583	2701
15450	1281	2718	523	561	567	2723
15500	1209	2686	475	481	615	2746
15550	1264	2703	524	517	599	2839
15600	1208	2599	472	519	563	2798
15650	1255	2696	489	534	673	2791
15700	1260	2693	501	529	559	2771

15750	1215	2672	481	502	654	2750
15800	1214	2656	476	519	634	2805
15850	1232	2633	486	492	561	2856
15900	1235	2657	478	491	597	2861
15950	1228	2663	455	486	688	2808
16000	1281	2683	496	492	642	2806
16050	1254	2690	515	578	588	2822
16100	1270	2665	499	519	542	2812
16150	1276	2710	506	553	588	2862
16200	1240	2655	486	508	579	2899
16250	1272	2683	501	525	545	2903
16300	1223	2646	530	522	595	2862
16350	1264	2697	534	551	609	2887
16400	1235	2648	486	520	644	2897
16450	1257	2663	507	517	542	2902
16500	1266	2685	526	554	591	2957
16550	1271	2708	480	519	583	2955
16600	1268	2686	498	514	578	2923
16650	1208	2618	449	472	652	2889
16700	1266	2681	494	521	636	2860
16750	1267	2713	522	518	790	2932
16800	1299	2723	564	600	705	2991
16850	1253	2641	486	492	505	2991
16900	1352	2716	542	560	520	2997
16950	1258	2697	561	564	485	2969
17000	1282	2674	518	556	620	2928
17050	1285	2675	548	560	667	2918
17100	1271	2671	554	608	700	2958
17150	1297	2664	497	527	781	2895
17200	1283	2671	591	597	689	2915
17250	1300	2659	528	572	540	2855
17300	1279	2652	528	534	576	2870

17350	1250	2627	494	523	619	2955
17400	1342	2697	606	600	563	2995
17450	1271	2638	551	565	560	3011
17500	1325	2658	524	547	625	2970
17550	1210	2578	461	478	790	2869
17600	1235	2624	513	521	762	2931
17650	1233	2588	475	504	729	2975
17700	1192	2585	492	526	806	3016
17750	1240	2596	504	513	574	3009
17800	1199	2547	457	471	572	2906
17850	1248	2584	488	500	492	2860
17900	1217	2569	462	475	596	2902
17950	1255	2582	507	532	662	2930
18000	1238	2591	556	572	615	2950
18050	1281	2611	560	610	844	2909
18100	1238	2577	569	543	592	2887
18150	1212	2553	485	502	738	2938
18200	1293	2593	508	538	626	2983
18250	1248	2572	519	537	606	2956
18300	1257	2590	531	533	726	2911
18350	1223	2563	473	487	609	2890
18400	1217	2535	501	489	687	2902
18450	1233	2552	534	524	731	2941
18500	1283	2564	504	523	758	2879
18550	1179	2512	455	489	739	2823
18600	1199	2518	480	502	519	2923
18650	1215	2523	500	498	654	2995
18700	1214	2540	487	517	612	2995
18750	1218	2525	492	571	633	2960
18800	1191	2507	498	508	646	2945
18850	1226	2503	478	498	666	2949
18900	1200	2506	469	480	678	2936

18950	1215	2503	496	524	698	2838
19000	1191	2491	462	464	612	2796
19050	1195	2485	473	492	670	2879
19100	1229	2497	510	506	696	2881
19150	1225	2503	490	514	728	2847
19200	1226	2503	531	535	611	2869
19250	1168	2459	451	467	725	2869
19300	1186	2478	499	499	655	2951
19350	1190	2493	506	544	631	2856
19400	1191	2457	467	504	684	2800
19450	1178	2458	463	511	672	2856
19500	1201	2473	503	511	626	2880
19550	1183	2473	516	499	675	2786
19600	1217	2476	518	539	684	2829
19650	1224	2489	527	560	624	2887
19700	1209	2515	518	532	615	2897
19750	1214	2478	536	545	651	2829
19800	1177	2453	495	514	702	2829
19850	1160	2456	492	511	590	2857
19900	1220	2511	524	536	569	2882
19950	1206	2467	476	500	412	2787
20000	1183	2451	456	490	505	2816
20050	1118	2458	494	498	609	2894
20100	1156	2444	472	538	636	2876
20150	1171	2429	472	482	656	2821
20200	1182	2457	456	488	646	2862
20250	1108	2421	414	489	586	2886
20300	1124	2450	462	470	506	2882
20350	1107	2439	455	465	530	2817
20400	1183	2447	430	460	500	2813
20450	1158	2447	481	508	531	2899
20500	1201	2496	496	521	504	2849

20550	1114	2419	425	463	577	2787
20600	1148	2490	462	478	627	2801
20650	1131	2425	417	.455	493	2815
20700	1107	2408	426	459	566	2840
20750	1089	2425	470	462	508	2800
20800	1123	2424	422	445	552	2743
20850	1123	2430	397	432	580	2823
20900	1116	2413	434	460	594	2874
20950	1113	2463	472	508	623	2862
21000	1144	2433	432	454	641	2777
21050	1134	2425	452	462	632	2784
21100	1127	2409	480	480	614	2845
21150	1167	2459	466	518	560	2883
21200	1158	2460	480	511	566	2848
21250	1134	2418	444	438	616	2789
21300	1243	2496	496	518	654	2851
21350	1182	2462	472	499	670	2912
21400	1159	2430	455	506	652	2887
21450	1212	2497	559	552	661	2874
21500	1222	2509	508	526	600	2839
21550	1212	2481	508	522	595	2876
21600	1217	2503	518	550	548	2955
21650	1181	2453	470	478	630	2912
21700	1169	2456	509	543	633	2902
21750	1219	2491	478	511	610	2899
21800	1138	2434	442	440	618	2917
21850	1149	2446	446	555	599	2970
21900	1176	2462	462	515	570	2960
21950	1186	2468	483	489	569	2869
22000	1150	2437	444	473	589	2864
22050	1142	2449	452	460	597	2928
22100	1142	2442	472	523	572	2966

22150	1222	2502	454	478	600	3009
22200	1144	2447	460	479	596	2934
22250	1137	2445	417	495	639	2936
22300	1139	2488	442	451	505	2931
22350	1187	2489	497	488	565	2993
22400	1186	2462	446	460	572	3019
22450	1161	2475	441	436	595	3017
22500	1128	2451	398	433	638	2951
22550	1177	2489	460	441	643	2905
22600	1172	2485	439	473	528	2938
22650	1150	2489	448	488	496	2925
22700	1203	2517	493	496	487	3022
22750	1126	2464	448	446	531	3029
22800	1222	2532	499	498	476	3044
22850	1170	2510	472	492	574	2981
22900	1196	2509	451	476	636	2928
22950	1176	2499	456	474	526	2918
23000	1220	2529	468	542	509	2992
23050	1175	2518	475	491	498	2977
23100	1240	2546	465	485	544	2945
23150	1198	2521	444	441	532	2872
23200	1178	2505	463	472	588	2857
23250	1196	2552	462	474	574	2825
23300	1187	2547	436	467	592	2847
23350	1212	2565	482	492	487	2883
23400	1212	2555	454	485	536	2909
23450	1221	2575	487	543	532	2829
23500	1249	2607	532	535	550	2789
23550	1192	2544	490	487	679	2728
23600	1226	2593	480	505	594	2745
23650	1261	2604	508	526	645	2767
23700	1249	2609	509	519	578	2831

23750	1227	2608	496	510	579	2783
23800	1248	2608	494	508	572	2768
23850	1225	2622	482	501	540	2716
23900	1246	2628	494	492	586	2712
23950	1223	2608	468	533	712	2762
24000	1262	2652	534	542	696	2793
24050	1234	2622	497	516	718	2729
24100	1294	2672	534	542	617	2709
24150	1242	2623	472	496	654	2662
24200	1315	2684	514	542	661	2692
24250	1244	2641	515	515	606	2755
24300	1269	2645	502	510	670	2831
24350	1239	2639	526	527	639	2778
24400	1284	2692	515	554	639	2751
24450	1230	2634	463	496	715	2723
24500	1268	2679	538	550	556	2782
24550	1278	2679	521	544	568	2858
24600	1260	2713	559	558	689	2886
24650	1246	2645	478	544	649	2854
24700	1254	2657	506	519	572	2784
24750	1251	2672	536	572	744	2799
24800	1273	2677	512	539	659	2859
24850	1253	2707	477	492	558	2880
24900	1257	2665	515	566	611	2974
24950	1231	2625	478	496	619	2874
Maximum	1370	2889	626	613	854	3138
Minimum	1089	2355	397	432	412	2390
Average	1247.59	2636.35	500.50	524.17	622.57	2886.8
Std Dev	52.22	116.75	35.61	35.22	81.97	132.58

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