THE UNIVERSITY OF MANITOBA

ELECTRONIC INSTRUMENTATION FOR MEASURING ENERGY REQUIREMENTS FOR TILLAGE SYSTEMS

by

SUPAWADEE CHONGRIAN

A thesis
submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the Degree
of Master of Science

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ABSTRACT

Electronic Instrumentation for Measuring Energy Requirements for Tillage Systems

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Current energy supplies are finite and are being depleted at an increasing rate. Tillage systems that can produce acceptable yields as well as conserving fuel, soil and water must be developed if the food-energy dilemma is to be successfully solved. In this study electronic instrumentation was developed to measure drawbar pull and fuel consumption for a tractor pulling a tillage implement. With these data, energy required for tillage was determined.

A semiconductor pressure transducer and a turbine fuel flow transducer were used as the sensors for draft and fuel flow, respectively. Energy requirements per hectare, fuel consumption per hectare, actual ground speed, slip, soil penetrometer resistance and soil moisture content were also observed. Two soil types, a tilled Osborne Clay and an Osborne Clay with Fababean stubble at the Glenlea Research Station, University of Manitoba, were tilled in these experiments. A conventional hydraulic dynamometer was used as a reference to which draft as measured by the semiconductor pressure transducer was compared. Actual field speeds and slips were measured by conventional methods.

The electronic instrumentation developed was field tested by determining the draft requirements for a hoe drill, a spike-toothed harrow, a disker seeder and a double disk harrow. The electronic system involved a regulated voltage power supply for the electrical transducers. The output signal was converted to a frequency modulated signal for recording on a portable cassette tape recorder. Laboratory analysis demodulated the signal for comparison of the data to the data recorded on the conventional strip chart pressure recorder.

The static calibration of the two pressure measuring systems determined that the semiconductor pressure system was more accurate. The uncertainties in the energy estimates based on pressure measurements by the semiconductor pressure transducer and the conventional strip chart pressure recorder were about 2.7 percent and 5.8 percent, respectively.

The average unit drafts for the double disk, disker seeder, hoe drill and the harrow were 2.7, 1.6, 2.3 and 0.34 kN/m, respectively. Energy requirements per hectare for these four tillage machines were 27, 16, 23 and 3.4 MJ/ha, respectively. Corresponding diesel fuel consumptions were estimated at 8.2, 5.5, 7.2 and 1.5 L/ha for the four tillage machines, respectively, when a Ford 7700 Diesel tractor was used.

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CHAPTER 1

INTRODUCTION

Three aspects of tillage operations are of increasing importance to modern agriculture. The aspects are the need to increase crop productivity, better utilization of energy, and consideration of the environmental effects of tillage operations. Several modified tillage systems have been introduced by agricultural engineers, plant scientists and soil scientists.

As an industry agriculture is unique since it produces more energy than it consumes [13, 35]. Unfortunately agriculture must compete with other industries for fossil fuels which are being depleted.

In 1976 Canadian farms consumed approximately 18 percent of the total energy used in the food supply system. The on-farm energy use is between 2.2 and 2.7 percent of total Canadian energy consumption [13]. It has been estimated that tillage operations required about 30 percent of the energy used on farms. More than half of this tillage energy is used in primary tillage operations [30].

Although on-farm energy consumption is only a small portion of total Canadian energy consumption, its use represents a critical need among producers. Under the pressures of limited energy supplies, higher costs and increased demands for agricultural production, many researchers are interested in finding the optimum tillage system to achieve higher crop production with a reasonable economic investment and at the same time to conserve soil and water.

Evaluation of tillage systems has been done in many ways. To determine the amount of fuel per hectare and the energy required from a tractor to perform tillage operations involves the precise measurement of the implement drawbar pull, the speed of operation and the amount of fuel the tractor has consumed. These measurements must be done simultaneously and the data properly evaluated if valid comparisons are to be made.

In this study the development of electronic instrumentation for measuring tillage energy requirements is based on the application of a semiconductor strain gage pressure transducer and a turbine fuel flow transducer. Semiconductor pressure transducers have been used for many years in aerospace and industrial applications. These transducers offer the advantages of ruggedness, low cost and relatively high output voltage, i.e. 100 mV at full load. The semiconductor pressure transducer measures pressure and produces a voltage signal which is proportional to drawbar pull.

With regard to fuel consumption, the turbine fuel flow transducer produces a current pulse signal whose frequency is proportional to the rate of fuel flow. The average fuel consumption for the tillage operation can be determined by monitoring the current pulse frequency over a given time period.

Other factors which affect tillage energy requirements are soil type, soil moisture content and soil plant cover [2, 11, 12, 23, 26, 28]. Soil penetrometer resistance and soil moisture content were measured in the field testing part of this research.

Investigations have been conducted in Manitoba since 1968 comparing zero tillage with conventional tillage operations. The effects of the tillage operations on soil physical properties have been monitored up to the end of harvesting and crop yields have been recorded as well [20, 23, 28]. Zero-tillage results have indicated significant advantages over conventional tillage but zero tillage has not been accepted widely in Manitoba. No attempt has been made to compare several tillage systems with zero tillage based on energy requirements.

The objectives of this study were as follows:

1. To develop and test instrumentation for in-field tillage energy studies. The parameters to be measured were drawbar pull and fuel consumption.

2. To determine a mathematical relationship between tillage energy requirements and fuel consumption for the specific tractor used in these studies.

3. To compare energy requirements and fuel consumption for five different tillage systems used under Manitoba conditions.

4. To monitor the effects of the tillage operations on soil penetrometer resistance at the existing soil moisture contents.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definitions

Tillage is the preparation of the soil for planting as well as a process for keeping the soil loose and free from weeds during the growth of crops [25]. The objectives and fundamental purposes of primary tillage are to prepare a suitable seedbed, to destroy competitive weeds and to improve the physical condition of the soil.

Secondary tillage follows the deeper primary tillage operation. The general objectives are (i) to improve the seedbed by greater pulverization of the soil, (ii) to conserve moisture or reduce evaporation, (iii) to cut up crop residue and cover crops and to mix vegetative matter with the top soil, (iv) to break up clods, firm the top soil, and put the soil in better tilth for seeding and the germination of seeds, (v) to destroy weeds on fallow lands, and (vi) to incorporate and mix fertilizers, pesticides or soil amendments into the soil.

2.2 Energy Requirements for Various Tillage Systems and Field Conditions

As energy from fossil fuel sources dwindles and subsequently becomes more expensive, the efficient utilization of energy resources becomes a major concern to agricultural producers. Many researchers are working on both short and long range studies aimed at conserving energy by reducing fuel consumption in soil preparation.

The University of Wyoming, Agricultural Engineering Department, has been comparing four summer fallow tillage methods with respect to energy requirements and wheat yields since 1963 [10]. Their study included comparisons of soil moisture storage, fuel efficiency and wheat yields.

The study indicated that machinery drawbar power requirements varied greatly with soil conditions, particularly soil moisture. The efficiency of the power unit was highly correlated with the drawbar power requirements. Fuel efficiency (kWh/L) improved as drawbar load increased. The studies also indicated that crop yields were more dependent on climatic conditions than on tillage operations and that significant yield differences due to tillage operations were found only in four out of twelve years of the study.

Development of zero-tillage planting equipment took place at the University of Manitoba, Agricultural Engineering Department, in 1975. Forty-three cm diameter plow coulters were installed in front of each pair of disk openers on a standard double-disk opener grain drill. The drill was for zero-tillage seeding of small grain and oil seed crops [4].

Advantages claimed for zero-tillage seeding of these crops include reduced soil erosion, better weed control, increased soil moisture, reduced labor requirements and, of major current interest, conservation of energy. The design of the zero-tillage attachment was relatively simple so that farmers could copy the design and convert existing drills to zero-tillage drills.

Five different tillage systems for Manitoba field conditions were compared in a tillage study that started in 1976 [32]. Table 2.1 illustrates the potential savings in energy and gives details for the different tillage systems. The tillage system in which plowing is used

Table 2.1 Hypothetical Energy Requirements for Five Different Tillage Systems for Tillage Operations to the End of Seeding [32]

System No.	Tillage Operation		No. of Times Over Field	Draft Required (N/m)1/	Energy Required (MJ/ha)	Ratio to System 5
1	Fall	Moldboard plow	1	10000	100	
		Light tillage	1	3500	35	
		Harrow	2	600	12	
	Spring	Press drill	1	730	7.3	
		TOTALS	5	14830	154.3	10.6
2	Fall	Deep tillage	2	5000	100	
		Harrow	1	600	6	
	Spring	Discer seeder	1	3000	30	
		Harrow	2	600	12	
		TOTALS	6	9200	148	10.1
3	(Conventional Valley)	Tillage in Red River				
	Fall	Discer	1	3000	30	
	Spring	Discer seeder	1	3000	30	
		Harrow	2	600	12	
		TOTALS	4	6600	72	4.9
4	Spring	Discer seeder	1	3000	30	
		Harrow	2	600	12	
		TOTALS	3	3600	42	2.9

Table 2.1 - Continued

System No.	Tillage Operation		No. of Times Over Field	Draft Required (N/m)1/	Energy Required (MJ/ha)	Ratio to System 5
5	Zero-tillage					
	Spring	Zero drill	1	1460	14.6	
		TOTALS	1	1460	14.6	1.0

1/ Systems 1, 2, 3 & 4: Average values of draft were taken from published literature [1],
System 5 : Actual field test values [4].

requires over ten times the amount of energy that is required in a zero-tillage system up to the end of the seeding operation. The energy required for the balance of the crop year would be similar for all systems except that the zero-tillage system might require an extra spraying operation and perhaps some additional energy for straw chopping and spreading. The total energy for the zero-tillage system would still be less than for any of the other systems.

According to the University of Nebraska, the energy output/input ratio ranged from 6.4 to 1 for till-planted grain sorghum to 3.6 to 1 for conventionally tilled and irrigated corn [35]. The diesel fuel required to chop old stalks, prepare a seedbed, plant and cultivate corn ranged from 45.6 L/ha for conventional tillage to 18.4 L/ha for a disk and plant tillage system, 16.8 L/ha for a till-plant system and only 12 L/ha for a slot-planting system. Changing from conventional tillage to one of the reduced tillage systems for corn could reduce fuel consumption by 60 to 74 percent. Such a changeover could amount to savings of up to 13.2 million litres of diesel fuel per day during spring planting in Nebraska alone.

Estimates of fuel consumption for farming and ranching operations under typical North Dakota conditions have been presented by the Agricultural Engineering Department of North Dakota State University [11]. The data show great variations in growing conditions, cultural practices and machinery efficiencies. These variations make fuel consumption vary greatly. The data have been presented to show average fuel consumptions that might be used as guidelines. Low and high fuel consumptions that can occur under different crop conditions are also presented.

2.3 Agricultural Tractor Fuel Consumption

Cost and time considerations prohibit extensive field performance testing of agricultural tractors. The Nebraska Tractor Tests report tractor performances and are a means of comparing different tractor makes and models [1]. The Agricultural Engineering Department of Oregon State University has developed a computer program in standard FORTRAN IV to predict the effect of tractive performance and soil strength on fuel economy for an agricultural tractor [19]. The computer model requires a tractor's physical and geometric characteristics as input data. These data are available in the Nebraska Tractor Test reports. Soil strength data are available from cone penetrometer samplings of the soil under investigation.

The model was used to determine the relationships between fuel economy, coefficient of traction and tire efficiency as a function of wheel slip on selected soils. In all cases maximum fuel economy occurred at higher wheel slips than the wheel slip corresponding to a tire's maximum traction efficiency. Wheel slips corresponding to both maximum fuel economy and maximum tire efficiency decreased as the soil strength increased.

2.4 Effect of Tillage on Soil Physical Properties

Agricultural soil structure is the result of a combination of tractor tillage operations over a period of years in the development and management of the soil. Soil structure is also affected by crop and soil management practices, the amount of rainfall, erosion, freezing and thawing [18].

Working soils that are too wet destroy soil structure and encourage the formation of clods in some soils. As a result of the high moisture content, the soil air supply is decreased [18]. The moisture content of the soil, the type of soil and the tillage management practices influence the time and labor required to prepare a good seedbed.

Studies have indicated that zero tillage can produce optimum crop growth with maximum soil and water conservation [28]. Significantly more soil moisture has been found under zero tillage compared to conventional tillage [2, 18, 23, 26]. Approximately 0.8 cm more available water has been reported in the 0 to 15 cm soil layer and 1.8 cm more available water in the 0 to 60 cm zone [26]. The greatest difference in soil moisture occurred in the top 8 cm of the soil [2]. Tillage had very little effect on soil moisture at depths below 60 cm.

Many field experiments have indicated that severe soil compaction caused by repeated tillage operations results in lower crop yields. Increased tractor power and weight as well as the increased use of farm machines have created problems with soil compaction.

Experiments have determined the influence of soil compaction on plant growth. Soil compaction causes a reduction of soil permeability and soil aeration while increasing soil resistance. These changes in soil properties result in reduced quantity and quality of food and fiber [12, 28]. Soil resistance as measured by a cone penetrometer is a good indication of root penetration resistance [12, 23]. Zero-tillage practices have resulted in less soil resistance to root penetration throughout the growing season. Disturbances in soil water and soil air due to compaction have an adverse effect on the biological process in the soil. Compaction occurs during cultivation, spraying and harvesting as well as during primary and secondary tillage operations [26].

2.5 Instrumentation for Measuring Energy Requirements

Researchers have been measuring drawbar power since 1930. Normally, drawbar pull, actual forward speed and slip of the traction device are the parameters measured. Equipment for the measurement of drawbar pull can consist of a hydraulic cylinder with an indicating or recording pressure gauge. The cylinder is inserted between the tractor drawbar and the load. The drawbar force or drawbar pull is obtained as the product of the average cylinder pressure and the active cross-sectional area of the cylinder.

More recently the hydraulic cylinder has been replaced by strain gages and electronic instrumentation to drive recorders [15]. Strain gages have become extremely important devices in research and development. Researchers have measured drawbar power using strain gage dynamometers and have developed many indicating and recording devices [5, 6, 10, 14, 27]. Temperature changes can cause problems due to differential thermal expansion between the resistance element and the material to which the strain gage is bonded [16].

Over a period of years many researchers have been conducting extensive experiments to determine the amount of energy used in tillage by measuring the amount of fuel consumed by the tillage systems. One report described a method of measuring energy requirements by using a positive displacement fuel meter and accurate time measurements in conjunction with known specific fuel consumption at rated engine speed [22]. This study was able to estimate the power output of the loaded engine.

The development of a flow transducer utilizing the distortion of the temperature profile created by a heating element was not successful in measuring gasoline flow. The flow meter was to be used for field measurement of fuel consumption or other fluid flows where there is inadequate pressure available to operate conventional flow meters. These tests were performed by the Agricultural Engineering Department at the University of Saskatchewan in 1969 [19]. The flow measuring system is inexpensive and gives good transient response. However, difficulty was noted with bubble formation in the fuel line during hot weather when the transducer and readout equipment were left on the tractor for a period of several weeks following the calibration tests.

A system was developed to measure fuel and energy requirements for tillage and other machinery operations [17]. A variable impedance transducer (LVDT) was used to monitor the position of a meter valve. Return flow fuel temperature was monitored by a thermocouple and the engine speed was monitored by a small tachometer generator. The measuring system had inadequate dynamic response. A much more reliable and accurate thermocouple amplifier was needed.

CHAPTER 3

INSTRUMENTATION

3.1 Power Requirements

A tractor engine develops the amount of power required for the particular implement being used and additional power for certain losses. This relationship can be expressed as:

$$TEP = IP + LP \qquad \ldots . (3.1)$$

where TEP = total net engine flywheel power, kW

IP = implement power requirements, kW

LP = losses, kW.

The implement power requirements will be the sum of the power-take-off power used by the implement and the drawbar power required. The losses for the tractor will be the losses in the power train, rolling resistance and drive wheel slippage. Several of the references in the review of literature have described the power components mentioned above.

The power requirements of a tillage operation consist only of drawbar power. The variables that affect the drawbar power requirements are the soil type and condition, the type of implement, the field speed and the width and depth of the operation [30]. These variables determine the force required at the drawbar.

The drawbar force parallel to the direction of travel is called the draft of the implement and is expressed in newtons or kilonewtons. In the case of trailed implements the draft is measured by simply inserting a hydraulic dynamometer between the tractor and the implement.

A dynamometer is a device for measuring power by measuring force and speed [16].

3.2 Hydraulic Dynamometer

A conventional hydraulic dynamometer consists of a hydraulic cylinder that generates a pressure which is recorded on a pressure recorder. The speed is determined by recording the time for a known field travel distance.

Unit draft for any tillage implement can be determined as follows:

$$DT = 10^3 \, p \, K_{cy} \qquad \ldots\ldots (3.2)$$

$$UD = 10^3 \, DT/w \qquad \ldots\ldots (3.3)$$

where DT = total draft, kN

UD = draft per unit width of implement, kN/m

p = pressure reading from pressure recorder, MPa

K_{cy} = hydraulic cylinder calibration constant, N/Pa

w = width of the implement, m.

The actual forward speed can be determined as follows:

$$v = 3.6 \, (K_{ct} \, d)/t \qquad \ldots\ldots (3.4)$$

where v = actual forward speed, km/h

K_{ct} = chart constant (metres of ground travel per centimetre of chart movement), m/cm

d = chart movement, cm

t = time for distance travelled in test, s.

Equations 3.2 and 3.4 can be combined to give the power or rate of doing work. An expression for power is:

$$DBP = DT \, v/3.6 \qquad \ldots\ldots (3.5)$$

where DBP = drawbar power, kW.

From the above draft and power relationships the energy requirements per unit area can be deduced. It is assumed that the soil conditions, draft and field speed do not change significantly from the values as calculated from equations 3.2, 3.3 or 3.4. With these assumptions the energy per unit area can be calculated as:

$$ET = 10\ UD \qquad \ldots . \ (3.6)$$

where ET = energy per unit area, MJ/ha.

3.3 Electronic Instrumentation for a Hydraulic Drawbar Dynamometer

Pressure transducers with an electrical output have a considerable advantage over a mechanical output. The electrical output is easy to amplify and record. This is particularly true where the measurement of dynamic pressures is required. Transducers of this type have been used in agricultural measurement since 1961 [7, 21, 24, 34].

Semiconductor strain gages are used in a wide range of pressure transducers of the aerospace type. These transducers have been applied to solve industrial pressure measuring problems since 1958 [8, 31]. The semiconductor strain gages can be thought of as strain sensitive resistors. The gages are bonded to a stressed member and the resistance of the gage changes as a function of the applied strain. The major advantages as compared to conventional metallic wire and foil gages are vastly higher gage factors (-100 to +150), lower hysteresis, higher resistance (200 Ω to 500 Ω), higher fatigue life and smaller size. The disadvantages are nonlinearity and temperature instability, both requiring sophisticated compensation techniques.

For the measurement of the hydraulic pressure a semiconductor strain gage pressure transducer (model IPT - 100 series, Kulite

Semiconductor, Inc.) was chosen. The transducer was of all-welded stainless steel construction, with integral pressure port and diaphragm. The diaphragm consisted of silicon chip containing an integral strain gage or strain gage pattern formed by solid state diffusion (Fig. 3.1). This model was light weight and operated from a 6 to 10 V dc voltage supply. The overall output of a four-arm bridge as illustrated in Fig. 3.1 is:

$$V_o = (m/4) F \varepsilon V_i \qquad \ldots . (3.7)$$

where V_o = output voltage, V

F = gage factor

ε = strain

n = number of active arms in bridge

V_i = input voltage, V.

In Fig. 3.1 the resistances R_p and R_z are used for thermal zero shift compensation and R_s is a thermal strain sensitivity shift compensator or span compensator.

The semiconductor pressure transducer was installed on the hydraulic cylinder to measure the pressure in the cylinder when a load was applied to the tractor drawbar. This provided an alternate method of determining draft or unit draft.

3.4 Slip or Travel Reduction

Slip or travel reduction can be defined by [12]:

$$S = 100(v_o - v)/v_o \qquad \ldots . (3.8)$$

where S = slip or travel reduction, percent

v_o = velocity of traction system without load, km/h

v = velocity of loaded traction system, km/h

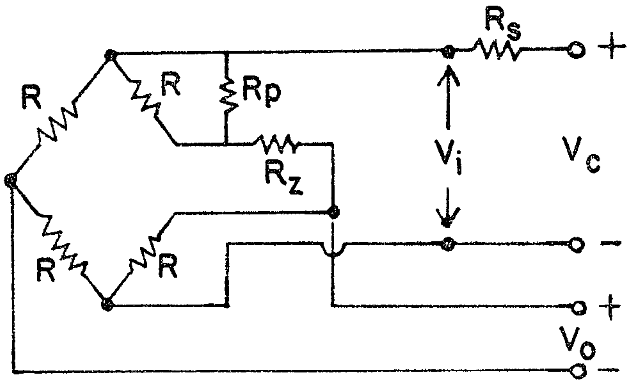
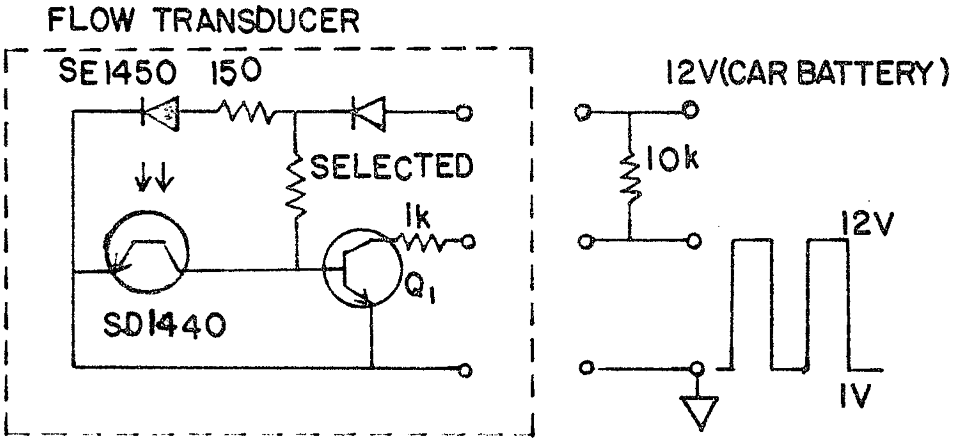


Figure 3.1 Semiconductor strain gage wiring diagram, with connections for bridge compensation. (Pressure transducer, model IPT-1000 series, Kulite Semiconductor, Inc.)



SE 1450 : Light emitting diode (LED)
SD 1440 : Phototransistor
Q_1 : npn transistor

Figure 3.2 Schematic diagram of flow transducer (Series 200 Model 201 A, FlosCan Instrument Co., Inc.).

Slip has also been defined by Vanden Berg et al. [33] as: the relative velocity between a traction device and the soil at the point of contact. Mathematically this is:

$$S = 100(R\omega - v)/(R\omega) \qquad \text{. . . . (3.9)}$$

where R = the rolling radius of the traction system, m

ω = the angular velocity of the traction system, rad/s

v = the velocity of the traction system, m/s.

The ASAE Yearbook (1973) in recommendation R296.1 gives an expression for slip similar to Eq. 3.9 above. The ASAE recommendation also describes that zero slip conditions may be those of zero net traction, or zero torque for the traction system as well as zero drawbar pull. For convenience, slip may also be expressed as

$$S = 100(D - d)/D \qquad \text{. . . . (3.10)}$$

where D = vehicle advance per revolution of traction device with zero drawbar pull, m

d = vehicle advance per revolution of traction device with drawbar pull, m.

If the vehicle engine speed remains approximately constant with or without drawbar pull, slip can be expressed as [12]:

$$S = 100(t - t_o)/t_o \qquad \text{. . . . (3.11)}$$

where t_o = time to traverse a known distance with zero drawbar pull, s

t = time to traverse the same distance with drawbar pull, s.

3.5 Fuel Consumption

It is frequently desirable when evaluating power requirements and tractor performance to measure fuel consumption. With the tractor performing so many different operations the power output and hence the fuel consumption obviously vary greatly.

The fuel consumption of an engine can be determined in several different ways. Some of the more practical methods are measuring directly the rate at which the fuel is flowing to the carburetor, measuring a volume of fuel and recording the time required to consume this quantity (volumetric) and measuring a mass of fuel and determining the time required to consume the quantity (gravimetric). Both the volumetric and gravimetric methods, although providing the greatest potential accuracy under steady loads, are not suitable for in-vehicle installation. Transient conditions can not be readily determined under field conditions. Several transducers currently available have adequate transient response and can be installed in the fuel line to overcome these problems.

Turbine or inferential flowmeters have had extremely rapid development in recent years because of advances in electronics technology. For example, the turbine output provides an electrical current pulse train which can be used to indicate the flow rate or upon integration to provide total fuel consumption. These flowmeters are small in size and relatively low in cost.

A turbine flow transducer (series 200 Model 201 A, FloScan Instrument Company Inc.) producing a current pulse signal from an opto-electronic pickup was used in this study. Fuel enters the flow chamber tangentially, follows a helical flow path, and exits vertically, thereby venting any entrained vapor bubbles. A neutrally buoyant rotor spins with the fuel between V-jewel bearings. The rotational velocity of the rotor is directly proportional to the fuel flow rate. The rotor movement is sensed when notches in the rotor interrupt an infrared light beam between a light emitting diode (LED) and a photo transistor. The output pulses have a frequency which is proportional to the rate of flow. The output is amplified and shaped by Q_1 before being counted by a counter as illustrated in Fig. 3.2.

Average fuel consumption of an engine should be based on the actual power of the engine over the test period. An estimate of the fuel consumption would be most useful if it could be expressed by an equation valid for all levels of power and for all engine speeds. Fuel consumption can be quoted as follows:

Fuel consumption per unit time ,	L/h
Fuel consumption per unit area ,	L/ha
Specific fuel consumption ,	kg/kWh.

3.6 Soil Resistance

Soil resistance can be determined by measuring the penetration resistance of soils. Soil penetration resistance can be used as a soil parameter in considering the compaction effect of tillage operations.

The penetrating element may be circular, rectangular, flat or cone shaped. The cone penetrometer is frequently used in agricultural soil studies. The device can be self-recording, reasonably accurate, light in weight, simple to build and require little adjusting. The recording pointer is positioned by the depth of penetration of the cone and the downward force required to overcome the soil resistance.

The pointer deflection is based on the fact that deflection of a spring is directly proportional to the force applied. To measure the depth of penetration, the chart holder is supported on a foot which rests on top of the ground. The pointer mechanically attached to the probe moves down a distance equal to the depth of the penetration.

Thus, as the point of the penetrometer is advanced into the soil at a steady rate, a continuous record of penetration resistance versus depth can be obtained. Several samples can be quickly taken and recorded on the same chart.

The ASAE recommends for field use a 30 degree circular cone penetrometer driven through the soil at a rate of approximately 3 cm/s. The results are quoted as a Cone Index, CI (N/cm^2). A description of this instrument is given in ASAE Recommendation R313 [1]. The accuracy of a soil cone penetrometer depends greatly on soil moisture content. The most accurate results are obtained when the soil moisture content is 20 percent of the dry soil mass [23].

3.7 Soil Moisture Content

One of the objectives of tillage operations is to improve water relationships in the soil for plant growth. Tillage affects the rate of infiltration, redistribution and storage of water within the soil profile and hence may have a direct or indirect influence on evaporation and transpiration.

Soil moisture content can be determined by sampling at any desired depth. The samples are weighed and then dried at 105-110°C for about 48 hours. The moisture content is then calculated as a percentage of the dry soil mass as described below:

$$M_s = 100\ (W - D)/D \qquad \ldots\ (3.12)$$

where M_s = soil moisture content, percent

W = wet soil mass, g

D = oven-dry soil mass, g

3.8 Instruments Used

Instrumentation was required to measure and record drawbar pull, actual ground speed, slip, fuel consumption, soil resistance and soil moisture content in the field studies. The instrumentation consisted of the following items:

(a) Test Tractor

A Ford tractor model 7700 diesel, dual power, 2-wheel drive, serial number 1771911219 equipped with 10.00-16 front tires and 18.4-34 rear tires was used.

(b) Tillage Implements

Tillage implements were available at the Glenlea Research Station, University of Manitoba. The implements available are listed below:

Table 3.1 Tillage implements available for draft measurement

Implement	Width of implement,m
Moldboard plow	1.8
Double Disk	4.0
Discer seeder	5.4
Hoe drill	4.1
Harrow (spike tooth)	14.3
Deep tillage (chisel plow)	4.0
Light tillage (cultivator)	4.0
Press Drill (Duplex)	5.1
Zero Drill (Duplex)	5.1

(c) Hydraulic dynamometer cylinders and cylinder constants

No. 1 - $K_{cy} = 0.0031$ N/Pa

No. 2 - $K_{cy} = 0.0074$ N/Pa

No. 3 - $K_{cy} = 0.0128$ N/Pa

(d) Hydraulic Dynamometer cart

(e) Stop watch

(f) Pressure transducer

The semiconductor pressure transducer is illustrated in Fig. 3.3.

(g) Flow transducer

The turbine flow transducer is illustrated in Fig. 3.3.

(h) Magnetic tape recorder

A Sony TC 126 two channel battery operated tape recorder was used to record the field data.

(i) Digital Counter

Model 5300 A (Hewlett packard, Inc.).

(j) Oscilloscope

A model 212 Tektronix oscilloscope was used to monitor data acquisition.

(k) Battery power supply

(l) FM Signal conditioning and Control boxes

This instrumentation had been designed and constructed in the Agricultural Engineering electronic laboratory, University of Manitoba. The circuits consisted of a differential amplifier for the signal from the pressure transducer, a FM conversion for recording on tape and a power supply as well as start, stop and mark controls for the tape recorder.

(m) Soil Cone Penetrometer

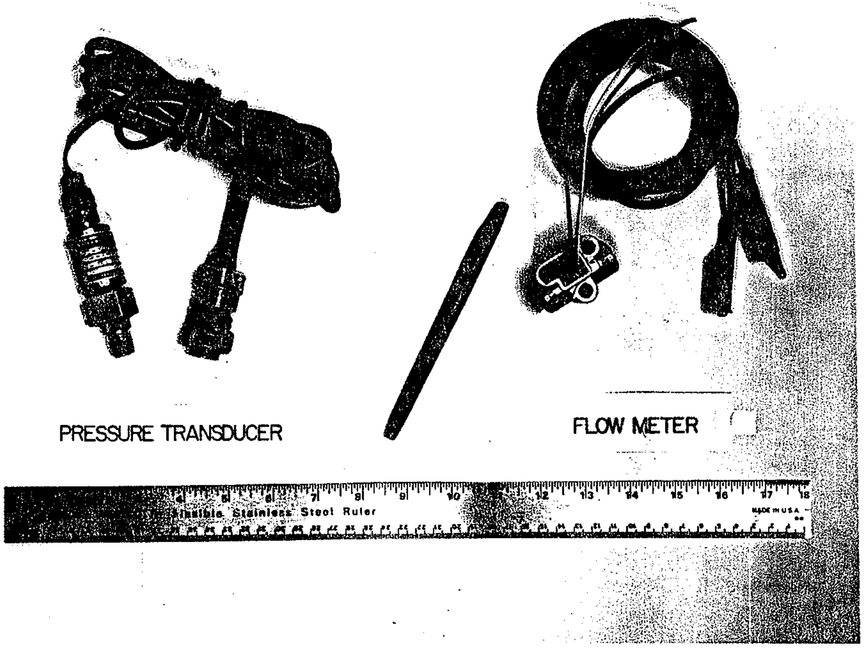


Figure 3.3 Semiconductor pressure transducer (model IPT-1000 series, Kulite Semiconductor Products, Inc.) and turbine flow transducer (Series 200 model 201A, FloScan Instrument Company, Inc.).

3.9 Tillage treatments

Five different tillage systems for Manitoba conditions as outlined in Table 2.1 were selected for comparison. The power requirements, fuel consumption and the effect of the tillage treatments on the physical properties of the soil were of interest.

CHAPTER 4

INSTRUMENTATION DESIGN

A significant part of the measurement system was the terminating or output device which displayed or recorded the data during the field testing. The semiconductor pressure transducer signal which was proportional to the drawbar force being measured had to be modified before being recorded on the magnetic tape recorder. Magnetic tape recorders offer several advantages. The tape recorder can be used when a simultaneous display and a permanent record of the measurement are desired.

There are two methods of tape recording, namely direct recording and FM recording. Direct recording has the major disadvantages of the inability to record low frequencies (the low frequency limit is 50 Hz) and limited high frequency response. These two major disadvantages are overcome by frequency modulation (FM). The low frequency signal of the semiconductor pressure transducer can be recorded as a frequency deviation proportional to the amplitude of the signal. It was necessary to design a circuit for obtaining frequency modulated signals and to produce an instrumentation package that was convenient for use in field testing.

4.1 FM Recording Principle for a Magnetic Tape Recorder

A basic FM recording system is illustrated in Fig. 4.1. The signal waveforms are assumed as:

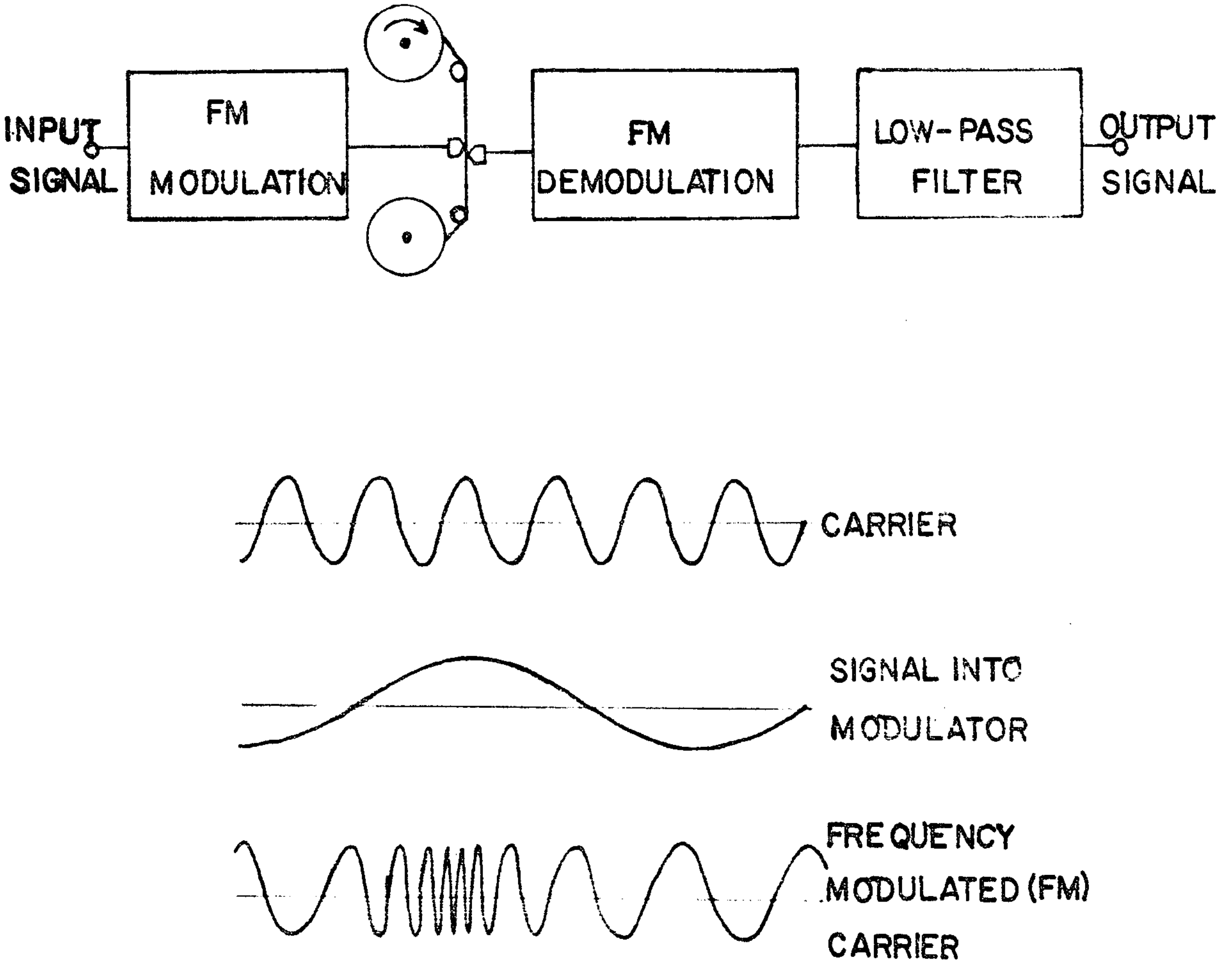


Figure 4.1 Basic principle of FM recording system.

$$e_s = B \cos (\omega_s t) \qquad \ldots . (4.1)$$

$$e_c = A \cos (\omega_c t + \phi) = A \cos\theta \qquad \ldots . (4.2)$$

where e_s = input signal, V

e_c = carrier signal, V

B = amplitude of input signal, V

A = constant amplitude of carrier, V

ω_s = angular frequency of signal, rad/s

ω_c = angular frequency of carrier, rad/s

$\phi = \int_o^t \omega_c dt$, rad

t = time, s

The center frequency of the carrier is selected to correspond to an input signal of zero.

If ω_c is proportional to the instantaneous value of e_s then the variation in carrier frequency is given by

$$\Delta\omega_c = k_f e_s = k_f B \cos(\omega_s t) \qquad \ldots . (4.3)$$

where k_f = a proportionality constant, (rad/s)/V

Since the instantaneous carrier frequency is $\omega_c + k_f B \cos(\omega_s t)$

then $\theta = \int_o^t \omega_c dt + \int_o^t k_f B \cos(\omega_s t) dt$

or $\theta = \omega_c t + (k_f B/\omega_s) \sin(\omega_s t) + \phi \qquad \ldots . (4.4)$

Therefore, the frequency modulated carrier is given by

$$e_c = A \cos (\omega_c t + m_f \sin(\omega_s t) + \phi) \qquad \ldots . (4.5)$$

where m_f = frequency modulation index

$$= \frac{\text{maximum deviation of the carrier frequency}}{\text{signal frequency}}$$

4.2 Method of Modulation

A Sony TC126 magnetic tape recorder has a recording range of 50 Hz to 10,000 Hz. A voltage-controlled oscillator (VCO) can be used to provide frequency modulation.

A VCO is an oscillator whose instantaneous frequency is controlled by an applied voltage signal. The defining equation is:

$$e_\gamma(t) = A \cos [\omega_c t + \mu \int_o^t e_s(t)dt] \quad . . . . (4.6)$$

where $e_\gamma(t)$ = output signal of VCO, V

A = amplitude, V

ω_c = frequency with zero control signal, Hz

μ = VCO sensitivity, Hz/V

$e_s(t)$ = control signal voltage, V.

A model LM 566 VCO was used in the FM design. The circuit provided a square and triangular output at frequencies up to 1 MHz. The voltage applied to the control terminal (V_c) was in the range $0.75V_{CC} \leq V_c \leq V_{CC}$ where V_{CC} is the supply voltage. The VCO sensitivity was 6 kHz/V. The center frequency was controlled by an external resistor, R_1 and a capacitor, C_1 and the voltage, V_c.

The center frequency can be determined by

$$f_o \approx 2(V_{CC} - V_c)/(R_1 C_1 V_{CC}) \quad . . . . (4.7)$$

where R_1 is selected in the range 2 kΩ to 20 kΩ.

4.3 Calculating the System Requirements

The electrical characteristics of the LM 566 VCO are:

sensitivity, μ = 6 kHz/V

supply voltage, V_{CC} = 10.6 V dc

output voltage, V_o = 2.4 V (typical valve, peak-to-peak)

The required output frequency range was from 10 kHz to 15 kHz which corresponds to a control voltage range of 1.6 V to 2.5 V.

4.3.1 DC Amplifier for VCO

In a differential-amplifier circuit as shown in Fig. 4.2, the output voltage is given as:

$$e_o = e_1(R_{fb} + R_i)/R_i - e_i R_{fb}/R_i) \quad \ldots . (4.8)$$

where e_o = output voltage (input to VCO), V.

$$\text{If } e_i = 0;\ e_{o1} = e_1(R_{fb} + R_i)/R_i \quad \ldots . (4.8 - a)$$

$$\text{and if } e_i \neq 0;\ e_{o2} = e_1\ (R_{fb} + R_i)/R_i - e_i R_{fb}/R_i \quad \ldots . (4.8 - b)$$

$$\text{Since} \quad e_{o1} = V_{CC} - 1.6 \quad \ldots . (4.9 - a)$$

$$\text{and} \quad e_{o2} = V_{CC} - 2.5 \quad \ldots . (4.9 - b)$$

substitution of Eqs. (4.9 - a) and (4.9 - b) into Eqs. (4.8 - a) and (4.8 - b) yields:

$$R_{fb}/R_i = 0.9/e_i$$

For an input voltage, e_i = 2V and an input resistance, R_i = 10 kΩ the feedback resistance, R_{fb} = 4.5 kΩ so that

$$e_1 = 6.2 \text{ V}$$

where e_1 is the reference voltage for the VCO.

4.3.2 Calculation of Center frequency, f_o

From Eq. 4.7, the frequency of oscillation, f_o = 15 kHz when V_{CC} = 10.6 V, V_c = 8.1 V, R_1 = 10 kΩ and C_1 = 0.003 μF.

4.3.3 Input and Output Buffers of VCO

An input buffer amplifier was needed to avoid changing the input resistance, R_i and the resistance, R_{fb} of A_2 when input attenuation was desired as shown in Fig. 4.3.

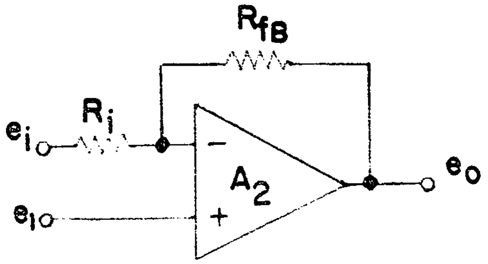


Figure 4.2 DC - differential amplifier

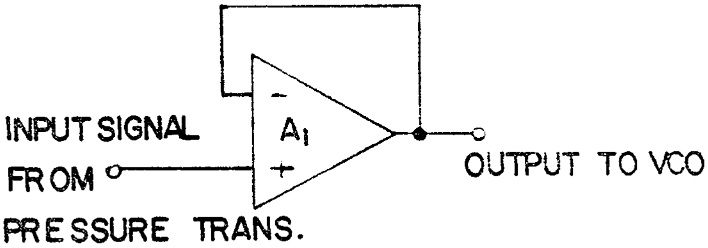


Figure 4.3 Input buffer circuit

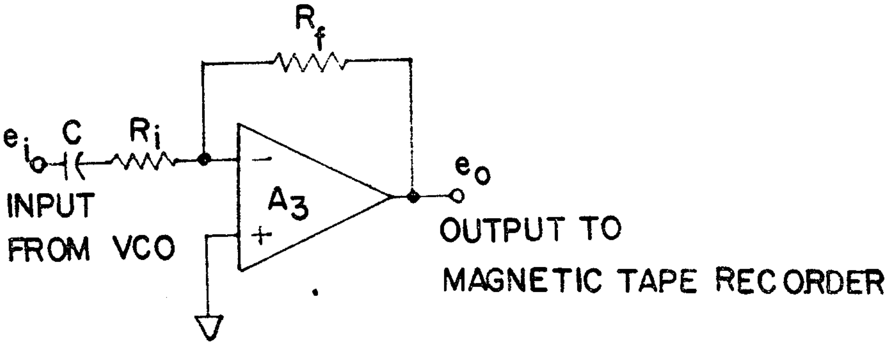


Figure 4.4 Output buffer amplifier

The maximum input signal level to the magnetic tape recorder was approximately 12 V. A typical output voltage from the VCO was 2.4 V_{p-p}. Therefore, an output buffer amplifier was needed to bring the signal up to a suitable level for recording.

In the amplifier of Fig. 4.4,

$$e_o = e_i \, R_f/R_i$$

where R_i = .10 kΩ and R_f = 140 kΩ. A capacitor, C is used to remove the dc component in the VCO output. The valve of the capacitor was 0.01 μF.

4.4 Voltage Regulator for FM System

Regulated voltages as illustrated in Fig. 4.5 were needed to supply the amplifiers, the VCO and the reference voltage.

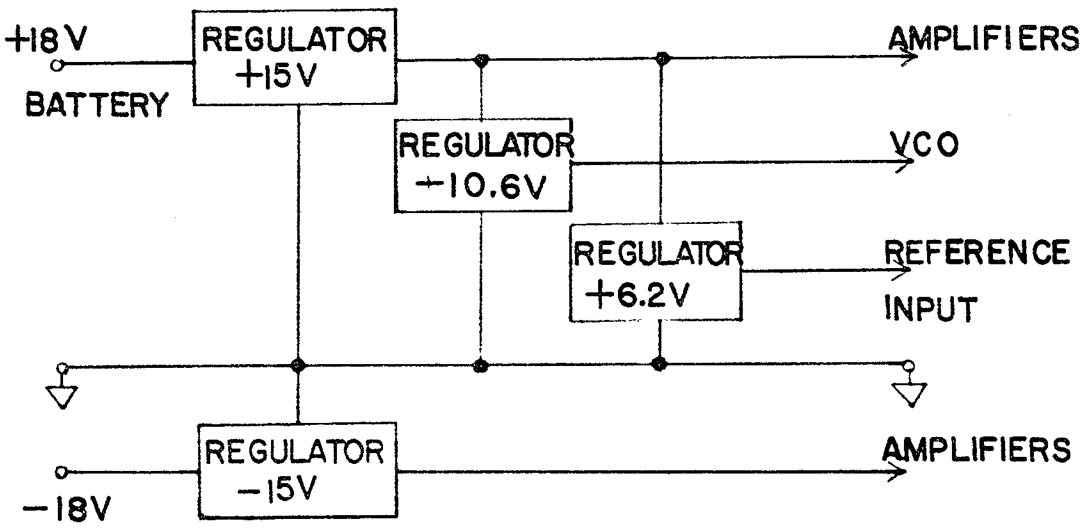
4.5 Assembly for FM

An attenuator was designed to reduce the amplitude of the semiconductor pressure transducer signal without distortion. A variable attenuator with ratios of 1.0, 0.5 and 0.1 was used. The resulting attenuator is shown in Fig. 4.6.

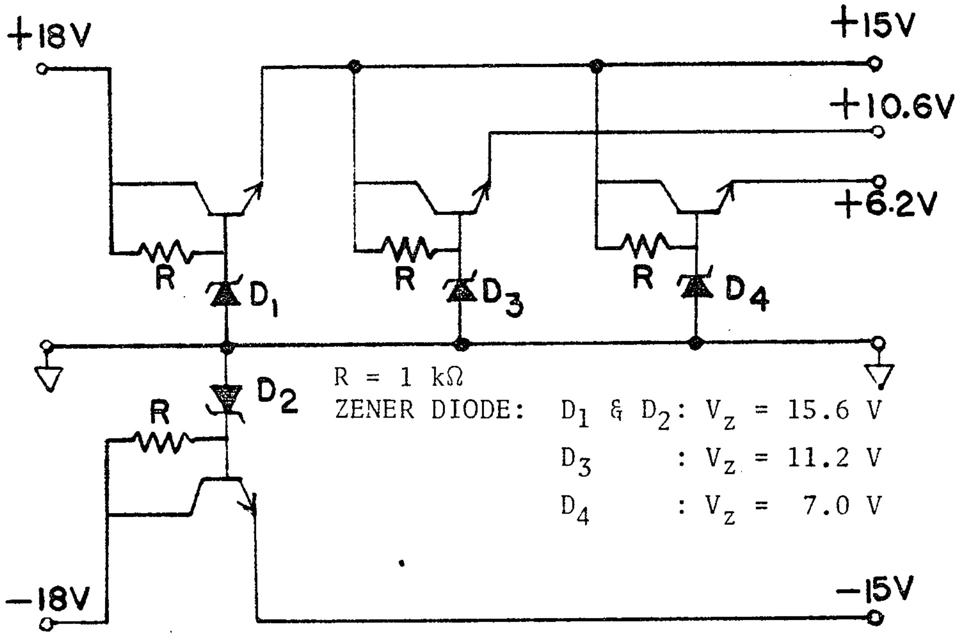
A level meter (0 - 1 μA) was required to indicate the level of the semiconductor pressure transducer signal. The components described above were connected to the magnetic tape recorder as shown in Fig. 4.6. The circuits were fitted into two boxes with start, stop and mark control switches for the tape recorder as shown in Fig. 4.7.

4.6 Semiconductor Pressure Transducer Input Circuit

The differential amplifier shown in Fig. 4.8 used three operational amplifiers in a non-inverting feedback mode. The amplifier was used for the precision amplification of the differential input

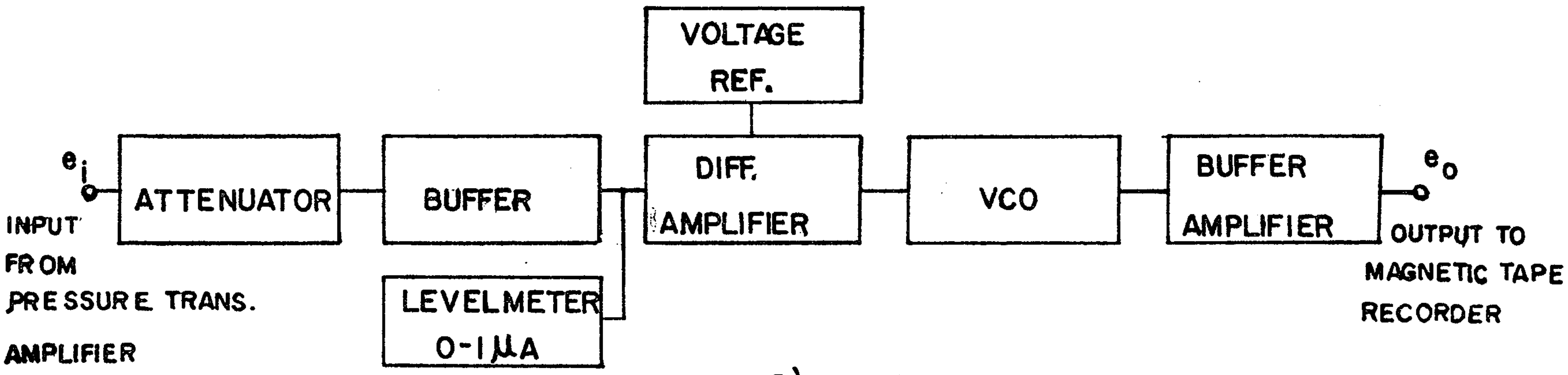


a) Block diagram of voltage regulator

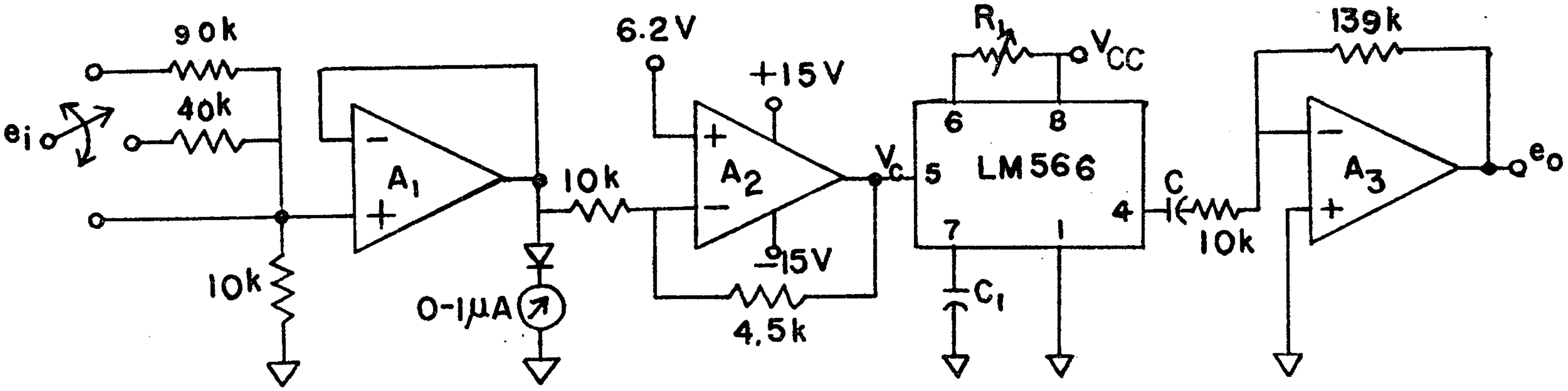


b) Voltage regulator equivalent circuit

Figure 4.5 Regulated voltage supply for FM system.



a) Block diagram



b) Circuit implementation

Figure 4.6 FM Recording system for magnetic tape recorder

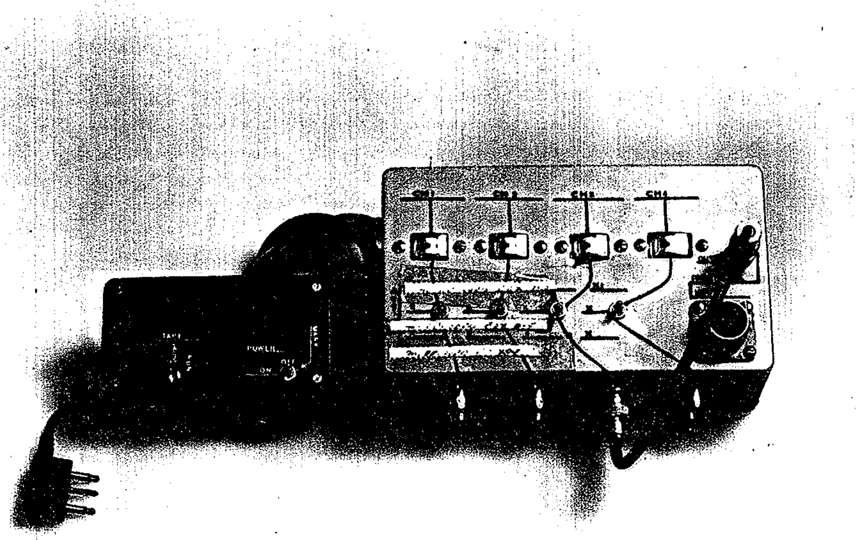
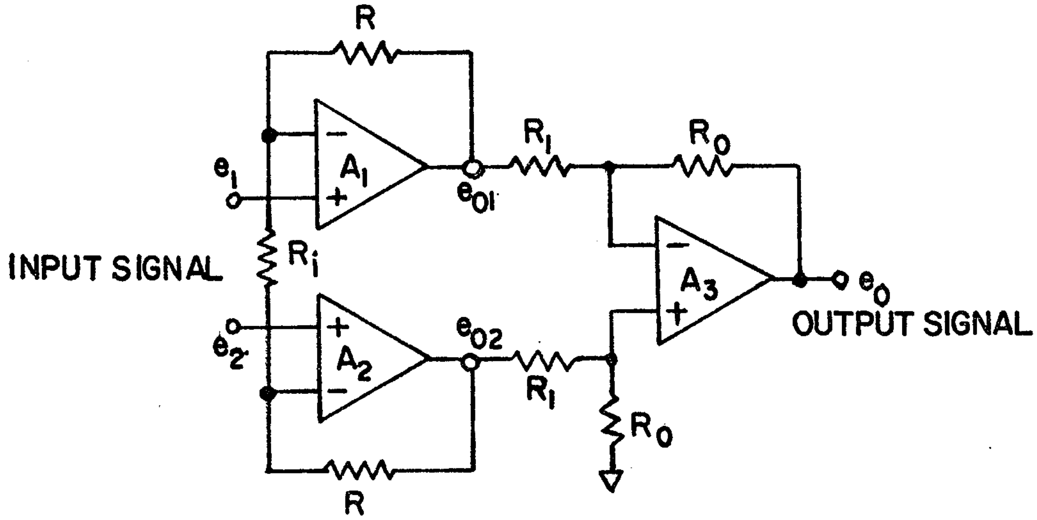


Figure 4.7 Central boxes for the signal conditioning and central circuits for FM recording on magnetic tape.



$R_i = R = R_o = 10\ k\Omega$

$R_1 = 3.3\ k\Omega$

$A_1 = A_2 = A_3 =$ ¼ Model 3403 Amplifier Chip

Figure 4.8 Circuit implementation of a differential amplifier used with the semiconductor pressure transducer.

signal from the semiconductor pressure transducer. The advantage of this circuit was its impedance buffering property. Undesired loading effects between the signal source and the load were prevented. The overall differential gain can be expressed as:

$$e_o = -(1 + 2R/R_i)(R_o/R_1)(e_1 - e_2) \quad \ldots\ldots (4.10)$$

For $R_i = R = R_o = 10\ \text{k}\Omega$, $R_1 = 3.3\ \text{k}\Omega$

$$e_o \approx -10(e_1 - e_2)$$

This amplifier circuit was fitted into the same box as the FM recording system shown in Fig. 4.7.

4.7 FM demodulation

To obtain the original signal from the modulated signal on the magnetic tape recorder, FM demodulation was required. The demodulation unit had been designed in the Agricultural Engineering electronics laboratory, University of Manitoba and a block diagram is shown in Fig. 4.9.

An important feature of this circuit was the fast response time at low carrier frequencies ($f_c \approx 12$ kHz). The circuit can record up to 3.5 kHz and demodulate the signal using a filter with a time constant of 10^{-5} s.

The basic approach for demodulation was to first convert the input signal into a train of narrow pulses (by limiters, differentiator and absolute value circuits) and then to measure the time between pulses by means of a gated integrator.

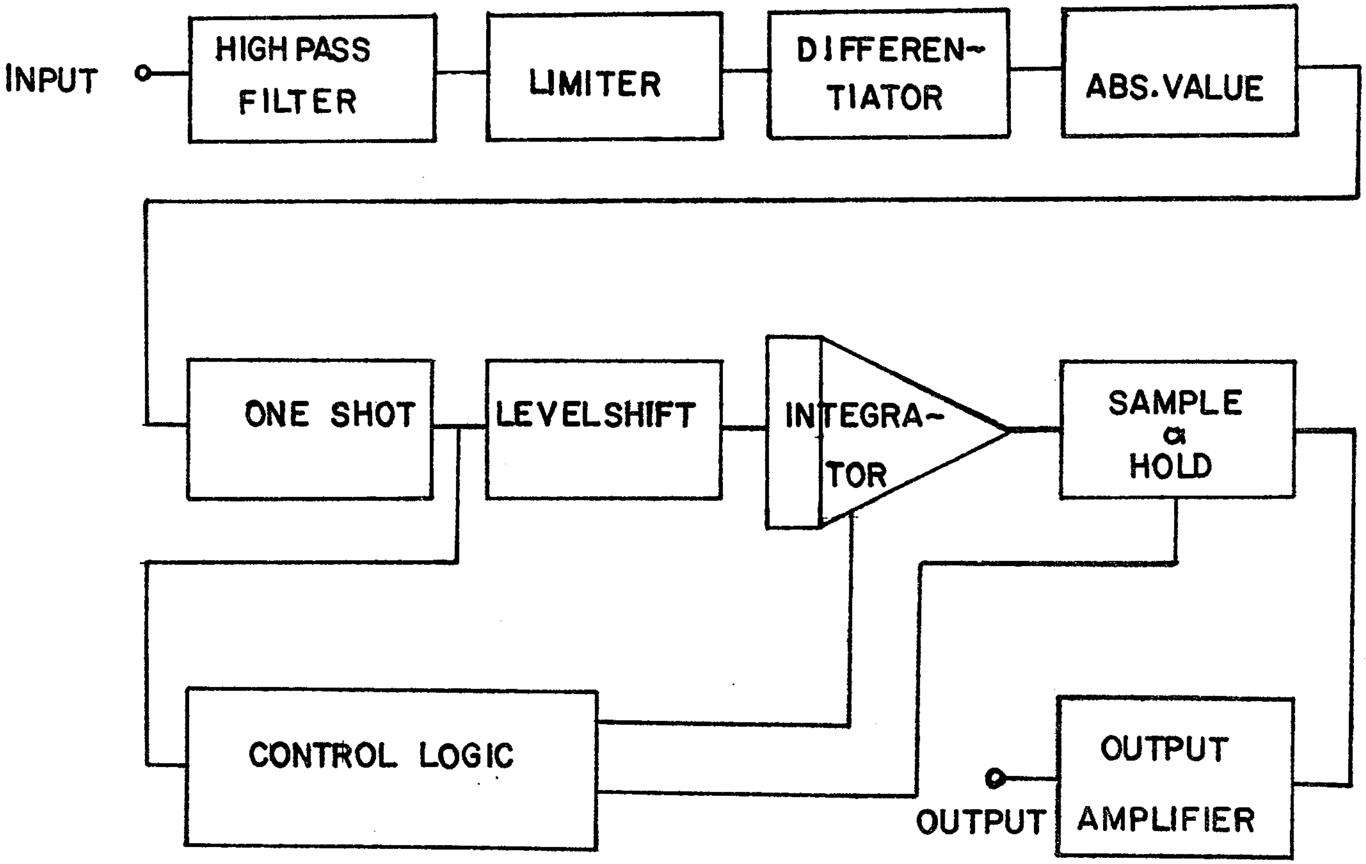


Figure 4.9 Block diagram of FM demodulation

CHAPTER 5

EXPERIMENTAL PROCEDURE

The testing of the instrumentation that was developed was done in two stages. The first stage consisted of calibration for field use. The second stage consisted of actual field testing where energy requirements for various field operations were determined. The field tests were performed using tillage implements to create drawbar loads as well as a towed tractor to simulate drawbar loads.

All drawbar power measurements were done using the semiconductor pressure transducer and the conventional hydraulic dynamometer so that comparisons were possible. In addition, fuel consumption, soil penetrometer resistance and soil moisture content were measured.

5.1 Instrument Calibration

Calibrations of the measurement systems were carried out both in the laboratory and under field conditions.

5.1.1 Calibration of the Semiconductor Pressure Transducer.

A preliminary static calibration was done using a dead weight tester. The relationship between input pressures and output voltages was determined for input pressures in the range of 0.7 to 7 MPa increments (Fig. 5.1).

Fig. 5.2 and Fig. 5.3 show the results of the calibration. The data points were fitted by a least-squares linear regression with a

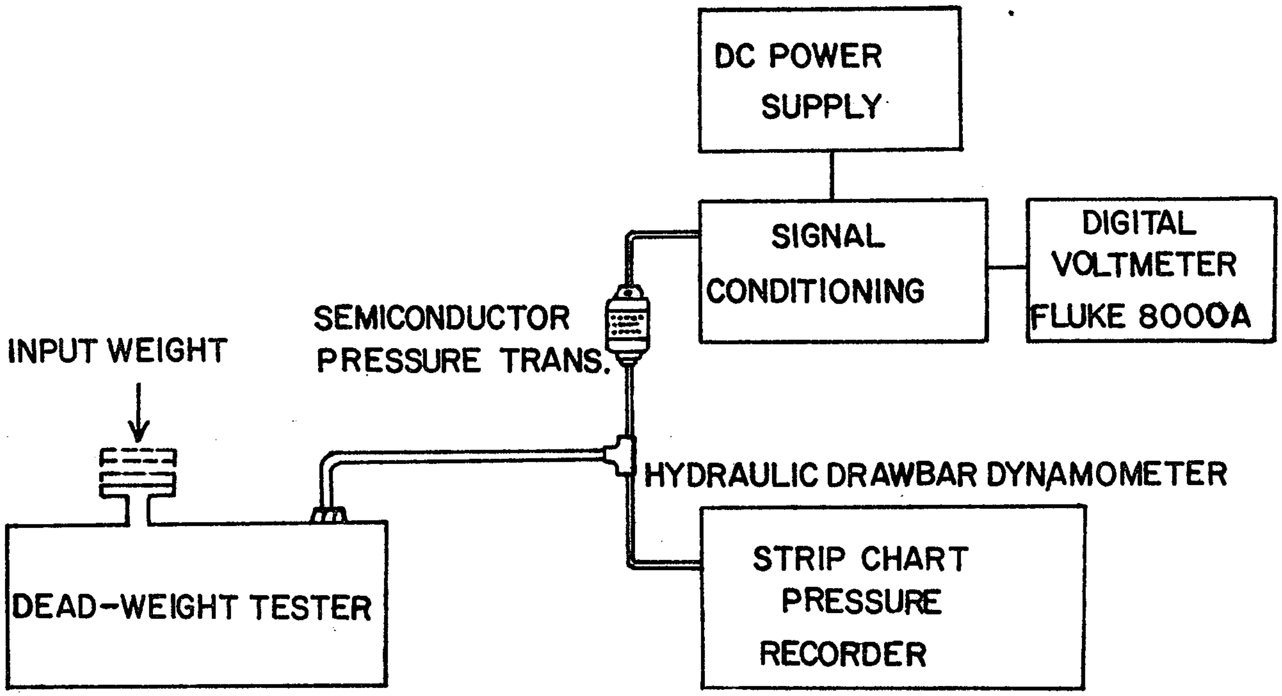


Figure 5.1 Semiconductor Pressure Transducer and Strip Chart Pressure Recorder Calibration.

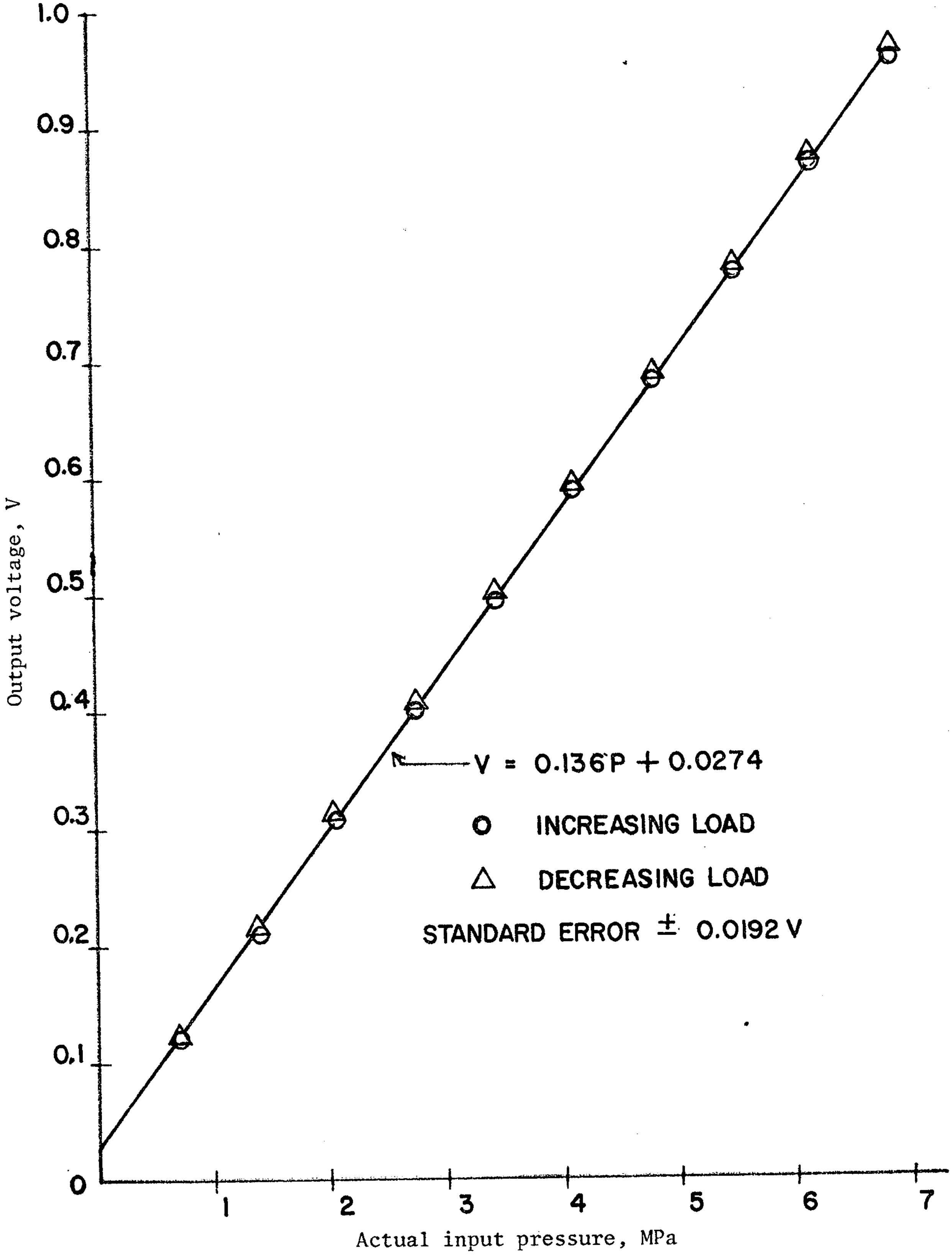


Figure 5.2 Semiconductor Pressure Transducer Calibration. Model: IPT-1000 series (Kulite Semiconductor, Inc.). (Dead weight tester used for reference pressures).

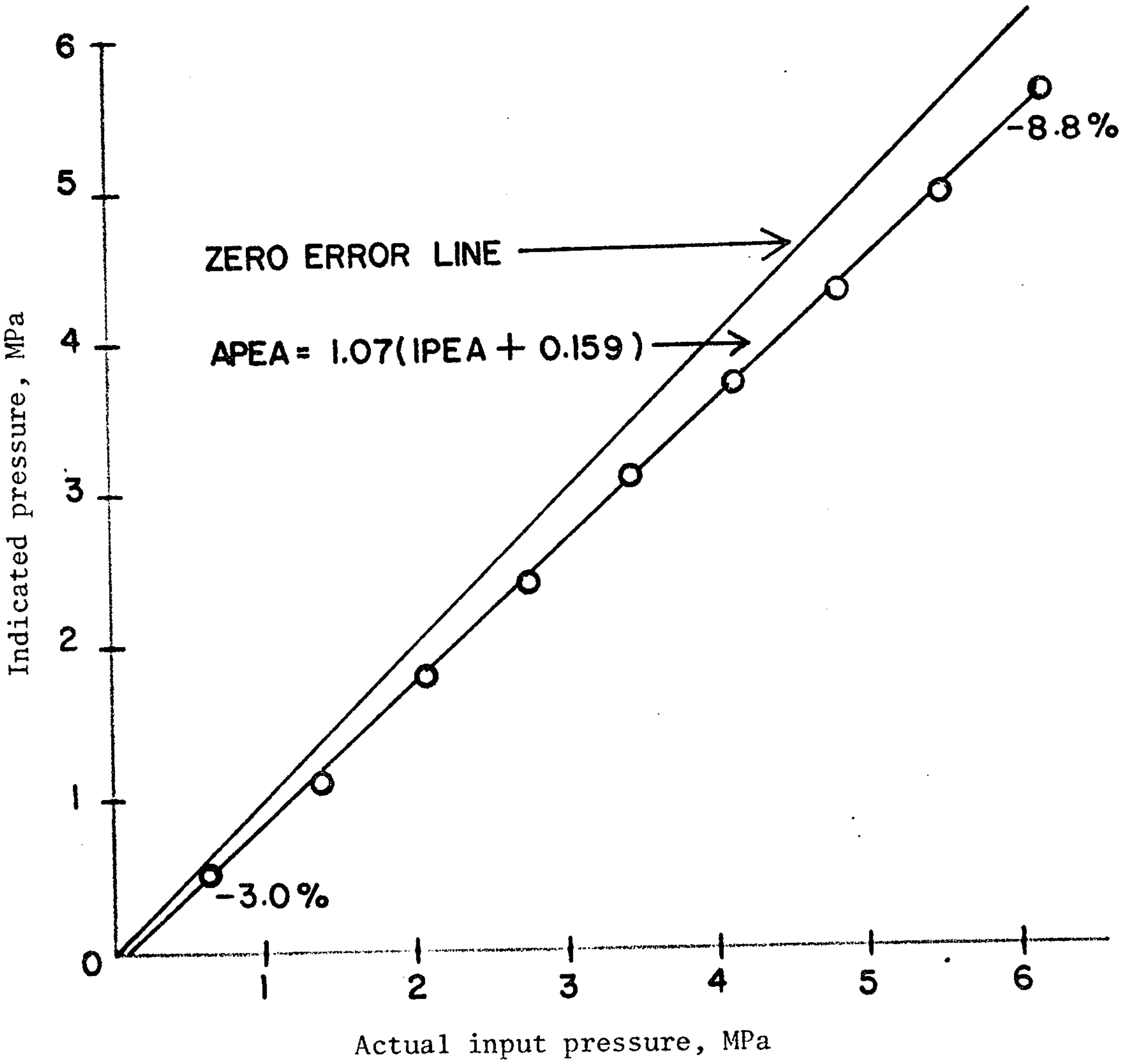


Figure 5.3 Strip chart pressure recorder calibration
(Dead weight tester used for pressure standard)

standard error of ± 0.0192 V. The linear regression equation was found to be

$$V = 0.136\ p + 0.0274 \qquad \ldots\ (5.1)$$

where V = output voltage of the semiconductor pressure transducer, V

p = input pressure, MPa.

The strip chart pressure recorder on the hydraulic drawbar dynamometer was also calibrated at the same time as the semiconductor pressure transducer (Fig. 5.1). Both measuring systems were subjected to the same input pressure as provided by the dead weight tester whose accuracy was 0.025%. The instruments were initially set to zero before static pressure loading started. The outputs were recorded and plotted against the input pressures (Fig. 5.2 and Fig. 5.3).

The information that was required from the calibrations was a correction to be applied to estimate the actual cylinder pressure as determined from the indicated pressure from the transducers.

$$APSC = 7.35\ (V - 0.0274) \qquad \ldots\ (5.2)$$

$$APEA = 1.07\ (IPEA + 0.159) \qquad \ldots\ (5.3)$$

where APSC = actual pressure of the semiconductor pressure transducer, MPa

V = output voltage of the semiconductor pressure transducer, V

APEA = actual pressure of the strip chart, MPa

IPEA = indicated pressure from the strip chart, MPa.

5.1.2 Fuel Flow Transducer Calibration

The fuel flow transducers were calibrated by using a volumetric method. The method measures precisely a volume of fuel passing through the flow transducer in a known time interval. Two flow transducers were used to determine the net fuel consumption of the tractor.

Fig. 5.4 illustrates the arrangement used for flow transducer calibration. A pump was used to return fuel to the storage tank to maintain constant head for the supply fuel. Two counters were used to count the current pulses from the flow transducer. The number of pulses was proportional to the flow. One counter counted the total number of pulses for the calibration period while the other counter was used to give pulses per second. The pulses per second measurement was used to indicate how constant the flow rate was.

A calibration run was started when fuel was diverted through the control valve and collected in the container. When the container was filled to the required level (2000 mL) the calibration run was terminated. Both a stop watch and the counters were started at the initiation of the calibration run and all were stopped at the end. The elapsed time and the total pulses were recorded. The flow rate was then determined by dividing the total volume of the fuel collected in the container by the elapsed time. The total number of pulses was also divided by the elapsed time to give the average instantaneous pulses per unit time during the run (Table A-2, Appendix A).

The calibration curves obtained for each flow transducer are shown in Fig. 5.5. The relationships between the fuel flows and pulse counts for the fuel flow transducers were determined by linear regression analysis. The calibration results were:

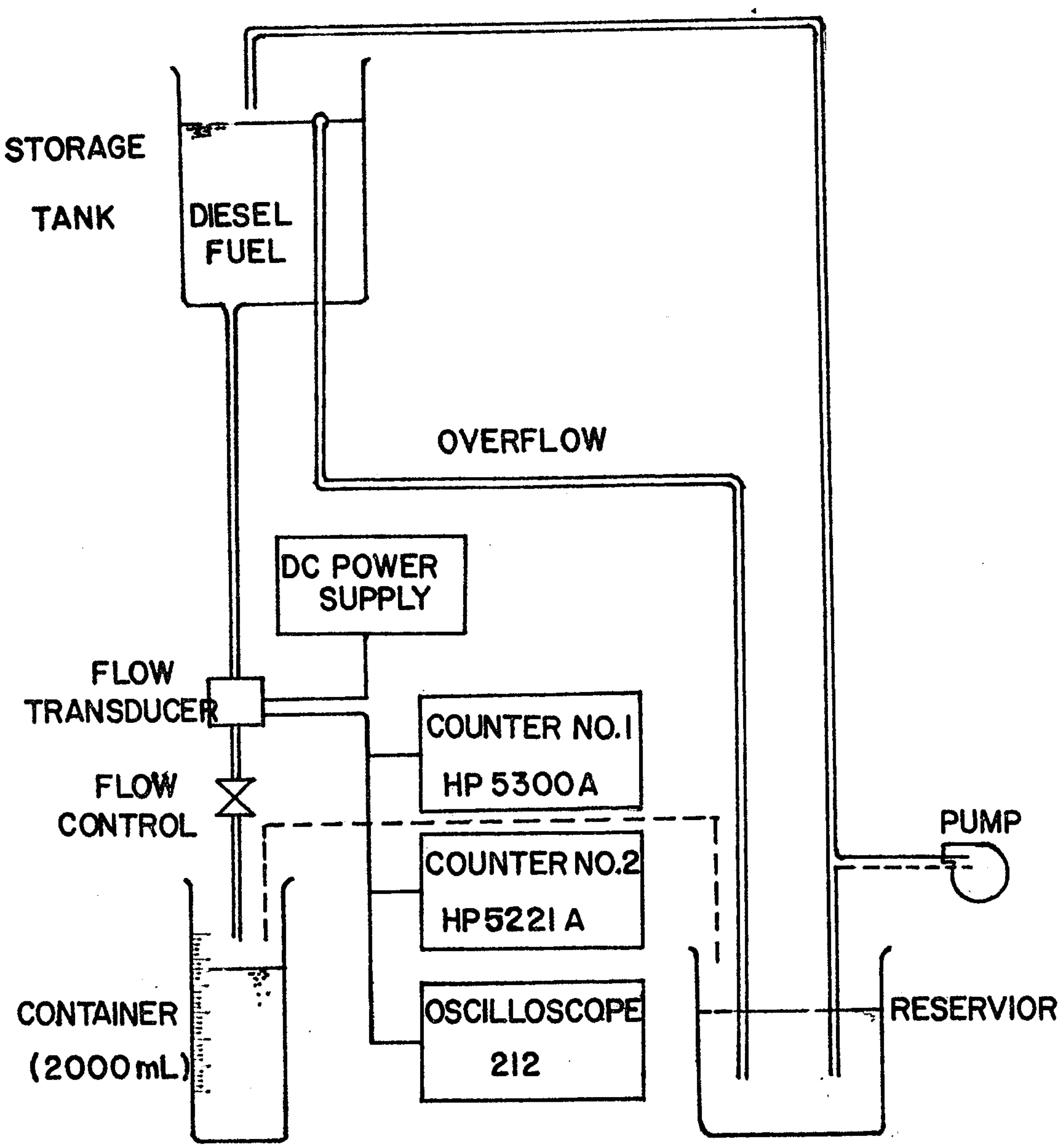
$$PPS_1 = 7.304\ Q + 8.984 \quad \ldots\ldots (5.4)$$

$$PPS_2 = 7.153\ Q + 2.232 \quad \ldots\ldots (5.5)$$

where PPS_1 = pulse output from transducer No. 1, pulses/s

PPS_2 = pulse output from transducer No. 2, pulses/s

Q = fuel flow rate, L/h



<u>Test Flow Meter:</u>	Turbine Flow Transducer (Series 200 Model 201 A, FloScan Instrument Company Inc.).
<u>Fuel:</u>	No. 2 Diesel
<u>Counters:</u>	No. 1 counts total pulses No. 2 counts pulses per second

Figure 5.4 Schematic of flow transducer calibration procedure.

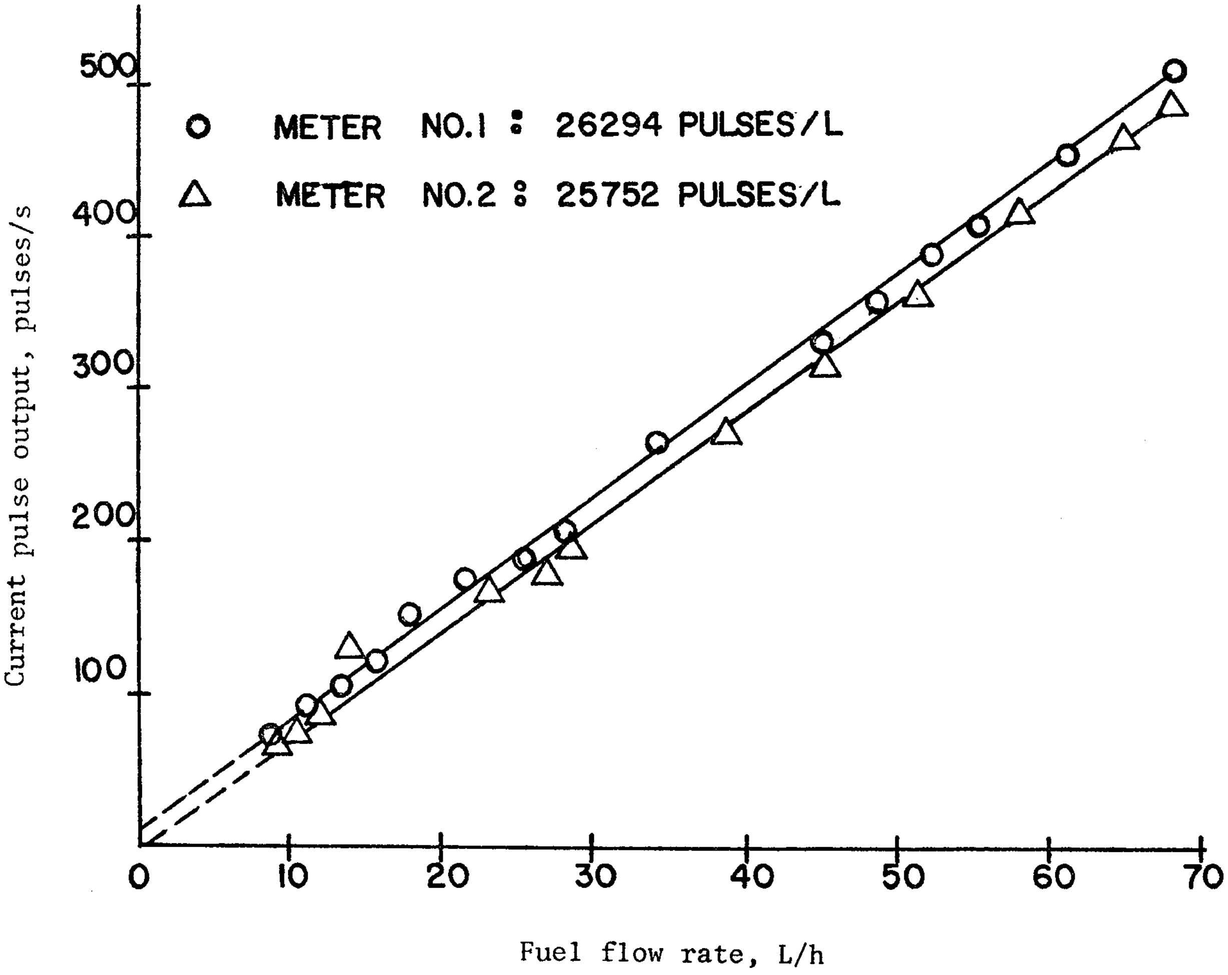


Figure 5.5 Calibration curves for fuel flow transducers

Flow Sensor: Turbine flow transducer
(series 200 model 201 A, FloScan Instrument
Company Inc.).

Fuel: No. 2 Diesel

The sensitivities of the fuel flow transducers were 26294 pulses/L and 25752 pulses/L, respectively. The total pulse count output can also be used to determine the sensitivity directly by dividing by the measured volume (2000 mL) for each run (Table A-2, Appendix A).

5.1.3 Cone Penetrometer Calibration

The soil cone penetrometer was calibrated by static loading methods to obtain a deflection versus load curve. The data points were analyzed by linear regression. The linear regression was:

$$F = 64.382\ X + 48.579 \qquad \ldots. \ (5.6)$$

where F = force required to deflect the penetrometer recording pen, N

X = penetrometer recording pen deflection, cm.

In this study the area of the cone base was 1.3 cm^2. The cone index (CI, N/cm^2) was calculated by dividing Eq. 5.6 by the cone base area. The equation for cone index was:

$$CI = (64.382\ X + 48.579)/1.3 \qquad \ldots. \ (5.7)$$

5.1.4 Chart Constant for the Hydraulic Dynamometer

The strip chart recorder on the hydraulic dynamometer chart was calibrated for chart distance versus ground distance. The chart constant was defined and determined as follows:

$$K_{ct} = GT/PT \qquad \ldots. \ (5.8)$$

where K_{ct} = chart constant, m/cm

GT = measured ground travel, m

PT = corresponding paper travel for measured ground travel, cm.

5.2 Field Tests for Measuring Energy Requirements

Field tests for measuring energy requirements of tillage operations were performed in 1977 at the Glenlea Research Station, University of Manitoba. The semiconductor pressure transducer and the conventional hydraulic dynamometer were used to measure drawbar force or draft. The actual forward speed was determined by measuring the time for a known distance. Slip was determined by comparing the distance travelled for 10 turns of the drive wheels with and without a drawbar load.

The semiconductor pressure transducer and the hydraulic dynamometer were installed between the test tractor and the implement (Fig. 5.6). The hydraulic pressure was detected by the semiconductor pressure transducer. A dc voltage signal, proportional to the pressure, was recorded by the magnetic tape recorder (Fig. 5.7) using the FM modulator described previously. The recorded signal was then analyzed in the electronics laboratory.

Draft was also measured using the hydraulic dynamometer. The pressure recorder recorded the pressure on a strip chart. The strip chart was driven by a wheel in contact with the soil surface. The length of chart paper used for each test was proportional to the distance travelled in the field. The time for the test was measured by a stop watch and recorded manually on the chart. A manually operated event marker on the strip chart recorder was used to indicate each turn of the drive wheels for 10 complete revolutions so that slip could be calculated.

Slip was determined as indicated above. In addition, another simple method was used to determine slip. The time to traverse a known distance was measured for the loaded and no-load test conditions. Assuming constant engine speed for the tests, the times for the tests

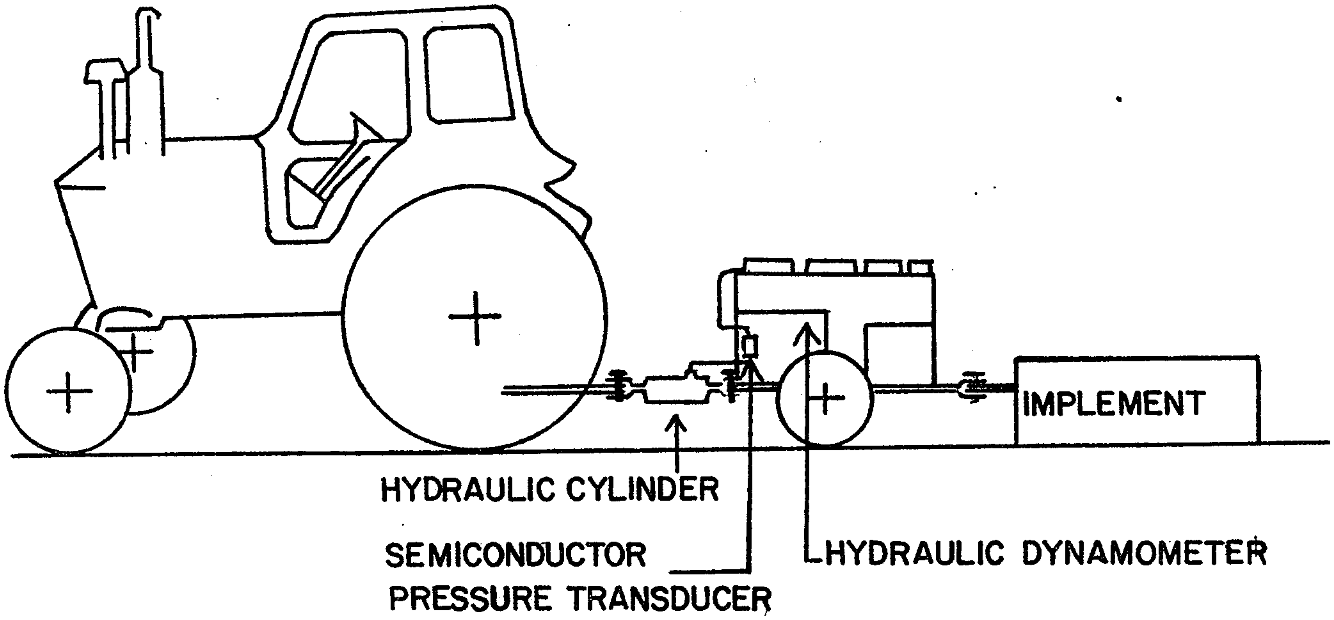


Figure 5.6 Arrangement of the test equipment for measuring energy requirements of tillage implements.

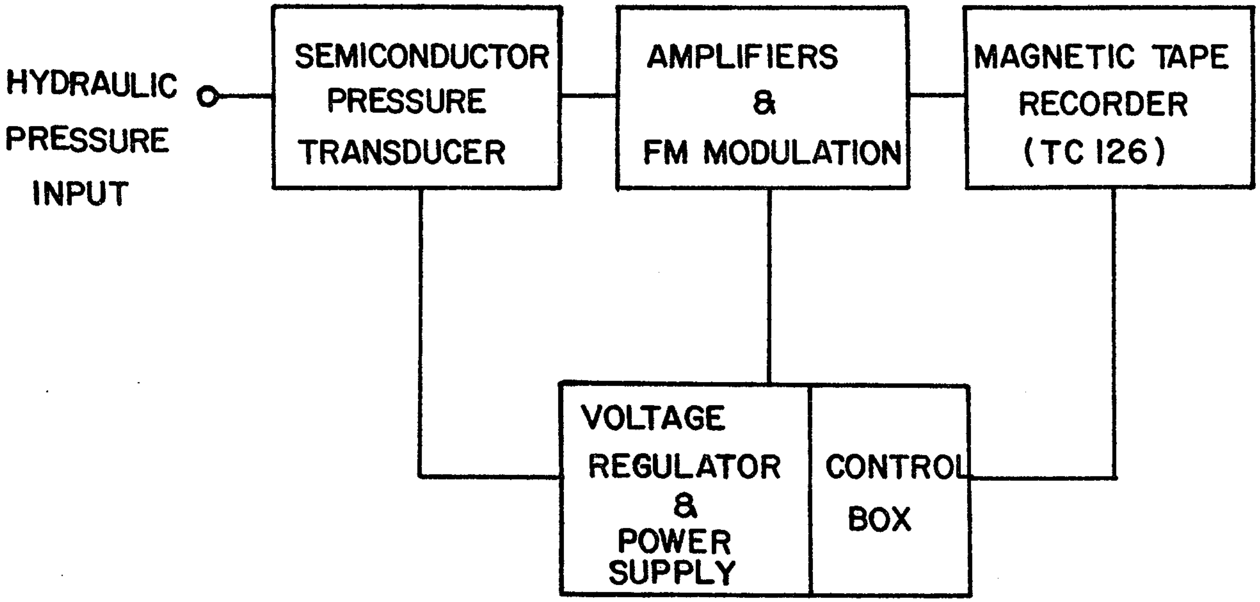


Figure 5.7 Recording arrangement for semiconductor pressure transducer system during the field tests.

can be used to calculate slip. The difference in the time with load and the time without load normalized to the time without load was taken as slip as defined by Eq. 3.11.

Six tests were run for each tillage implement to determine the average energy requirements. The length of each test was long enough to ensure that the magnetic tape recorder and the strip chart recorder recorded sufficient information for further analysis.

5.3 Fuel Consumption Tests

The objective of these tests was to determine the relationship between fuel consumption and the drawbar energy requirements. The drawbar dynamometer was used with a towed tractor for an adjustable load so that drawbar conditions could be varied (Fig. 5.8). During each test the fuel flow rate to the injection pump and the return flow rate were measured so that net fuel use could be determined. The fuel flow transducers were installed in the fuel lines and were powered by the tractor battery (Fig. 5.9). The current pulse outputs of the two fuel flow transducers were counted by a HP 5300 A counter and a Textronix 212 oscilloscope.

In addition to the determination of fuel consumption for various drawbar loads, fuel consumption was determined in the laboratory for various throttle settings. The throttle was set at full, 3/4 and 1/2 throttle setting with corresponding crankshaft speeds of 2100, 1600 and 1050 rev/min, respectively. Varying loads were applied to the engine using the power-take-off dynamometer. At each throttle setting, data were taken at 30 second intervals. Power-take-off shaft speeds were measured using a stroboscope. The test arrangement is illustrated in

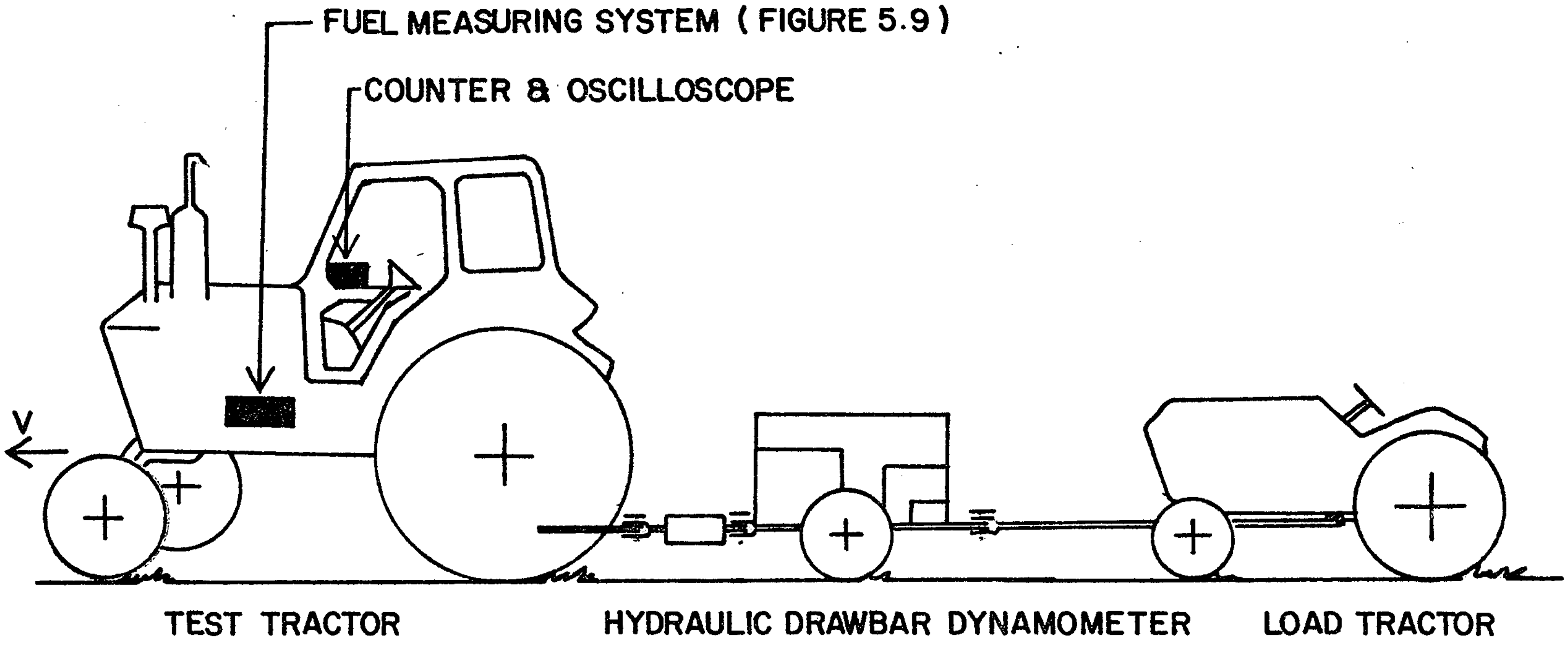


Figure 5.8 Arrangement for measuring fuel consumption for varying drawbar loads.

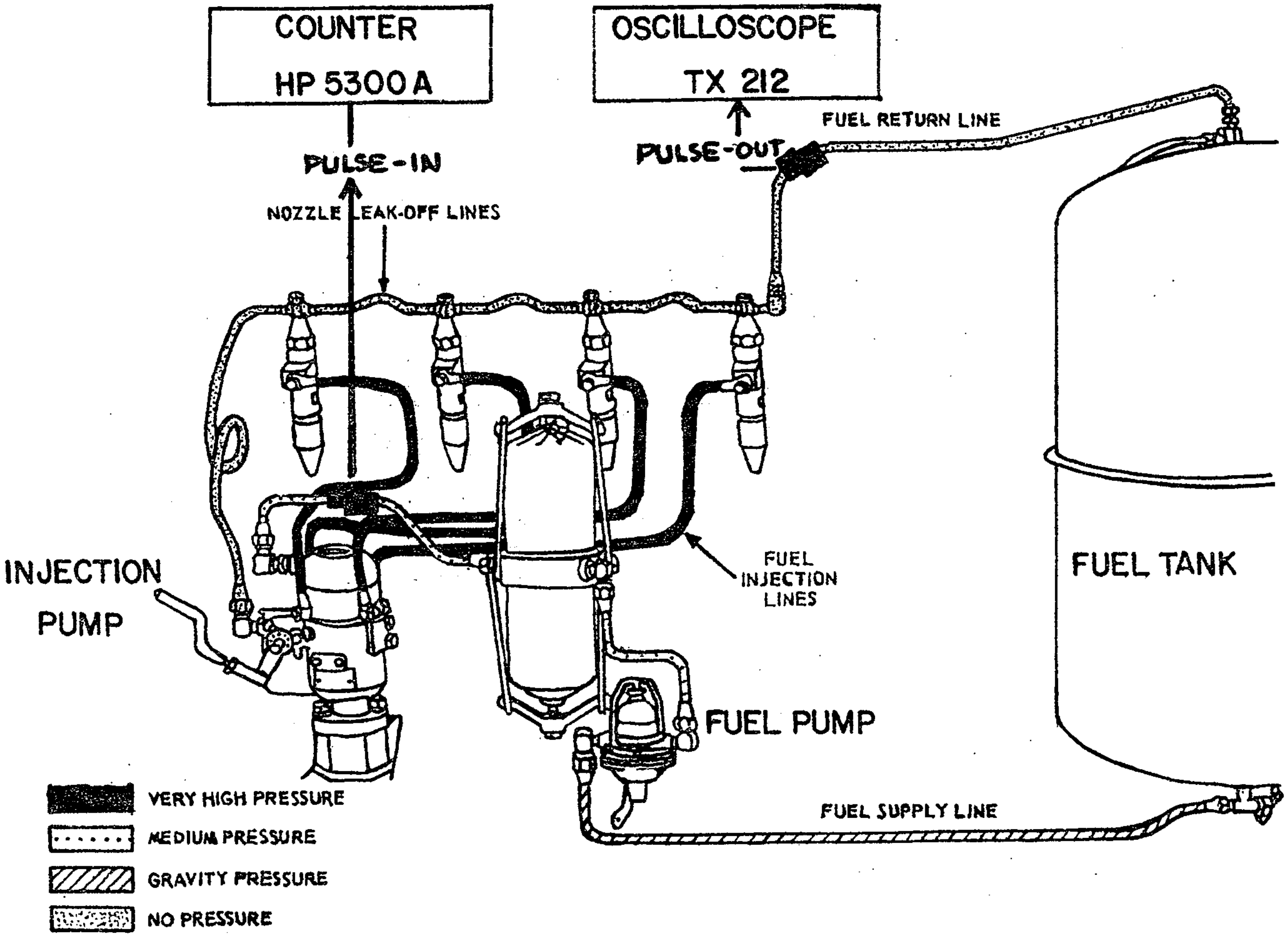


Figure 5.9 Diesel fuel consumption measurement on the test tractor (FORD 7700 Diesel).

Fig. 5.10.

5.4 Tests for Soil Physical Properties

5.4.1 Soil Penetrometer Resistance

Soil resistance expressed as a Cone Index (CI, N/cm^2) was measured for each tillage implement. The soil cone penetrometer was used before and after each tillage implement was used. The soil resistances were recorded at 5, 10, 15, 20, 25 and 30 cm depths from the soil surface.

5.4.2 Soil Moisture Content

Soil moisture was measured by the gravimetric method. The samples were randomly taken from the field the same day as the tillage implements were tested. The samples were taken at depths ranging from 0 to 8 cm.

5.5 Analyses of Data

The field data obtained were analyzed in the Agricultural Engineering laboratory using the instrument arrangement shown in Fig. 5.11. The modulated voltage signal of the semiconductor pressure transducer was demodulated to obtain the original dc voltage signal. The signal was recorded on a strip chart recorder (Clevite Brush, MARK 220). The average voltage for each run was determined. The signal was also displayed on the screen of an oscilloscope so that the variations in the signal could be observed.

The average pressures for the semiconductor pressure transducer and the Esterline-Angus pressure recorder were determined by three methods. The three methods were a visual averaging of the recorded

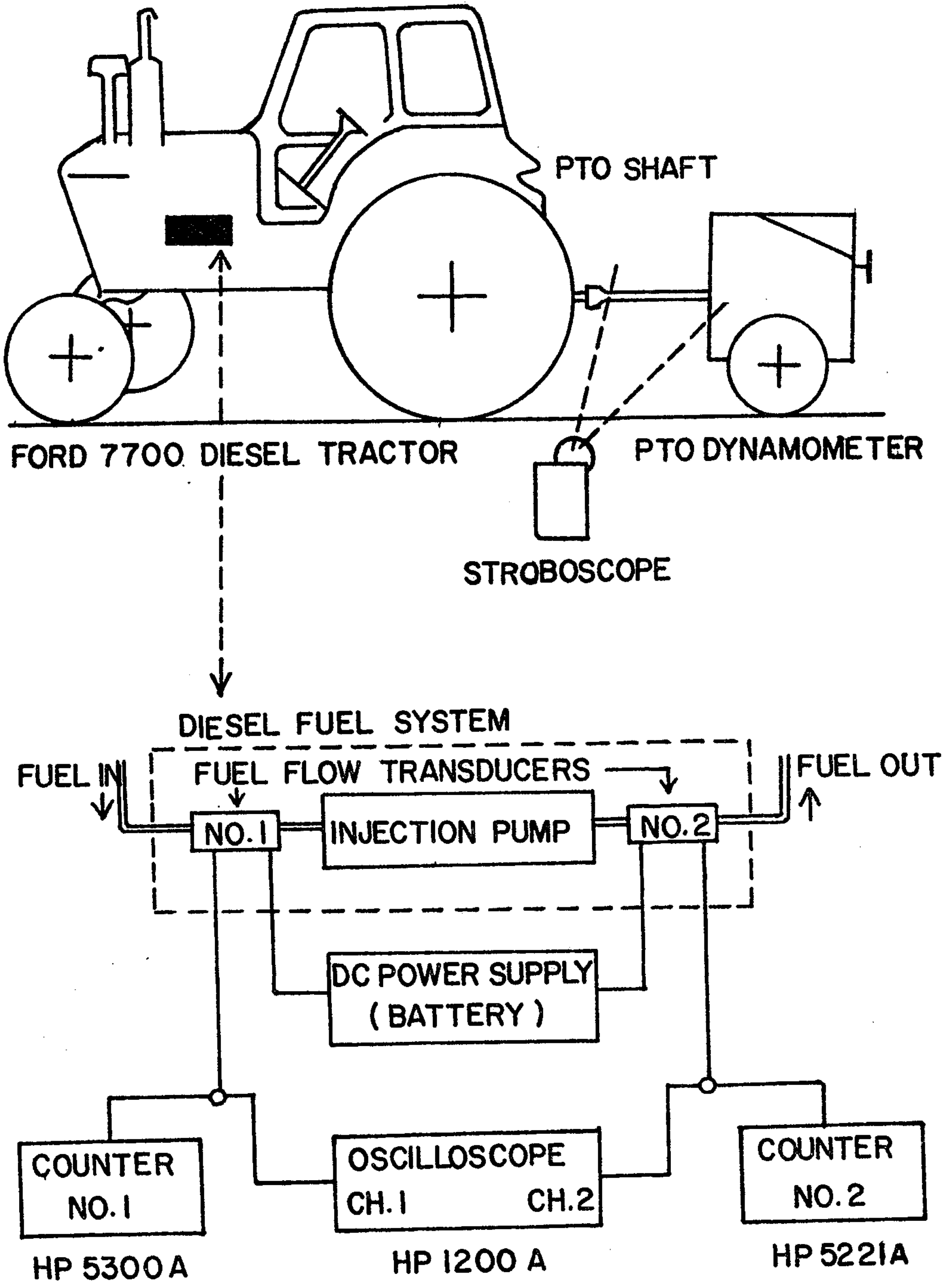


Figure 5.10 Arrangement for measuring fuel consumption at different throttle settings and engine loads.

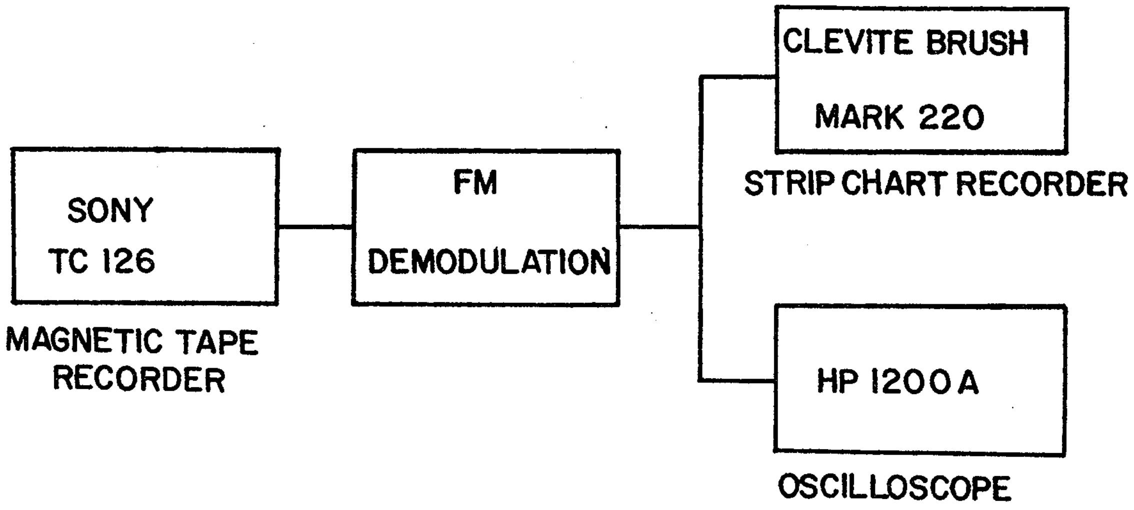


Figure 5.11 Instrument arrangement for analyzing the semiconductor pressure transducer data on the magnetic tape.

voltage or pressure, a mechanical polar planimeter and numerical integration by Simpson's rule.

Computer programs were written to do the calculations, based on equations 3.2 to 3.11 (Appendix B). Unit draft, power requirements, energy required per unit area, fuel consumption, speed and slip were calculated as illustrated in Fig. 5.12.

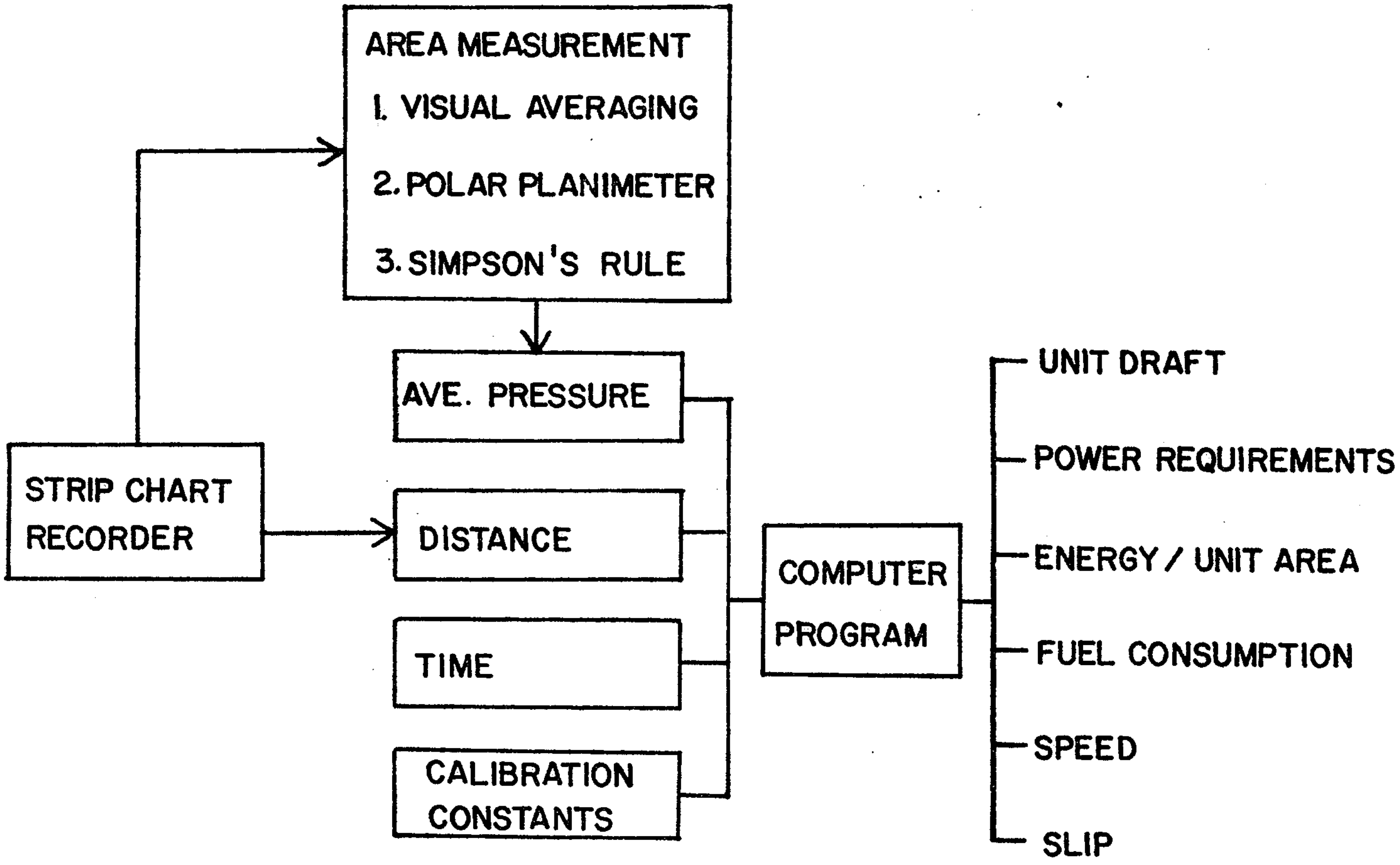


Figure 5.12 Flow chart of procedure followed to analyze the field data.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Measuring Energy Requirements

Energy requirements for a variety of tillage implements were determined. The measurements were performed on a tilled Osborne Clay and on Fababean Stubble on Osborne Clay at Glenlea. The hydraulic pressures in the hydraulic cylinder on the drawbar dynamometer were measured by the semiconductor pressure transducer and by the strip chart pressure recorder (Table 6.1). The pressures of Table 6.1 were determined from the strip charts (Appendix B) using the arrangement shown in Fig. 5.12.

In measuring the energy requirements of the harrows, the pressures as measured by the semiconductor pressure transducer were found to be lower than the pressures indicated by the strip chart pressure recorder. This situation was opposite to what was observed for the double disk harrows, the disker-seeder and the hoe drill. A possible explanation of this was that because of the lower draft requirement of the harrows a hydraulic cylinder of smaller cross-sectional area was used (K_{cy} = 0.0031 N/Pa). After installation of the smaller cylinder it was possible that the damper value was not properly adjusted. The large pressure vibrations may have contributed to errors in determining the average pressure.

Table 6.2 lists the energy requirements for the four tillage implements. The table is based on average values for draft and speed as determined from six test runs for each implement (Tables D.2.1 to D.2.4, Appendix D). Energy as determined by the conventional method was

Table 6.1 Comparison of average hydraulic cylinder pressures as measured by the semiconductor pressure transducer and by the strip chart pressure recorder.

Implement	Hydraulic Cylinder Pressure (MPa)					Difference (%)†
	Semiconductor Pressure Transducer*		Strip Chart Pressure Recorder*			
	2	3	1	2	3	
Double Disk	1.465	1.449	1.345	1.325	1.374	-9.6
Disker Seeder	1.185[1/]	1.176	1.023	0.997[1/]	1.024	-15.9
Hoe Drill	1.283[1/]	1.279	1.176	1.155[1/]	1.200	-10.0
Harrow	1.592[1/]	1.568	1.974	1.965[1/]	1.959	+23.4

*Cylinder pressures were obtained using analysis methods 1, 2 & 3 in Fig. 5.12.

†Percent differences were normalized to the semiconductor pressure transducer method No. 2 versus strip chart pressure recorder method No. 2.

[1/] Values were significantly different at the 5 percent level.

Table 6.2 Comparison of energy requirements as measured by the semiconductor pressure transducer and the conventional method (strip chart pressure recorder).*

Implement	Width	Speed	Semiconductor Pressure Transducer			Conventional Method (Strip Chart Pressure Recorder)			Tractor Slip (percent)	
	(m)	(km/h)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Eq. 3.10	Eq. 3.11
Double Disk[1]	4.0	7.63	2.71	23.0	27.1	2.45	20.8	24.5	12.2	10.6
Disker Seeder[1]	5.4	7.69	1.63	18.7	16.3	1.37	15.8	13.7	15.4	9.0
Hoe Drill[1]	4.1	8.09	2.29	21.3	22.9	2.07	19.2	20.7	8.4	12.8
Harrow[2]	14.3	9.95	0.344	13.6	3.44	0.425	16.8	4.25	4.9	6.1

[1] Field Condition - Osborne Clay Fababean Stubble, (K_{cy} = 0.0074 N/Pa).

[2] Field Condition - Tilled Osborne Clay, (K_{cy} = 0.0031 N/Pa).

[*] Method No. 2 (Planimeter) was used for average hydraulic pressure determination.

consistently lower than that determined by the semiconductor pressure transducer except for the harrow.

6.2 Slip Measurements

Tractor drive wheel slip results for the tillage treatments were calculated using Eqs. 3.10 and 3.11. The results are listed in Table 6.2. Large differences were noted in the measured slips for the disker seeder and the hoe drill. These large differences were considered unacceptable but were the best that could be obtained. The slip calculated by Eq. 3.10 was considered more accurate.

6.3 Determining the Relationship Between Fuel Consumption and Power

Tests to determine the relationship between fuel consumption and drawbar power were conducted at the University of Manitoba (Fig. 5.8). The first tests were performed in a tilled field. The tests could not be completed since the field surface was too rough. The rough, loose surface caused excessive vibrations and drive wheel slippage (Table D.1. tests No. 1 and No. 2). The tests were completed on an earthern roadway (Table D.1 and Fig. 6.1).

The relationship between fuel consumption and drawbar power on the earthen roadway was analysed using a linear regression analysis on the data obtained (Test No. 5 was rejected because of excessive slippage).

The relationship was found to be

$$FCT = 0.572\ P + 11.8 \qquad \ldots\ldots (6.1)$$

where FCT = fuel consumption, L/h

P = drawbar power, kW.

The standard error for the regression equation was ± 0.83 (L/h)/kW and the coefficient of correlation was 0.90.

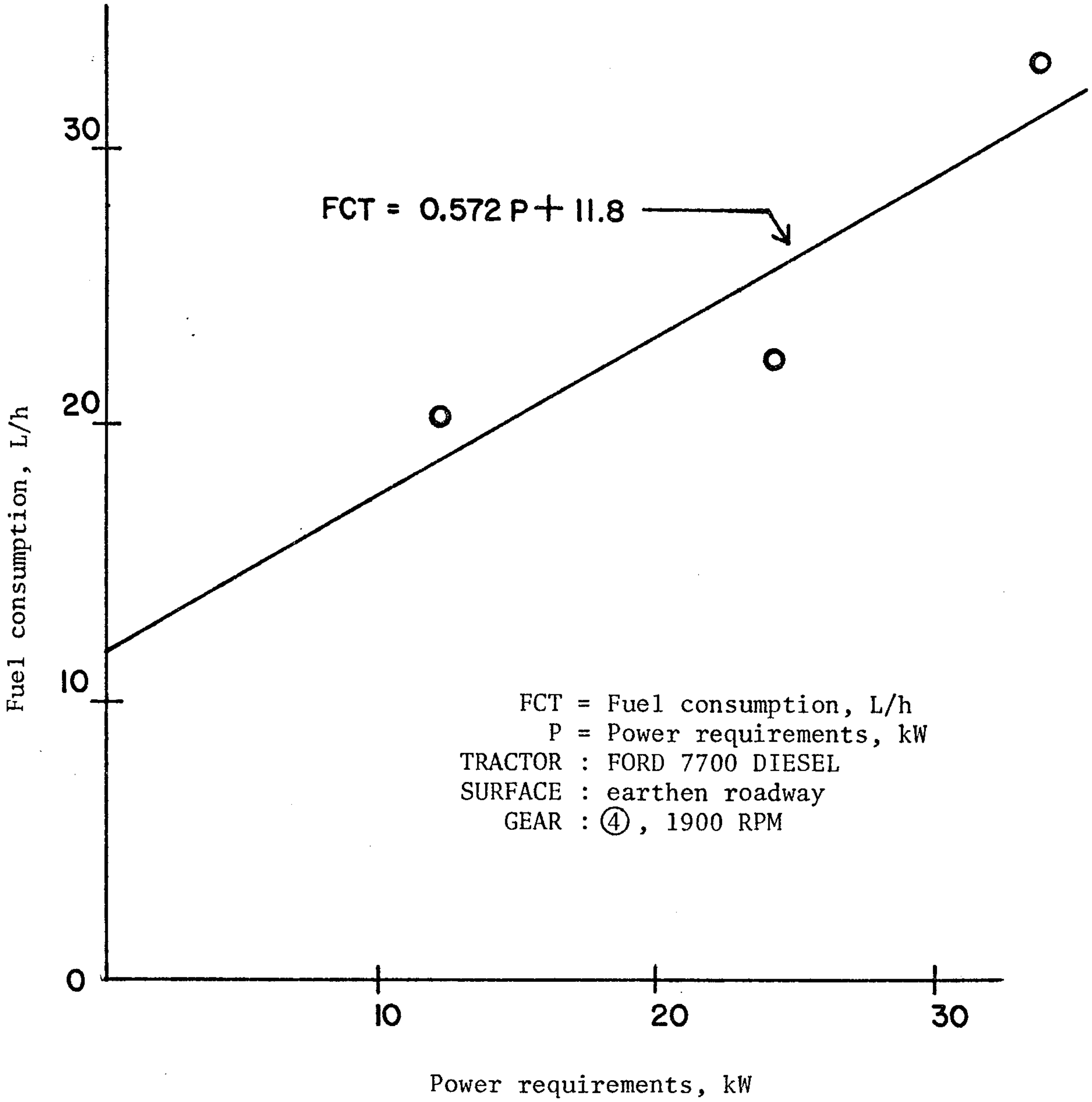


Figure 6.1 Fuel consumption as a function of drawbar power.

The fuel consumption per hectare can be estimated by multiplying the fuel consumption (L/h) by the time required to cover one hectare assuming no changes in field conditions. The fuel consumption per hectare is:

$$FCA = t[0.572\ P + 11.8] \qquad \ldots\ (6.2)$$

where FCA = fuel consumption per hectare, L/ha

P = drawbar power, kW

t = 10/(swη), h/ha

s = field speed, km/h

w = width of the test implement, m

η = field efficiency (Assumed 100 percent).

Table 6.3 contains the estimated diesel fuel requirements for tillage implements based on the actual power requirements measured at Glenlea. The amount of fuel required for the different tillage operations can be compared. The differences are caused by the different power requirements, the speeds of operation, and the width of the implement.

6.4 Fuel Consumption Versus Power-take-off Power

Fuel consumption was determined for varying power-take-off power at different throttle settings. A power-take-off dynamometer was used in the Agricultural Engineering laboratory (Hydra-Gauge Dynamometer, Model No. P-355, M & W Gear Co., Inc.).

Prediction equations based on PTO power were developed for the 3/4 and full throttle settings. From linear regression analyses (Fig. 6.2) the estimating equations are:

$$FC1 = 0.052\ P_p + 23.6 \qquad \ldots\ (6.3.a)$$

$$FC2 = 0.226\ P_p + 24.5 \qquad \ldots\ (6.3.b)$$

Table 6.3 Fuel consumption for four different tillage operations at Glenlea.

Implement	Width of implement (m)	Speed (km/h)	Theoretical field capacity (ha/h)	Energy requirements (MJ/ha)[1]	Fuel consumption L/h	Fuel consumption L/ha
Double disk	4.0	7.63	3.05	27.1	24.9	8.16
Disker seeder	5.4	7.69	4.13	16.3	22.5	5.45
Hoe drill	4.1	8.09	3.35	22.9	24.0	7.16
Harrow	14.3	9.95	14.26	4.25	21.4	1.50

[1] Based on semiconductor pressure transducer for double disk harrow, disker seeder and hoe drill but on the strip chart pressure recorder for the harrow.

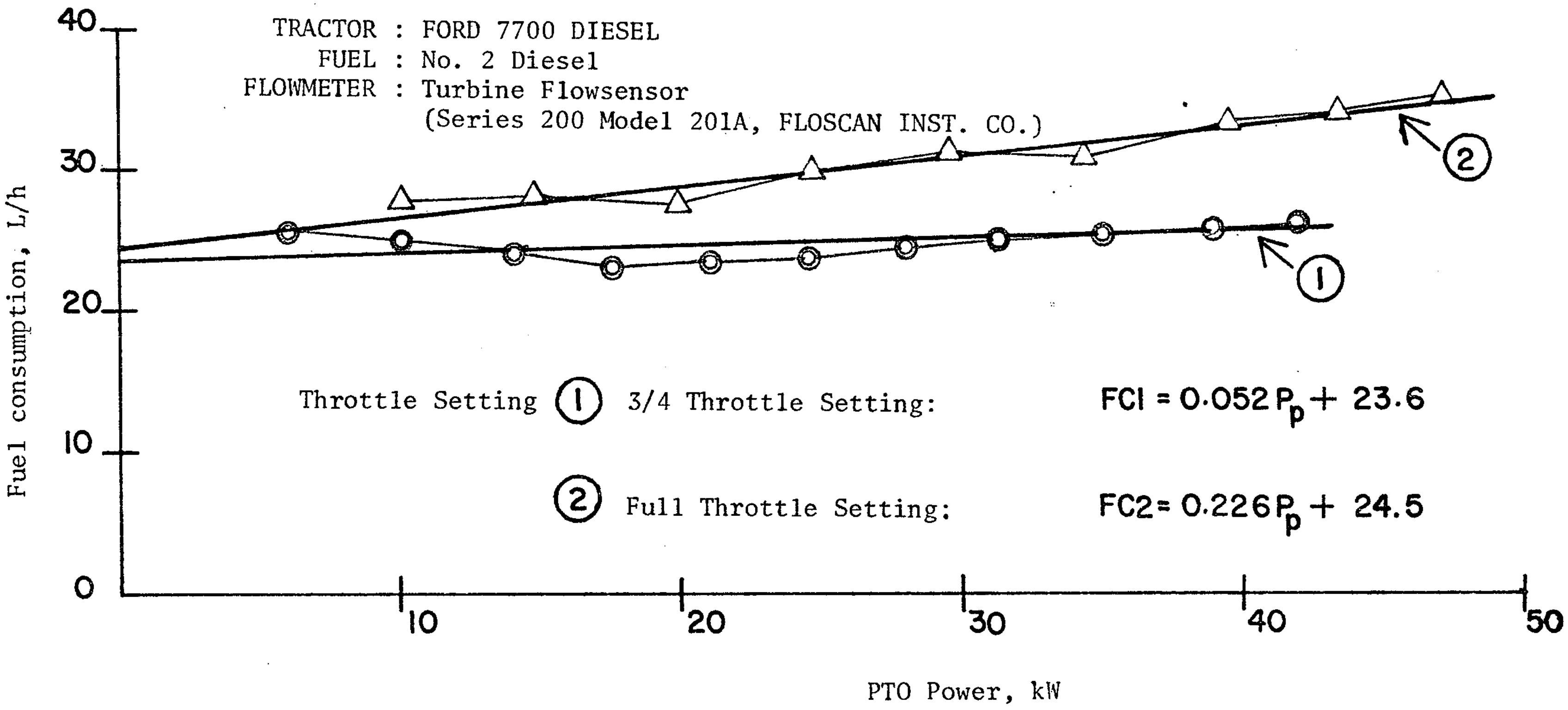


Figure 6.2 Tractor fuel consumption with varying load and throttle settings.

where FC1 = fuel consumption at 3/4 throttle, L/h

FC2 = fuel consumption at full throttle, L/h

P_p = PTO power, kW.

The standard errors for the regression equations were ± 0.67 (L/h)/kW and ± 0.43 (L/h)/kW, respectively. The correlation coefficients were 0.47 and 0.97, respectively.

6.5 Soil Properties

An attempt was made to compare the energy and draft requirements for each tillage implement to soil physical properties. The two soil physical properties studied were soil penetrometer resistance and soil moisture content.

Soil penetrometer resistance expressed as a cone index was measured the same day that the energy requirements were determined at the Glenlea Research Station. The soil resistance results were tabulated at 5, 10, 15, 20, 25 and 30 cm depths as shown in Fig. 6.3. The average resistances of the soil before and after each tillage operation are recorded in Table D.4 (Appendix D). Cone indexes for the soil were higher at greater depths in the soil for all four tillage treatments. Valid comparisons can only be made at the 5 cm depth. Tillage had little effect on penetration resistance at the 5 cm depth.

The average soil moisture contents were determined for the 0 to 8 cm deep layer on the two soil surfaces. The results are presented in Figure 6.3.

6.6 Total Energy Requirements for Five Tillage Systems

Five different tillage systems were compared using the above measured energy requirements and estimated fuel consumptions for Manitoba

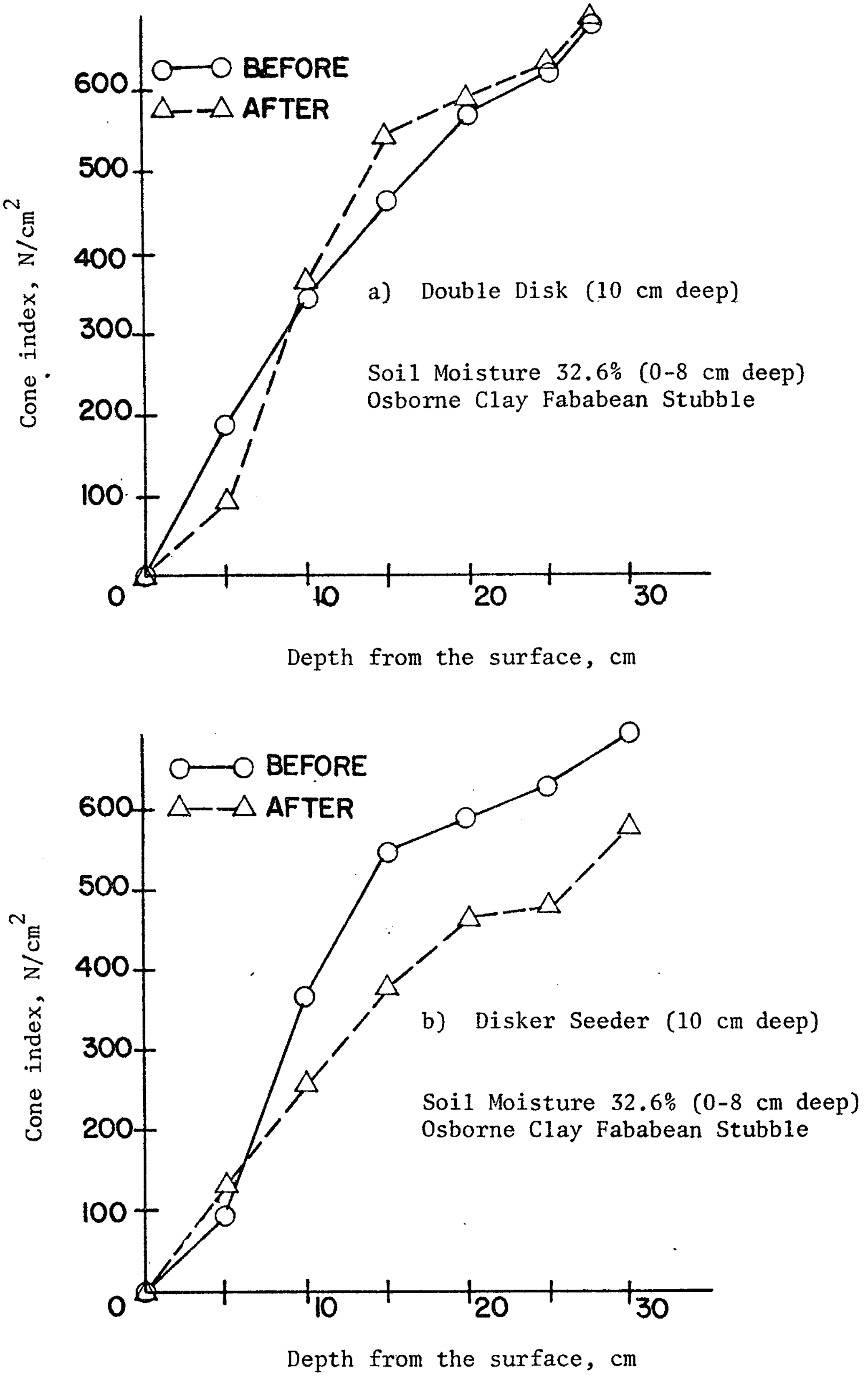
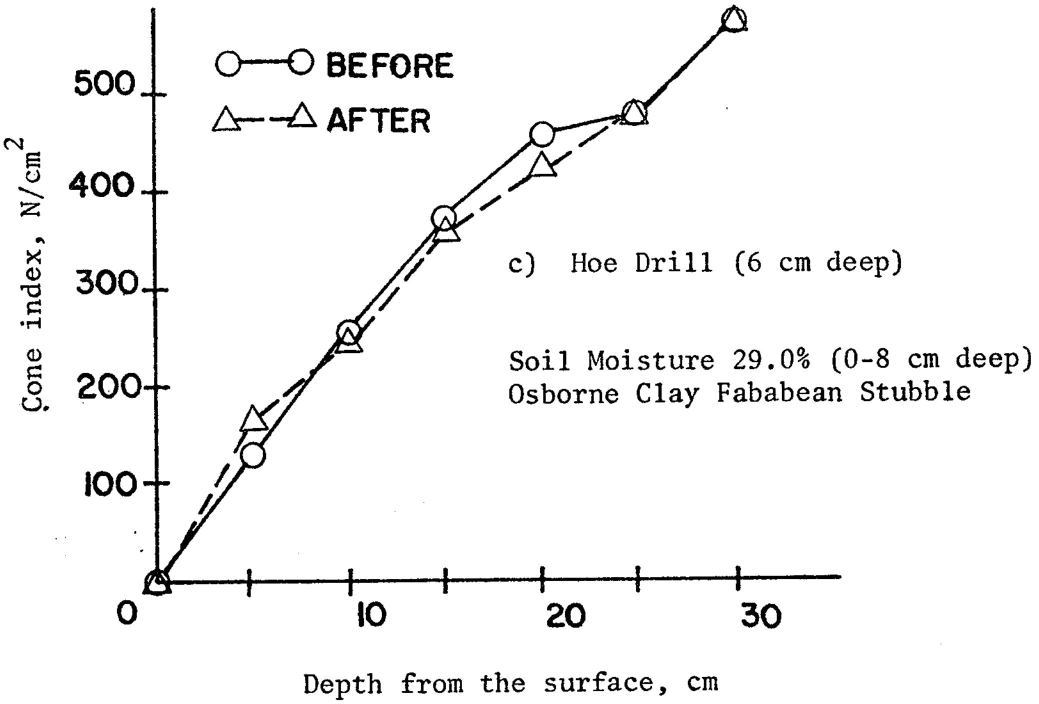


Figure 6.3 Average soil penetrometer resistance, CI, before and after tillage and soil moisture content in the 0-8 cm deep layer.



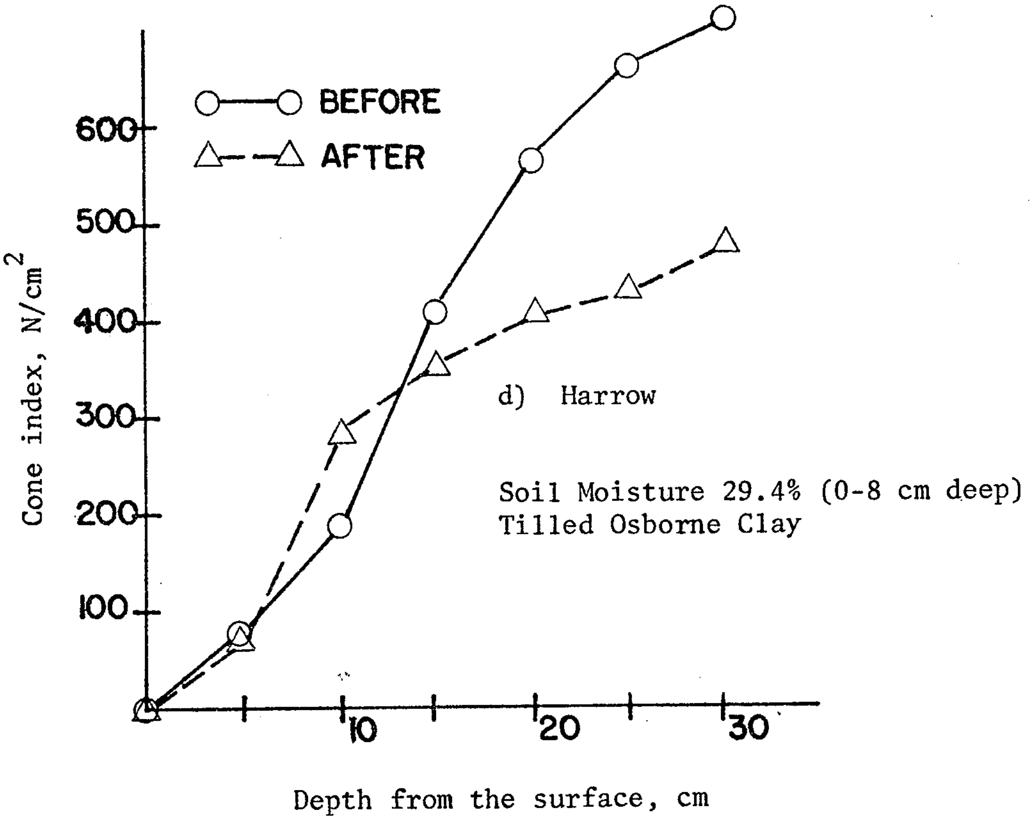


Figure 6.3 (Concluded)

conditions. Table 6.4 and Fig. 6.4 show the energy requirements and fuel consumption for the different tillage operations using a 62 kW (rated PTO power) tractor (FORD 7700 diesel). The tillage operations included were the operations up to the end of seeding. The table lists the tillage energy requirements and fuel consumption for each system and also gives the ratio of energy requirements and fuel use compared to a zero-tillage system (T-5A).

The respective energy requirements for T-1 (141.0 MJ/ha), T-2 (127.4 MJ/ha), T-3 (41.1 MJ/ha), T-4 (24.8 MJ/ha) and T-5B (22.9 MJ/ha) were 12.5, 11.3, 3.6, 2.2 and 2.0 times greater than T-5A (11.3 MJ/ha). The respective fuel consumption for T-1 (43.6 L/ha), T-2 (28.6 L/ha), T-3 (13.2 L/ha), T-4 (7.7 L/ha) and T-5B (7.2 L/ha) were 7.6, 5.0, 2.3, 1.4 and 1.3 times greater than T-5A (5.7 L/ha). The results indicated that the differences in fuel consumption for system operations varied proportionately with the energy requirements (Fig. 6.4). It should be noted that the lowest energy requirements were for zero-tillage (T-5A) and were estimated at 11.3 MJ/ha when the average field speed was 5.9 km/h.

The extremely wet summer and fall of 1977 did not permit field testing of the moldboard plow and cultivators for fall tillage. The drafts were estimated from ASAE data with allowances for the soil conditions at Glenlea (Appendix E).

Table 6.4 Energy requirements and fuel consumption for five different tillage systems for tillage operations to the end of seeding.

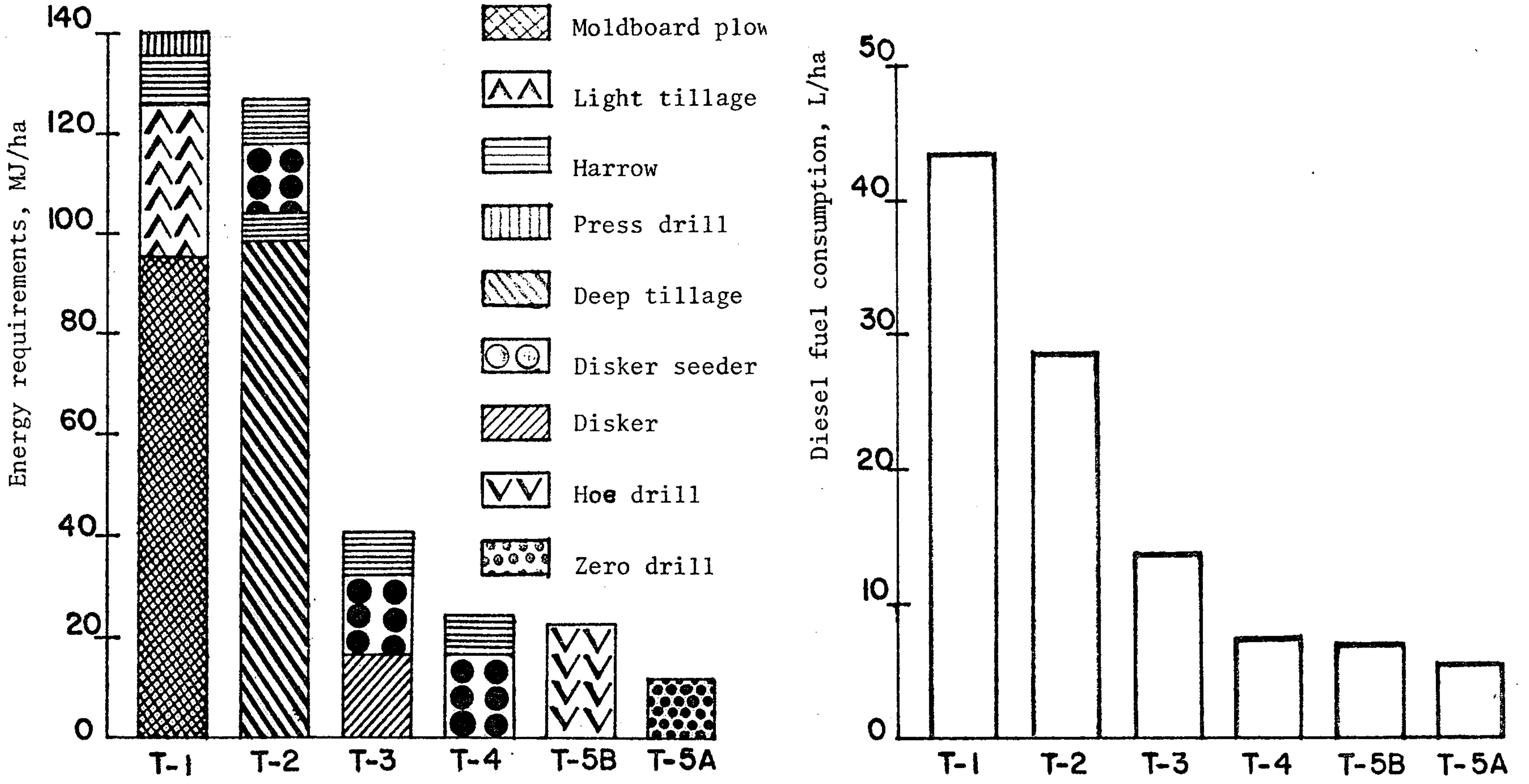
System No.	Tillage Operation		No. of Times Over Field	Draft Required (kN/m)	Energy Required (MJ/ha)	Fuel Consumption (L/ha)	Ratio to T-5A	
							(MJ/ha)	(L/ha)
T-1	Fall	Moldboard Plow[1]	1	9.50	95.0	25.9		
	Spring	Light Tillage[1]	1	3.35	33.5	10.9		
		Harrow	2	0.425	8.5	2.2		
		Press Drill[2]	1	0.400	4.0	4.6		
		TOTALS	5		141.0	43.6	12.5	7.6
T-2	Fall	Deep Tillage[1]	2	4.92	98.3	19.4		
		Harrow	1	0.425	4.3	1.5		
	Spring	Discer Seeder	1	1.63	16.3	5.5		
		Harrow	2	0.425	8.5	2.2		
		TOTALS	6		127.4	28.5	11.3	5.0
T-3	Conventional Tillage for Red River Valley							
	Fall	Discer	1	1.63	16.3	5.5		
	Spring	Discer Seeder	1	1.63	16.3	5.5		
		Harrow	2	0.425	8.5	2.2		
		TOTALS	4		41.1	13.2	3.6	2.3
T-4	Spring	Discer Seeder	1	1.63	16.3	5.5		
		Harrow	2	0.425	8.5	2.2		
		TOTALS	3		24.8	7.7	2.2	1.4

Table 6.4 - Continued

System No.	Tillage Operation	No. of Times Over Field	Draft Required (kN/m)	Energy Required (MJ/ha)	Fuel Consumption (L/ha)	Ratio to T-5A	
						(MJ/ha)	(L/ha)
T-5	Zero Tillage						
	<u>Spring</u> A) Zero Drill[2] (Duplex Hitch)	1	1.13	11.3	5.7		
	TOTALS	1		11.3	5.7	1.0	1.0
	B) Hoe Drill	1	2.29	22.9	7.2		
	TOTALS	1		22.9	7.2	2.0	1.3

[1] Table E-1, Appendix E

[2] Actual Field Test Values, 1976 [4]



(a) (b)

Figure 6.4 (a) Tillage energy requirements, MJ/ha, and (b) Estimated fuel consumption, L/ha for five different tillage systems at Glenlea research farm.

CHAPTER 7

CONCLUSIONS

Consideration of the foregoing results of this research project resulted in the following conclusions:

1) Instrumentation was designed to measure drawbar pull and fuel consumption. Drawbar pull was measured by a semiconductor pressure transducer. Net fuel consumption was measured by using two turbine fuel flow meters. FM modulation of the electrical signal from the pressure transducer permitted recording of the field test data on a tape recorder. Demodulation in the electronics laboratory recovered the analog signal of pressure. Fuel flow was inferred by simply counting current pulses from the turbine fuel flow transducers.

2) The results from the semiconductor pressure transducer were compared to results from a conventional hydraulic drawbar dynamometer. The uncertainties associated with the two methods were 2.7 percent and 5.8 percent, respectively.

3) An empirical relationship between fuel consumption and drawbar power required for a tillage implement was found to be:

$$FCT = 0.572\ P + 11.8$$

where FCT = fuel consumption, L/h

P = drawbar power, kW

The tractor used in developing this equation was a Ford 7700 diesel. The standard error for the regression equation was ± 0.83 (L/h)/kW and the correlation coefficient was 0.90.

4) Five different tillage systems were compared for energy requirements. A zero-tillage system required 11.3 MJ/ha (5.73 L/ha diesel fuel). This system was compared to the four other tillage systems. Energy requirements and fuel consumptions were found to be directly proportional to the intensity of tillage.

5) Soil penetrometer resistances were not very different among the four tillage operations on the two field surfaces for the average tillage depths. The soil penetrometer resistances compared before and after tillage were found to be higher after the Disker seeder and the Harrow treatments. The manner in which moisture affects the soil penetrometer resistance was not determined.

CHAPTER 8

RECOMMENDATIONS FOR FUTURE STUDY

The development of instrumentation to measure energy requirements and fuel consumption for tillage operations was the main objective of this study. Further developments and research in instrumentation and tillage systems are recommended as follows:

1. The electronic dynamometer instrumentation, including a slip monitor, should be rationalized and made easy to use under field conditions.

2. More than energy requirements and fuel consumption should be compared for the different tillage systems. Yields, weed control, costs, timeliness of operations, environmental considerations and energy input-output ratios are some of the other areas that should be included in a complete study.

3. More soil types should be included in further studies.

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APPENDIX A

INSTRUMENTATION CALIBRATION DATA

Table A-1 Calibration results of semiconductor pressure transducer and strip chart pressure recorder (EA).

Test No.	Actual input pressure (MPa)	Indicated pressure (MPa)	
		(Semiconductor pressure transducer)	(Strip chart pressure recorder)
1	0.689	0.607	0.483
2	1.379	1.343	1.103
3	2.068	2.004	1.793
4	2.758	2.740	2.413
5	3.447	3.436	3.103
6	4.137	4.137	3.723
7	4.826	4.799	4.344
8	5.516	5.514	4.964
9	6.205	6.209	5.654

Table A-2 Calibration data for fuel flow transducers (2000 mL constant volume for each run)

Run No.	Time (s)	Flow Rate (mL/s)	Total Pulses	Pulse Rate Pulses/s	Pulses Per Litre	Flow Rate (L/h)
			Flow Transducer No. 1			
1	791.2	2.53	55693	70.40	27847	9.10
2	641.6	3.12	58587	91.31	29294	11.22
3	627.9	3.20	56829	90.51	28415	11.57
4	530.0	3.77	56350	106.32	28175	13.58
5	455.6	4.39	56127	123.19	28064	15.80
6	405.1	4.94	61639	152.16	30820	17.77
7	336.0	5.95	58870	175.21	29435	21.43
8	282.0	7.09	53473	189.62	26737	25.53
9	258.2	7.75	53073	205.55	26537	27.89
10	255.5	7.83	55693	217.98	27847	28.18
11	212.3	9.42	56192	264.68	28096	33.91
12	159.8	12.52	52822	330.55	26411	45.06
13	148.3	13.49	52949	357.04	26475	48.55
14	137.6	14.53	53347	387.70	26674	52.33
15	131.1	15.26	53482	407.95	26741	54.92
16	118.1	16.93	53644	545.23	26822	60.97
17	106.3	18.81	54301	510.83	27151	67.73
				MEAN	27690 ± 4.4%	
			Flow Transducer No.2			
1	766.5	2.61	52838	68.93	26419	9.4
2	695.2	2.88	52269	75.19	26135	10.36
3	680.4	2.94	53151	78.12	26576	10.60
4	593.6	3.37	51508	86.77	25754	12.13
5	382.7	5.23	50598	132.21	25299	18.81
6	315.5	6.34	52416	166.14	26208	22.82
7	270.1	7.40	48418	179.26	24209	26.66
8	251.6	7.95	48868	194.23	24434	28.62
9	186.4	10.73	49968	268.07	24984	38.63
10	159.3	12.55	50092	314.45	25046	45.20
11	140.3	14.26	50690	361.30	25345	51.32
12	124.4	16.08	51751	416.00	25876	57.88
13	111.4	17.95	51975	466.56	25988	64.63
14	105.6	18.94	51698	489.56	25849	68.18
				MEAN	25580 ± 2.8%	

APPENDIX B

SAMPLE OF ORIGINAL DRAWBAR FORCE RECORDINGS

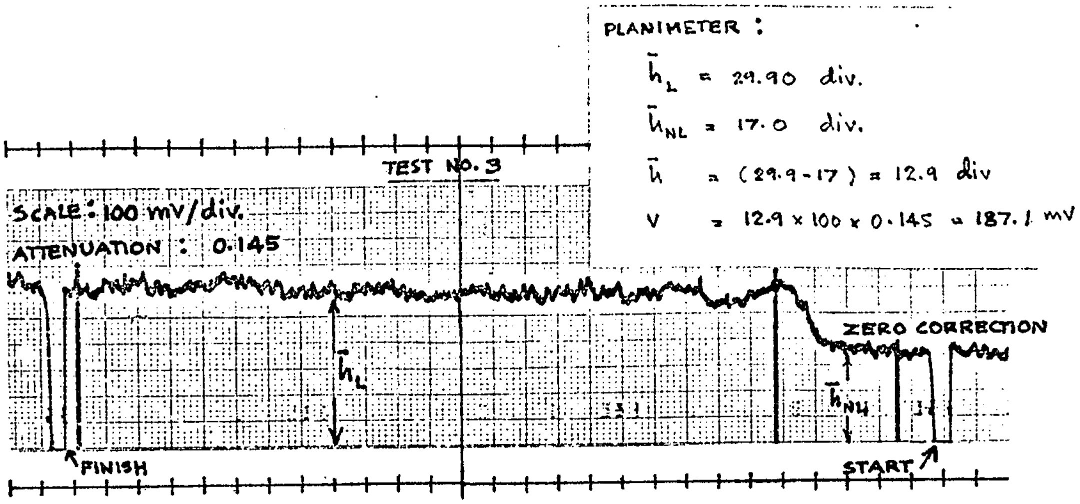


Figure B-1.a Typical signal from the semiconductor pressure transducer (Disker seeder treatment).

B-1 Sample calculation of hydraulic dynamometer pressure from the semiconductor pressure transducer.

The calibration equation for the semiconductor pressure transducer was given by

$$V = 0.136\ (APSC) + 0.0274 \qquad \ldots. (5.1)$$

or $$APSC = 7.35\ (V - 0.0274) \qquad \ldots. (5.2)$$

From the data of Figure B-1.a, the average output voltage was 0.1871 V (as determined by planimetering):

Then APSC = 7.35 (0.1871 - 0.0274) = <u>1.1738 MPa</u>.

The resulting average hydraulic dynamometer pressures were used in a computer program to calculate energy requirements (Appendix C).

B-2 Sample calculation of hydraulic dynamometer pressure for the strip chart pressure recorder.

The calibration equation for the strip chart pressure recorder was given by

$$APEA = 1.07\ (IPEA + 0.159) \qquad \ldots. (5.3)$$

From the data of Figure B-1.b, the indicated pressure was 0.041 MPa (as determined by planimetering). The actual or true pressure was 1.008 MPa. The average pressures were used to calculate energy requirements for the tillage implements (Computer program, Appendix C).

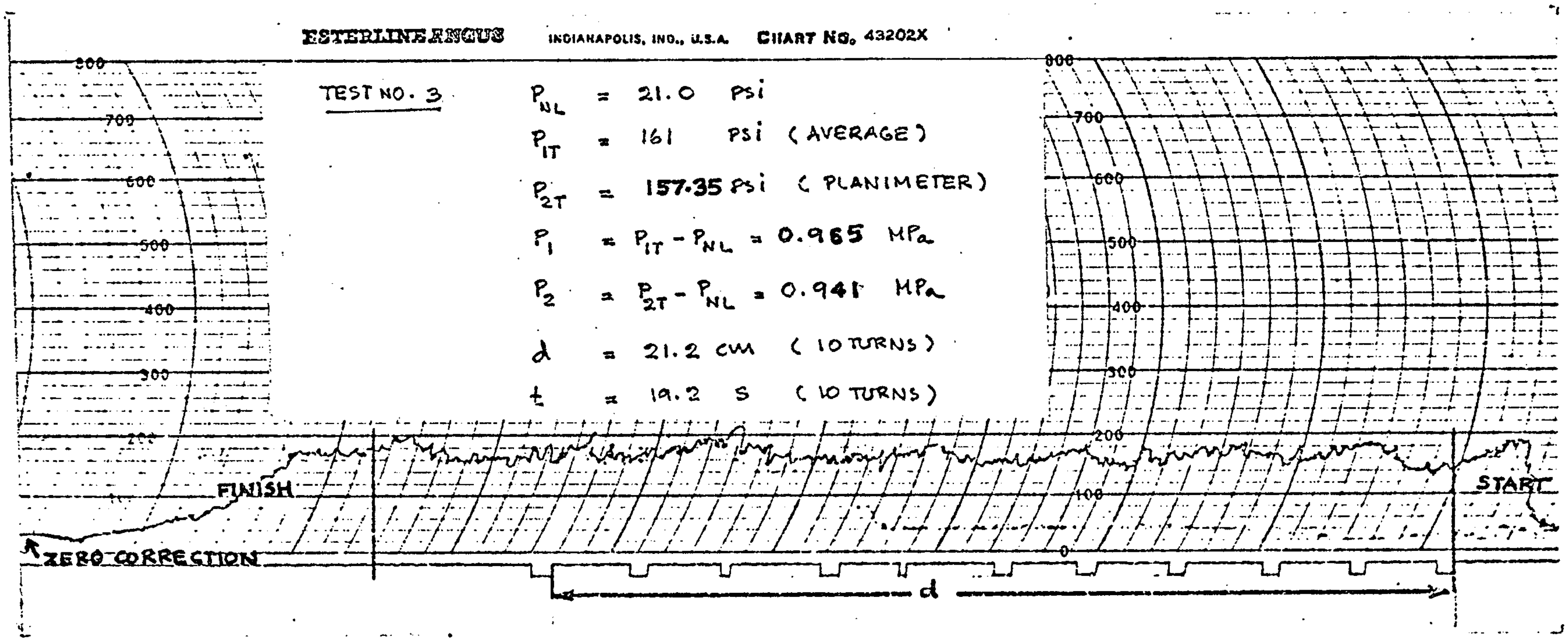


Figure B-1.b Typical pressure recording on strip chart pressure recorder for the conventional hydraulic dynamometer (Disker seeder).

APPENDIX C

ANALYSIS OF ENERGY REQUIREMENTS AND FUEL CONSUMPTION FOR TILLAGE

C-1 Definitions relating to Appendix C.

C-2 Computer programs for calculating draft, energy requirements and fuel consumption.

C-3 Typical data print-out from the computer.

C-1 Definitions relating to Appendix C

APSC = actual drawbar pressure from the Semiconductor pressure transducer, MPa

APEA = actual drawbar pressure from the strip chart pressure recorder, MPa

IPEA = indicated drawbar pressure from the strip chart pressure recorder, MPa

VOLT = output voltage of the Semiconductor pressure transducer V

DISNO = no-load distance for 10 revolutions of the tractor drive wheel, m

DISL = distance traversed with load for the tractor drive wheel, m

TIME = time for the distance travelled (DISL), s

KCY = hydraulic cylinder calibration constant, N/Pa

KCT = strip chart recorder constant, m/cm

WIDTH = width of the implement, m

DRAFT = total draft requirement, kN

UD = draft per unit width of the implement, N/m

SPEED = actual forward speed, km/h

POWER = power requirements, kW

ENERGY = energy requirement per unit area, MJ/ha

SLIP = travel reduction (Equation 3.10), percent

SLIPI = travel reduction (Equation 3.11), percent

TNL = time for no-load distance, s

TL = time of the given distance at load, s

LH = fuel consumption, L/h

LHA = fuel consumption per unit area, L/ha

c = effective field capacity, ha/h

```
       $JOB  WATFIV    SUPAWADEE,NOEXT       G-156847
       C ENERGY REQUIREMENTS ANALYSIS
       C CONVENTIONAL METHOD
              INTEGER N,I,ENDATA
              REAL APEA(6),IPEA(6),DIS(6),TIME(6),DISNO,DRAFT(6),UD(6),SPEED(6),
             *POWER(6),ENERGY(6),SLIP(6),KCY,KCT,DISL(6),WIDTH,LH(6),LHA(6),C(6)
              ENDATA=0
              READ,N
              EXECUTE RDDATA
              WHILE(ENDATA.EQ.0) DO
              KCT=2.0
              I=1
              WHILE(I.LE.N) DO
              APEA(I)=0.0069*(1.07*(IPEA(I)+0.159))
              DISL(I)=DIS(I)*KCT
              DRAFT(I)=APEA(I)*KCY*1000.0
              UD(I)=DRAFT(I)*1000./WIDTH
              SPEED(I)=DISL(I)*3.6/TIME(I)
              POWER(I)=DRAFT(I)*DISL(I)/TIME(I)
   a          ENERGY(I)=UD(I)/100.
              LH(I)=0.64*POWER(I)+12.42
              C(I)=SPEED(I)*WIDTH/10.
              LHA(I)=LH(I)/C(I)
              SLIP(I)=100.*(DISNO-DISL(I))/DISNO
              I=I+1
              END WHILE
              PRINT 50
              PRINT 60
              PRINT 70,(I,APEA(I),DISL(I),TIME(I),DRAFT(I),UD(I),SPEED(I),
             * POWER(I),ENERGY(I),LH(I),LHA(I),SLIP(I),I=1,N)
              EXECUTE RDDATA
              END WHILE
              STOP
       C READ DATA
              REMOTE BLOCK RDDATA
              READ,DISNO,WIDTH,KCY,(IPEA(I),DIS(I),TIME(I),I=1,N)
   b          AT END DO
              ENDATA=1
              END AT END
              END BLOCK
          50  FORMAT('1'//,30X,'MEASURING ENERGY REQUIREMENTS (THE CONVENTIONAL
             * METHOD)',
             * ' '///,25X,'IMPLEMENT:',30X,'TEST DATE:',
             * ' '//,25X,'WIDTH:            METRES',21X,'LOCATION:',
             * ' '//,25X,'KCY:            N/PA',24X,'SURFACE:',
             * ' '//,25X,'KCT:              M/CM',
             * ' '//,25X,'DISNO:              M',///)
           60 FORMAT(' ',10X,'NO.',2X,'APEA',3X,'DISL',4X,'TIME',4X,'DRAFT',4X,
             * 'U.DRAFT',4X,'SPEED',4X,'POWER',4X,'ENERGY',4X,'L/H',4X,'L/HA',
             * 3X,'%SLIP',///)
           70 FORMAT(' ',9X,I2,3X,F7.3,1X,F5.2,2X,F5.2,3X,F7.3,2X,F10.2,2X,F5.2,
             * 3X,F7.3,2X,F7.3,2X,F6.3,2X,F6.3,2X,F5.2/)
              END
        $ENTRY
```

C-2.1 Conventional hydraulic dynamometer data

a) transformation into performance parameters,
b) input data

```
    $JOB  WATFIV   SUPAWADEE,NOEXT       G-156847
    C ENERGY REQUIREMENTS ANALYSIS
    C ELECTRICAL METHOD
          INTEGER N,I,ENDATA
          REAL VOLT(6),WIDTH,APSC(6),KCY,KCT,DRAFT(6),UD(6),DIS(6),TIME(6),
         *SG(6),TNL,TL(6),SPEED(6),POWER(6),ENERGY(6),SLIP1(6),LH(6),LHA(6),
         * C(6)
          ENDATA=0
          READ,N
          EXECUTE RDDATA
          WHILE(ENDATA.EQ.0) DO
          I=1
          WHILE (I.LE.N) DO
          APSC(I)=(VOLT(I)-0.037)*7.45
          DRAFT(I)=APSC(I)*KCY*1000.0
          UD(I)=DRAFT(I)*1000./WIDTH
          SG(I)=DIS(I)*KCT/TIME(I)
          SPEED(I)=SG(I)*3.6
a         POWER(I)=DRAFT(I)*SG(I)
          ENERGY(I)=UD(I)/100.0
          LH(I)=0.64*POWER(I)+12.42
          C(I)=SPEED(I)*WIDTH/10.
          LHA(I)=LH(I)/C(I)
          SLIP1(I)=(1-TNL/TL(I))*100.0
          I=I+1
          END WHILE
          PRINT 50
          PRINT 60
          PRINT 70,(I,VOLT(I),APSC(I),DRAFT(I),UD(I),SPEED(I),POWER(I),
         * ENERGY(I),LH(I),LHA(I),SLIP1(I),I=1,N)
          EXECUTE RDDATA
          END WHILE
          STOP
    C READ DATA
          REMOTE BLOCK RDDATA
          READ,WIDTH,KCY,KCT,TNL,(VOLT(I),DIS(I),TIME(I),TL(I),I=1,N)
b         AT END DO
          ENDATA=1
          END AT END
          END BLOCK
      50  FORMAT('1'///,20X,'MEASURING ENERGY REQUIREMENTS (SEMICONDUCTOR PR
         *ESSURE TRANSDUCER)',
         * ' '///,25X,'IMPLEMENT:',30X,'TEST DATE:',
         * ' '//,25X,'WIDTH:          METRES',21X,'LOCATION:',
         * ' '//,25X,'KCY:           N/PA',24X,'SURFACE:',///)
        60 FORMAT(' ',14X,'NO.',2X,'VOLT',2X,'APSC',3X,'DRAFT',3X,'U.DRAFT',
         *3X,'SPEED',5X,'POWER',3X,'ENERGY',3X,'L/H',4X,'L/HA',3X,
         * '%SLIP',///)
        70 FORMAT(' ',14X,I2,2X,F6.4,F7.4,F7.3,1X,F10.3,1X,F5.2,2X,F7.3,
         * 1X,F7.3,2X,F6.3,1X,F6.3,2X,F5.2/)
          END

    $ENTRY
```

RO:7

C-2.2 Semiconductor pressure transducer data

a) transformation into performance parameters,
b) input data.

```
            MEASURING ENERGY REQUIREMENTS (THE CONVENTIONAL  METHOD)

        IMPLEMENT:   HARROW                      TEST DATE:  1977 08 11
        WIDTH: 14.33  METRES                     LOCATION:   GLENLEA
        KCY:  0.0031  N/PA                       SURFACE:  TILLED - OSBORNE CLAY
        KCT:   2.0     M/CM
        DISNO: 49.67   M

NO.  APEA   DISL   TIME    DRAFT    U.DRAFT   SPEED   POWER   ENERGY   L/H     L/HA   %SLIP
      MPa    m      s       kN       N/m      km/h     kW     MJ/ha    L/h     L/ha     %
1    1.711 47.30  16.50    5.303    370.04   10.32   15.201   3.700  20.485   1.385   4.77
2    2.186 46.64  17.00    6.776    472.84    9.88   18.589   4.728  22.416   1.584   6.10
3    1.896 47.60  17.60    5.877    410.08    9.74   15.893   4.101  20.879   1.496   4.17
4    2.045 47.20  17.50    6.340    442.44    9.71   17.100   4.424  21.567   1.550   4.97
5    1.837 47.60  17.50    5.693    397.29    9.79   15.485   3.973  20.647   1.471   4.17
6    2.114 47.00  16.50    6.553    457.28   10.25   18.666   4.573  22.459   1.528   5.38
-------------------------------------------------------------------------------------------
MEAN 1.965 47.22  17.10    6.090    424.99    9.95   16.822   4.250  21.409   1.502   4.98
-------------------------------------------------------------------------------------------
STD.  0.18  0.37   0.51     0.56     39.10    0.27    1.54     0.39    0.88   0.07    0.74
-------------------------------------------------------------------------------------------
```

C-3 Typical data print-out from the computer

MEASURING ENERGY REQUIREMENTS (SEMICONDUCTOR PRESSURE TRANSDUCER)

IMPLEMENT: DISKER SEEDER
WIDTH: 5.37 METRES
KCY: 0.0074 N/PA

TEST DATE: 1977 08 11
LOCATION: GLENLEA
SURFACE: OSBORNE CLAY FABABEAN STUBBLE

NO.	VOLT V	APSC MPa	DRAFT kN	U.DRAFT N/m	SPEED km/h	POWER kW	ENERGY MJ/ha	L/H L/h	L/HA L/ha	%SLIP %
1	0.1824	1.1397	8.434	1570.543	8.02	18.783	15.705	22.526	5.232	8.21
2	0.1898	1.1941	8.836	1645.524	7.32	17.973	16.455	22.065	5.611	12.67
3	0.1871	1.1743	8.690	1618.165	7.95	19.189	16.182	22.758	5.331	7.54
4	0.1871	1.1743	8.690	1618.165	7.79	18.805	16.182	22.539	5.387	7.88
5	0.1863	1.1684	8.646	1610.059	7.51	18.047	16.101	22.107	5.478	10.18
6	0.1985	1.2581	9.310	1733.677	7.53	19.462	17.337	22.913	5.670	7.54
MEAN	0.1885	1.1848	8.768	1632.688	7.69	18.710	16.33	22.485	5.452	9.00
STD.	0.01	0.04	0.30	55.07	0.27	0.60	0.55	0.34	0.17	2.06

C-3 Concluded

APPENDIX D

DATA FOR ENERGY REQUIREMENTS AND FUEL CONSUMPTION IN FIELD TESTS

Table D-1 Comparison of semiconductor pressure transducer and strip chart pressure recorder (MPa)[1]

Implement		Strip Chart Pressure Recorder			Pressure Trans.	
		I	II	III	II	III
Double Disk		1.345	1.391	1.352	1.360	1.416
		1.397	1.361	1.342	1.362	1.451
		1.278	1.285	1.436	1.379	1.124
		1.419	1.363	1.276	1.808	1.815
		1.315	1.284	1.419	1.529	1.506
		1.315	1.264	1.418	1.349	1.379
	MEAN	1.345	1.325	1.374	1.465	1.449
	STD.	0.05	0.05	0.06	0.18	0.223
Harrow		1.732	1.711	1.738	1.441	1.423
		2.235	2.186	2.172	1.831	1.840
		1.954	1.896	1.973	1.480	1.419
		2.013	2.045	2.032	1.670	1.675
		1.880	1.837	1.865	1.504	1.465
		2.028	2.114	1.976	1.627	1.577
	MEAN	1.974	1.965	1.959	1.592	1.567
	STD.	0.17	0.18	0.15	0.15	0.16
Disker		1.047	1.010	1.092	1.140	1.136
		0.974	0.939	0.996	1.194	1.190
		1.033	1.008	1.058	1.174	1.171
		1.025	1.008	1.065	1.174	1.160
		1.010	1.003	1.032	1.168	1.160
		1.047	1.012	0.903	1.258	1.235
	MEAN	1.023	0.997	1.024	1.185	1.176
	STD.	0.03	0.03	0.07	0.04	0.03
Hoe Drill		1.141	1.161	1.164	1.286	1.250
		1.178	1.146	1.191	1.337	1.279
		1.222	1.205	1.266	1.375	1.352
		1.156	1.125	1.171	1.271	1.241
		1.215	1.190	1.252	1.304	1.277
		1.141	1.105	1.156	1.125	1.274
	MEAN	1.176	1.155	1.200	1.283	1.279
	STD.	0.04	0.04	0.05	0.09	0.04

[1] Pressures were analyzed by the methods of Figure 5.13.

Table D-2.1 Comparison of measured energy requirements for the semiconductor pressure transducer and the conventional strip chart pressure recorder.

Implement : Double Disk
Width : 4.0 m
K_{cy} : 0.0074 N/Pa
K_{ct} : 2.0 m/cm
DISNO : 51.0 m

Test Date : 1977 08 11
Surface : Osborne Clay (Fababean Stubble)
Location : Glenlea

				Semiconductor Pressure Transducer				Conventional Method				% Slip	
Test No.	DISL (m)	Time (s)	Speed (km/h)	Pressure[1] (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Pressure[1] (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Equa. 3.10	Equa. 3.11
1	44.7	21.1	7.63	1.36	2.52	21.3	25.2	1.39	2.57	21.7	25.7	12.4	-
2	44.8	21.3	7.57	1.36	2.52	21.2	25.2	1.36	2.52	21.3	25.2	12.2	10.2
3	45.4	20.9	7.82	1.38	2.55	22.2	25.5	1.28	2.38	20.7	23.8	11.0	10.2
4	44.2	21.4	7.44	1.80	3.34	27.6	33.5	1.36	2.52	20.8	25.2	13.3	11.3
5	45.3	21.1	7.74	1.53	2.83	24.3	28.3	1.28	2.38	20.4	23.8	11.1	11.2
6	44.1	20.9	7.60	1.35	2.50	21.1	25.0	1.26	2.34	19.7	23.4	13.5	10.2
Ave.	44.8	21.1	7.63	1.47	2.71	23.0	27.1	1.33	2.45	20.8	24.5	12.2	10.6
Std.	±0.55	±0.20	±0.12	±0.18	±0.34	±2.60	±3.35	±0.05	±0.1	±0.68	±0.98	±1.08	±1.32

[1] Pressures were analyzed using the planimeter (Method No. 2, Fig. 5.13).

Table D-2.2 Comparison of measured energy requirements for the semiconductor pressure transducer and the conventional strip chart pressure recorder.

Implement : Discer seeder
Width : 5.37 m
K_{cy} : 0.0074 N/Pa
K_{ct} : 2.0 m/cm
DISNO : 49.9 m

Test Date : 1977 08 11
Surface : Osborne Clay (Fababean Stubble)
Location : Glenlea

				Semiconductor Pressure Transducer				Conventional Method				% Slip	
Test No.	DISL (m)	Time (s)	Speed (km/h)	Pressure (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Pressure (MPa)	Unit Draft (N/m)	Power (kW)	Energy (MJ/ha)	Equa. 3.10	Equa. 3.11
1	42.8	19.2	8.02	1.14	1.57	18.8	15.7	1.01	1.39	16.7	13.9	14.2	8.21
2	43.1	21.2	7.32	1.19	1.65	18.0	16.5	0.94	1.29	14.1	13.0	13.5	12.7
3	42.4	19.2	7.95	1.17	1.62	19.2	16.2	1.01	1.39	16.5	13.9	14.9	7.54
4	42.2	19.5	7.79	1.17	1.62	18.8	16.2	1.02	1.39	16.1	13.9	15.4	7.9
5	41.1	19.7	7.51	1.17	1.61	18.1	16.1	1.00	1.38	15.5	13.8	17.5	10.2
6	41.6	19.9	7.53	1.26	1.73	19.5	17.3	1.01	1.39	15.7	13.9	16.6	7.5
Ave.	42.2	19.8	7.69	1.19	1.63	18.7	16.3	0.997	1.37	15.8	13.7	15.4	9.0
Std.	±0.7	±0.7	±0.27	±0.04	±0.06	±0.60	±0.55	±0.03	±0.04	±0.91	±0.39	±1.5	±2.10

Table D-2.3 Comparison of measured energy requirements for the semiconductor pressure transducer and conventional strip chart pressure recorder.

Implement : Hoe drill
Width : 4.1 m
K_{cy} : 0.0074 N/Pa
K_{ct} : 2.0 m/cm
DISNO : 49.6 m

Test Date : 1977 08 12
Surface : Osborne Clay (Fababean Stubble)
Location : Glenlea

				Semiconductor Pressure Transducer				Conventional Method				% Slip	
Test No.	DISL (m)	Time (s)	Speed (km/h)	Pressure (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Pressure (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Equa. 3.10	Equa. 3.11
1	44.6	20.1	7.99	1.29	2.29	21.12	23.0	1.16	2.08	19.1	20.8	10.1	14.0
2	46.0	20.2	8.20	1.34	2.39	22.53	23.8	1.15	2.05	19.3	20.5	7.3	13.3
3	46.2	20.3	8.19	1.38	2.46	23.16	24.6	1.21	2.15	20.3	21.5	6.9	14.6
4	44.8	20.0	8.06	1.27	2.27	21.06	22.7	1.13	2.01	18.7	20.1	9.7	10.5
5	46.1	20.5	8.10	1.30	2.33	21.71	23.3	1.19	2.13	19.8	21.3	7.1	11.9
6	44.8	20.2	7.98	1.13	2.01	18.46	20.1	1.11	1.98	18.1	19.8	9.7	12.3
Ave.	45.4	20.2	8.09	1.28	2.29	21.34	22.9	1.16	2.07	19.2	20.7	8.4	12.8
Std.	±0.78	±0.17	±0.10	±0.09	±0.15	±1.63	±1.54	±0.04	±0.07	±0.78	±0.68	±1.5	±1.5

Table D-2.4 Comparison of measured energy requirements for the semiconductor pressure transducer and the conventional strip chart pressure recorder.

Implement : Harrow
Width : 14.3 m
K_{cy} : 0.0031 N/Pa
K_{ct} : 2.0 m/cm
DISNO : 49.7 m

Test Date : 1977 08 11
Surface : Tilled Osborne Clay
Location : Glenlea

				Semiconductor Pressure Transducer				Conventional Method				% Slip	
Test No.	DISL (m)	Time (s)	Speed (km/h)	Pressure (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Pressure (MPa)	Unit Draft (kN/m)	Power (kW)	Energy (MJ/ha)	Equa. 3.10	Equa. 3.11
1	47.3	16.5	10.3	1.44	0.31	12.8	3.12	1.71	0.370	15.2	3.70	4.77	4.89
2	46.6	17.0	9.88	1.83	0.396	15.6	3.96	2.19	0.473	18.6	4.73	6.10	6.14
3	47.6	17.6	9.74	1.48	0.320	12.4	3.20	1.90	0.410	15.9	4.10	4.17	5.31
4	47.2	17.5	9.71	1.67	0.361	14.0	3.61	2.05	0.442	17.1	4.42	4.97	6.96
5	47.6	17.5	9.79	1.50	0.325	12.7	3.25	1.84	0.397	15.5	3.97	4.17	7.76
6	47.0	16.5	10.3	1.63	0.352	14.4	3.52	2.11	0.457	18.7	4.57	5.38	5.31
Ave.	47.2	17.1	9.95	1.59	0.344	13.6	3.45	1.97	0.425	16.8	4.25	4.93	6.06
Std.	±0.37	±0.5	±0.27	±0.15	±40.3	±1.62	±0.40	±0.18	±39.10	±1.54	±0.39	±0.74	±1.10

Table D-3 Data for drawbar power measurements and fuel consumption at the University of Manitoba

Load : Tractor
KCY : 0.0074 N/Pa
KCT : 1.974 m/cm

Test Date : 1977 11 02
Surface : Grassy Field (Tests No. 1 & 2)
Gravel Road (Tests No. 3 to 6)

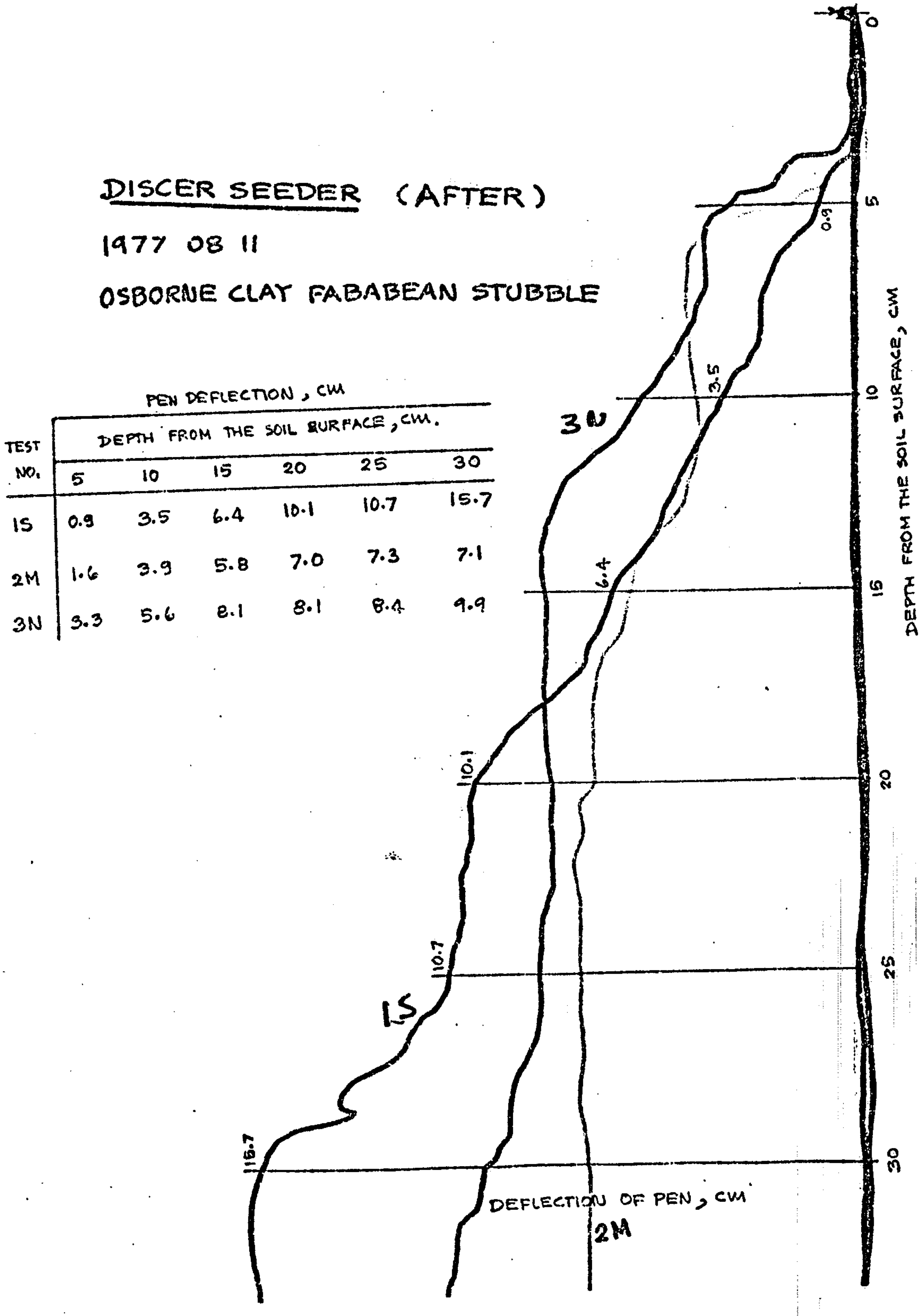
Test No	Average Pressure (MPa)	Drive Wheel 10-Turn Distance (cm)	Time (s)	Speed (km/h)	Power (kW)	Fuel Consumption			
						Number of Pulses in	Number of Pulses out	Time (s)	L/h
1	1.83	10.1	35.7	2.01	7.6	5760	-[*]	35.2	22.4
2	2.21	9.8	31.6	2.20	10.0	5067	-	30.0	23.1
3	1.37	13.6	22.3	4.32	12.2	3940	-	26.5	20.4
4	1.64	22.8	22.6	7.17	24.2	4502	-	27.8	22.2
5[†]	2.40	11.3	23.0	3.49	17.2	6618	-	30.0	30.2
6	2.76	19.0	22.6	5.97	33.9	3628	-	15.0	33.1

[*] Return flow pulses for the flowmeter from the fuel system were very low as observed on an oscilloscope.

[†] Results rejected due to excessive slippage.

APPENDIX E

SAMPLE OF ORIGINAL PENETROMETER RESISTANCE DATA



DISCER SEEDER (AFTER)

1977 08 11

OSBORNE CLAY FABABEAN STUBBLE

PEN DEFLECTION, CM

TEST NO.	DEPTH FROM THE SOIL SURFACE, CM.					
	5	10	15	20	25	30
1S	0.9	3.5	6.4	10.1	10.7	15.7
2M	1.6	3.9	5.8	7.0	7.3	7.1
3N	3.3	5.6	8.1	8.1	8.4	9.9

Figure E-1 Sample of soil penetrometer resistance measurements (three tests for Disker Seeder).

E-1 Sample Calculation of the soil penetrometer resistance, CI.

The calibration equation for calculating the Cone Index was given by Eq. 5.6:

$$CI = (64.382X + 48.579)/1.3 \qquad \ldots\ldots (5.6)$$

where CI = soil resistance in CI, N/cm^2

X = penetrometer recording pen deflection, cm.

From the raw data (Fig. E-1) for a depth from the surface of 25 cm, $X = 10.7$ cm (Test No. 1, South).

$$CI = [64.382(10.7) + 48.579]/1.3 = \underline{567.28\ N/cm^2}$$

The cone indices for the soil penetrometer resistance tests were calculated by a computer program and are summarized in Table E-1.

Table E-1 Average soil resistance (CI, N/cm^2) before and after tilling at Glenlea.

Field Condition	Implement	Treatments	Average soil resistance, CI, at different depths (cm)						Standard deviation at 5 cm
			5	10	15	20	25	30	
Osborne Clay Fababean Stubble	Double Disk	Before	185.9	347.2	461.6	570.6	626.7	687.8	± 68.8
		After	93.5	362.6	545.8	583.8	631.7	691.1	± 46.0
	Disker seeder	Before	93.5	362.6	545.8	583.8	631.7	691.1	± 46.0
		After	133.1	252.0	372.5	453.4	473.2	577.2	± 61.1
	Hoe drill	Before	133.1	252.0	372.5	453.4	473.2	577.2	± 61.1
		After	164.5	248.7	370.8	420.4	474.8	580.5	± 103.2
Tilled Osborne Clay	Harrow	Before	77.0	192.5	410.5	564.0	658.1	707.6	± 51.7
		After	69.6	298.2	354.3	402.2	435.2	476.5	± 32.8

APPENDIX F

ENERGY REQUIREMENTS FOR TILLAGE AS ESTIMATED FROM ASAE DATA

F-1 Relationship between field test data at Glenlea and ASAE data

The spring of 1977 was extremely wet and the planting season was delayed. Due to wet fall conditions the fall tillage treatments could not be performed. Therefore some of the energy requirements were estimated from ASAE data (ASAE D230.2, [1]). The ASAE data were modified to suit the depth of penetration used, the speed of operation used, the type of implement used and the soil conditions at Glenlea. Table F-1 lists the estimated unit draft and fuel consumption for the moldboard plow, heavy duty cultivator and field cultivator. Fuel consumption was estimated from Eq. 6.2.

Table F-1 The estimated draft requirements and fuel consumption.

Implement	Speed (km/h)	Draft required (kN/m)	Fuel consumption (L/ha)
Moldboard plow (1.8 m-width, 10.4 cm-deep)	7.63	9.50	25.9
Heavy duty cultivator (4.0 m-width)	7.63	4.92	19.4
Light tillage (Cultivator) (4.0 m-width)	7.63	3.35	10.9

APPENDIX G

ERROR ANALYSIS

G-1 Consideration of Errors

Holman (1971) has described a method of estimating the uncertainty in experimental results [16]. The uncertainty in a given function R of independent variables x1, x2, x3, . . . , xn is equal to

$$\Delta R = (((\partial R/\partial x1)\Delta 1)^2 + ((\partial R/\partial x2)\Delta 2)^2 + \ldots + ((\partial R/\partial xn)\Delta n)^2)^{1/2} \quad \ldots . (G\text{-}1)$$

where ΔR is the uncertainty in the result and $\Delta 1$, $\Delta 2$, . . . , Δn are the uncertainties in the independent variables.

The uncertainties of the voltage readings from the semiconductor pressure transducer, ΔV, the pressure readings from the conventional strip chart pressure recorder, Δp, chart distances, Δd, ground surface distances, Δw, and times, Δt, were estimated from the scale readings. The uncertainties in the hydraulic cylinder constant ΔK_{cy}, the chart constants ΔK_{ct} and the fuel consumption Δf were the standard errors of the hydraulic cylinder calibration constant, the chart constants and the fuel consumption regression equation FCT. The respective standard errors are listed in Table G-1.

G-2 Uncertainty in Power Measurements

The uncertainty in the measured power requirements using the semiconductor pressure transducer can be determined by applying Eq. G-1. The power requirement was calculated by combining Eqs. 3.2, 3.4 and 3.5. The resulting equation is:

$$DBP = 10^3 K_{cy} K_{ct} d (V - 0.0274)/(0.136 t) \quad \ldots . . (G\text{-}2)$$

Eq. G-1 applied to Eq. G-2 results in:

$$\Delta DBP = ((A\Delta V)^2 + (B\Delta K_{cy})^2 + (C\Delta K_{ct})^2 + (D\Delta d)^2 + (E\Delta t)^2)^{1/2} \quad \ldots . (G\text{-}3)$$

Table G-1 The estimated uncertainties in the experimental parameters.

Physical Variable	Value of Uncertainty	
ΔV	± 5.0	mV
Δp	± 0.069	MPa
Δd	± 0.05	cm
Δw	± 0.01	m
Δt	± 0.1	s
ΔK_{cy}	$\pm 5.806 \times 10^{-6}$	N/Pa[1/]
ΔK_{ct}	$\pm 2.5 \times 10^{-3}$	m/cm
Δf	± 0.83	(L/h)/kW

[1/] from reference 6.

where A, B, C, D and E are the partial derivatives of equation G-1. Applied to Eq. G-2 the partial derivatives are:

$$A = 10^3 K_{cy} K_{ct} d/0.136t$$

$$B = 10^3(V - 0.0274)K_{ct} d/0.136t$$

$$C = 10^3(V - 0.0274)K_{cy} d/0.136t$$

$$D = 10^3(V - 0.0274)K_{cy} K_{ct}/0.136t$$

$$E = -10^3(V - 0.0274)K_{cy} K_{ct} d/0.136t^2$$

The data for the disker seeder (from Table 6.2 and Appendix D) were substituted into Eq. G-3 with the following result:

$\Delta DBP = \pm 0.59$ kW

DBP was calculated as 18.71 kW so that the relative error was ± 3.2 percent.

The average uncertainties in the measurement of power, energy requirements and fuel consumption were calculated using the methods as given above and are listed in Table G-2.

Table G-2 Typical percent uncertainties in the measurement of energy requirements, power requirements and fuel consumptions (for data of Table 6.2 and Appendix D).

Implement	Semiconductor pressure transducer		Conventional strip chart pressure recorder		Fuel Consumption (L/ha)
	Drawbar Power (kW)	Tillage Energy (MJ/ha)	Drawbar Power (kW)	Tillage Energy (MJ/ha)	
Double Disk	± 2.6	± 2.5	± 5.6	± 5.6	± 3.4
Disker Seeder	± 3.2	± 3.1	± 7.4	± 7.4	± 3.7
Hoe Drill	± 2.9	± 2.9	± 6.4	± 6.4	± 3.5
Harrow	± 2.4	± 2.3	± 3.8	± 3.8	± 3.9