



Four wheel drive tractors : field performance in Montana
by John William Ohrmann

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Agricultural Engineering
Montana State University
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Abstract:

During the summer of 1978, tests were conducted on four wheel drive tractors in the state of Montana. Measurements were made to determine how farmers are utilizing high horsepower four wheel drive tractors. These measurements were used to determine how efficiently the farmers were using this power. Comparisons were made between the data and the theoretical prediction equations to determine the accuracy of the prediction equations when applied to field conditions. Data gathered provided information on drawbar power, speed, slip, capacity, and energy utilization under various conditions of tractor operation.

The data showed that many farmers are not utilizing the full power potential of their tractors. The drawbar power was often less than half of the rated engine power. Operating speeds were often lower than desired for good tractor performance and optimum life.

Comparison of the field data to the prediction equations showed poor correlation between the two in most cases. Insufficient data and extreme field variation may be responsible. Prediction equations developed for two wheel drive tractors may not be applicable to four wheel drive tractors. Modification of the prediction equation resulted in better correlation in some cases.

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Date May 24, 1979

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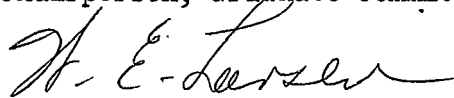
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ABSTRACT

During the summer of 1978, tests were conducted on four wheel drive tractors in the state of Montana. Measurements were made to determine how farmers are utilizing high horsepower four wheel drive tractors. These measurements were used to determine how efficiently the farmers were using this power. Comparisons were made between the data and the theoretical prediction equations to determine the accuracy of the prediction equations when applied to field conditions. Data gathered provided information on drawbar power, speed, slip, capacity, and energy utilization under various conditions of tractor operation.

The data showed that many farmers are not utilizing the full power potential of their tractors. The drawbar power was often less than half of the rated engine power. Operating speeds were often lower than desired for good tractor performance and optimum life.

Comparison of the field data to the prediction equations showed poor correlation between the two in most cases. Insufficient data and extreme field variation may be responsible. Prediction equations developed for two wheel drive tractors may not be applicable to four wheel drive tractors. Modification of the prediction equation resulted in better correlation in some cases.

GLOSSARY OF TERMS USED TO DESCRIBE TRACTION CHARACTERISTICS

Ballast--Any weight that can be added to or removed from a vehicle or transport device for the purpose of changing its total weight or weight distribution.

Draft--The force to propel an implement in the direction of travel.

Equal and opposite to drawbar pull.

Flotation--Ability of the traction or transport device to resist sinkage into the medium being traversed.

Power, drawbar--The product of vehicle velocity and the drawbar pull in the direction of travel.

Pull, drawbar--Force in the direction of travel produced by the vehicle at the drawbar.

Slip--Relative movement in the direction of travel at the mutual contact surface of the traction device and the surface which supports it.

Traction device--A device for propelling a vehicle using the reaction forces from the supporting surface.

Travel reduction--One minus the ratio of distance traveled per revolution of the traction device to the rolling circumference under the specified zero conditions.

Weight, dynamic--Total force normal to the plane of the undisturbed supporting surface, exerted by the traction device under operating

conditions.

Weight, static--Total force normal to the plane of the undisturbed supporting surface, exerted by the traction device while stationary on level ground with zero pull and zero torque.

Weight transfer--The change in normal forces on the traction devices of the vehicle under operating conditions, as compared to those for a static vehicle on level ground.

PREFACE

In recent years, large acreage farms have been turning to four-wheel drive (4WD) tractors to increase capacity while simultaneously decreasing the labor force required to raise crops. Many farms have at least one 4WD tractor, with two, three, or more units on one farm being common.

Energy use and availability for agriculture has been of increasing concern. Possible shortages and increasing costs make efficient utilization of energy in agriculture of growing importance. Techniques of saving energy and reducing labor requirements could save farmers a significant amount on an annual and long term basis.

Four-wheel drive tractors have the potential for increased efficiency and reducing costs. These cost savings can only be achieved if this power is being used efficiently. There is concern that the farmer who is used to medium-sized two-wheel drive tractors might not make full use of a large horsepower 4WD unit. If the tractor is operating well below capacity, the efficiency will be well below the tractor's potential.

There is little information available on how a 4WD tractor performs under actual farm use. The information currently available has been obtained from theoretical model studies, and tests conducted under controlled conditions. Test track conditions provide little information about the performance that can be expected by individual operators under farm conditions.

This research project was designed to determine how the farmers are actually using their tractors, and to generate field data which may be used to test the accuracy of the prediction equations.

These results should be helpful to farmers in improving the performance of these operations. Improved performance equations will be useful in predicting field performance.

These tests will benefit both the farmer and the manufacturer. The farmer will in many cases be able to operate more efficiently. Increased knowledge on how the tractors will be used will help the manufacturer build a tractor which better serves the farmers' needs.

1. LITERATURE REVIEW

TRACTION PREDICTION

Traction is defined as the force in the direction of travel developed by a traction device. Extensive work has been done to develop models which describe the expected performance of traction devices.

Soil strength is an important factor in the prediction of traction. Effective pull will be limited to a value somewhat less than the resisting force in the supporting soil. Shearing strength in the soil then becomes a limiting value in developing drawbar pull.

The weight of the tractor is important in predicting traction. Friction between soil particles contributes to the total soil strength, and the effective soil friction is proportional to the normal force produced by the tractor weight.

Figure 1.1 illustrates the basic forces associated with a traction device (3).^{*} The drawbar pull is the difference between the horizontal force developed by the traction device and the rolling resistance on

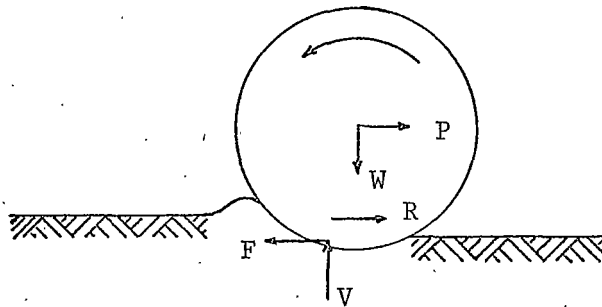


Figure 1.1. Free-body diagram of a driving wheel of a traction device

^{*}Numbers in () refer to literature cited in the bibliography.

the traction device. It can be determined by the equation:

$$P = F - R \quad [1.1]**$$

where P = drawbar pull, N;

F = total force developed at soil tire interface, N;

R = rolling resistance, N; and

V = vertical soil reaction, N.

If the soil has some cohesion, the theoretical soil thrust on the tire is given (3) by the equation:

$$F = Ac + W \tan \phi = A(c + \rho \tan \phi) \quad [1.2]$$

where A = area of soil-tire contact, m^2 ;

c = cohesion of the soil, N/m^2 ;

W = dynamic load on the traction device, N;

ϕ = internal friction angle of the soil; and

ρ = pressure exerted on the soil by the tire, N/m^2 .

If the tire contact surface is assumed to be an ellipse, then:

$$\rho = \frac{W}{0.78 bx} \quad [1.3]$$

where b = tire section width, m;

x = length of tire track or footprint, m; and

ρ , W as previously defined.

**Numbers in [] refer to equation number.

Rolling resistance is a value which is somewhat more difficult to determine. Barger (3) has derived a formula in which the rolling resistance is defined by the following formula:

$$R = \frac{2}{(n+1)(K_c + bK\phi)^{1/n}} (W/2x)^{(n+1)/n} \quad [1.4]$$

where K_c = cohesive modulus of soil deformation, N/m^{n+1} ;

$K\phi$ = frictional modulus of soil deformation, N/m^{n+2} ;

n = coefficient of Z , dimensionless;

Z = wheel sinkage, m; and

R , x , b , W as previously defined.

If the sinkage, Z , is large in proportion to the tire deflection, the equation developed by Bekker (5) is more applicable. In this case, the rolling resistance is defined as:

$$R = \frac{(3W/b)^{0.5} (2n+2)/(2n+1)}{(3-n)^{[(2n+2)/(2n+1)]} (n+1)(K_c + bK\phi)^{1/(2n+1)}} \quad [1.5]$$

Knowing the rolling resistance, the expected pull can be determined by solving Equation [1.1].

The main objection to using Equations [1.2] and [1.5] for the determination of pull is the number of soil variables involved. For each soil, an analysis of c , ϕ , K_c , $K\phi$, and n must be made. Bekker indicates that this analysis may be carried out by using a pressure plate and a recorder to obtain a plot of pressure verses sinkage (4). The informa-

tion must then be transferred to log-log paper in order to find the variables K_c and $K\phi$. Presumably, c and ϕ are already known (which is reasonable if the type of soil and moisture conditions are known).

Wismer and Luth (17) used dimensional analysis to simplify the prediction equations. The set of dimensionless ratios for the variables is:

$$\frac{TF}{W}, \frac{P}{W}, \frac{Q}{rW} = f\left(\frac{CIbd}{W}, \frac{b}{d}, \frac{r}{d}, S\right) \quad [1.6]$$

where TF = towing force, N (used in towed wheel condition);

W = load (vertical reaction at soil-tire interface), N;

P = pull, N;

Q = torque on wheel, N-m;

r = rolling radius of wheel, m;

CI = cone index of soil, N/m^2 ;

b = tire section width, m;

d = overall tire diameter, m; and

S = slip, dimensionless.

Traction equations are then developed using these variables.

The dimensionless ratios given in Equation [1.6] can be applied to the performance of a towed wheel, a self-propelled wheel, or a driving wheel. Since the tractor is intended to create a net pull, the driving wheel equation applies. This equation is:

$$\frac{P}{W} = 0.75 (1 - e^{(-0.3 C_n S)}) - \left(\frac{1.2}{C_n} + 0.04 \right) \quad [1.7]$$

where P = wheel pull parallel to soil surface, N ;

W = dynamic wheel load, normal to soil surface, N ;

C_n = dimensionless wheel numeric, $\frac{CIbd}{W}$; and

CI , b , d , S as previously defined.

The dimensions of CI , b , d , and W must be chosen so that the wheel numeric is dimensionless. If the cone index is in newton per square meter, then b and d must be in meters, and W must be in newtons.

The cone index of the soil must be determined for Equation [1.7] developed by Wismer and Luth (17). This measurement is accomplished by driving a cone of standard size into the ground at a prescribed rate, and measuring the force necessary to drive the cone. The value determined is actually a composite measurement, combining factors such as soil cohesion, angle of internal friction, and soil-to-metal friction (17). Since these factors are also important in determining the total soil thrust against the tire, the cone index can be used as a factor for predicting traction.

Bekker's equations contain variables for soil characteristics such as internal friction angle and soil cohesion. The Wismer and Luth equations combine all these factors into one simple soil measurement which provides the value directly. Cone index is easy to measure and use.

The Wismer and Luth equations are therefore more easy to use as traction

prediction equations than Bekker's analysis.

The wheel numeric, C_n , which introduces the cone index into Equation [1.7], includes a characteristic area of the tire footprint, bd , and the load on the soil, W . The area of contact is important when developing traction on cohesive soils, such as clay. On frictional soils such as sand the load on the soil determines the traction which can be developed. Both factors may be involved on many soils, as shown by Equation [1.2].

Various references (17), (8), (16) recommend different methods for determining the cone index for a particular soil. In most cases, the cone index will vary with depth and with different sites in an area. A value which in some way averages the several measurements obtained is therefore necessary. Generally, measurements taken at 2.5 centimeter increments of depth, and averaged over a 15 centimeter penetration depth is recommended. If the tire sinkage is greater than 7.5 centimeters, then the average of the measurements 7.5 centimeters above and 7.5 centimeters below the depth of sinkage is recommended.

The dynamic weight on the tires is included in both Bekker's analysis and the Wismer and Luth equations. The usual method to determine dynamic weight is to treat the tractor as a free body unit. A moment diagram using static front and rear weights plus drawbar pull is used to determine the weight transfer. The following equation is used:

$$V_F = W_F - \frac{P y}{w} \quad [1.8]$$

where V_F = dynamic load on front axle, N;

W_F = static weight on front axle, N;

P = total drawbar pull, N;

y = drawbar height, m; and

w = wheelbase, m.

The method outlined above would be accurate if the tractor were stationary, and producing only enough torque on the wheels to provide a stationary pull equal to the given drawbar pull. According to Smith and Murillo-Soto (13), however, this method is not entirely correct. Some accounting for the accelerations involved during operation must be made. The complete equation for determining dynamic weight according to Smith, et. al. is as follows:

$$V_F = W_F + \frac{P r_o}{w} - \frac{P y}{w} - \frac{T_F}{w} - \frac{T_R}{w} - \frac{H_F y'}{w} \quad [1.9]$$

where r_o = effective wheel radius, m;

y' = difference in sinkage between front and rear wheels, m;

H_F = horizontal force developed by front axle, N;

T_F = torque developed by front axle, N-m;

T_R = torque developed by rear axle, N-m; and

V_F , P , w , y , W_F as previously defined.

The axle torques, horizontal force, effective wheel radius, and sinkage all require specialized equipment for their measurement. The necessary instrumentation was not available, and if available, it would have been difficult to adapt this equipment to the variety of tractors tested. Also, the time required to install the equipment on each tractor would have been excessive.

The error involved in using Equation [1.8] to determine the dynamic weight rather than the exact method given by Equation [1.9] is relatively small. As a check, Smith's equation was solved using actual test data, assuming the front axle torque was equal to the rear axle torque and assuming the difference in sinkage between front and rear wheels was 7.5 centimeters. The approximate method was within one percent of the exact method. For these reasons, the approximate method of calculating dynamic axle loads was used rather than the more exact method described by Smith, et. al.

SLIP PREDICTION

Developing traction in a deformable medium such as soil requires that there is some distortion of the soil. The tractive force is a function not only of the vertical load and the dynamic properties of the soil, but also of the displacement between the device and the soil (9). The traction device will displace the soil until the soil has built up enough stress to either equal the necessary tractive force, or

fail. If the tractive force is attained, the vehicle will develop pull. If failure occurs, the vehicle will be incapable of forward motion. This displacement is related to the travel reduction and slip. Travel reduction refers to the difference between the distance traveled per revolution of the wheel and the distance which would be traveled if there were no displacement. Slip refers more specifically to the relative motion between wheel and soil at the interface. The two terms are often used interchangeably.

Slip is expressed as either a percentage or as a decimal. The basis for calculation can be velocity, as given by Gill, et. al. (9):

$$S = \frac{v_o - v}{v_o} \quad [1.10]$$

where S = slip expressed as a decimal;

v_o = velocity of the vehicle without slip, m/s; and

v = actual velocity of the vehicle relative to the earth, m/s.

The reduction in distance traveled per wheel revolution is defined as travel reduction and is often used as a basis for calculating slip:

$$S = \frac{\text{No-load advance per wheel revolution} - \text{Loaded advance per revolution}}{\text{No-load advance per wheel revolution}} \quad [1.11]$$

If a common distance is used for both the loaded and no-load conditions, Equation [1.11] simplifies to:

$$S = \frac{\text{Number of wheel revolutions, loaded} - \text{Number of wheel revolutions, no-load}}{\text{Number of wheel revolutions, loaded}} \quad [1.12]$$

The no-load condition considers the traction device as a self-propelled vehicle, with no pull at the drawbar, and negligible rolling resistance. A hard surface, such as concrete, is necessary for the no-load condition if the slip measurement is to be completely accurate (7). If a softer surface, such as soil, is used for all tests, then the measurement is more accurately called travel reduction, and the slip measurement is actually a measurement of the difference between the no-load slip and the loaded slip. Presumably, the no-load slip will be negligible compared to the loaded slip.

Slip can be predicted if the proper variables are known. Equation [1.7] can be rearranged as follows:

$$S = \frac{1}{0.3 C_n} \ln \frac{0.75}{0.75 - \left(\frac{P}{W} + \frac{1.2}{C_n} + 0.04 \right)} \quad [1.13]$$

This equation, and Equations [1.11] and [1.12] yield slip as a decimal value.

PREDICTION OF TILLAGE TOOL DRAFT

An idea of the magnitude of the expected draft on a tillage tool is necessary to properly match the tillage tool to the tractor. In Agricultural Machinery Management Data, ASAE D230.3 (2) equations are pre-

sented which can be used to predict the draft on various tillage tools with varying soil conditions. These equations incorporate implement speed and depth of tool penetration in the draft prediction equation. Variations of ten percent about the mean values are indicated as common variations.

Sial and Harrison (12) showed an increase in draft with an increase in speed or in depth. Vertical and lateral reactions on the individual tools also increased in magnitude with greater speed and greater depth.

MATCHING TILLAGE TOOLS TO TRACTORS

Efficient use of the power of a tractor is possible only if the tractor is matched with an implement of the appropriate size. An implement which is too small will not put enough load on the engine for efficient operation, while an implement which is too large may cause excessive wear on the drive train of the tractor. Excessive wear may be caused by high torques on the drive train. In order to pull an implement which is too large for the tractor, the farmer will have to operate in a low gear. In a low gear, power is transferred to the traction wheels at low speeds. Power is proportional to the product of torque and angular speed, therefore slow angular speeds (associated with low ground speeds) require high torque for full power to be transferred to the traction wheels. Bowers (6) suggests matching implements to tractors so that field speeds will be in the 7.25 to 10.0 kilometers per hour range.

Drawbar power is proportional to the product of ground speed and drawbar pull. Therefore, if the recommended ground speed and the usable drawbar power which can be expected from a given tractor are known, then the drawbar pull which the tractor can be expected to develop can be calculated. Implement draft per unit width can be estimated from Agricultural Machinery Management Data, ASAE D230.3 (2) or Bowers (6). The implement with the proper width will produce a draft equal to the drawbar pull which the tractor can be expected to develop. By using a ground speed in the range recommended by Bowers it is possible to calculate the width of an implement which would be well matched to the tractor.

Bowers (6) has investigated the relationship between usable power at the various levels in the drive train. A "rule of thumb" conversion factor of 0.86 was developed for comparing one power level to the next. The consecutive power levels referred to, as well as the relative power at each level, are given below:

Maximum engine power	= max eng power x 0.86 ⁰
Maximum PTO power	= max eng power x 0.86 ¹
Maximum drawbar power, concrete	= max eng power x 0.86 ²
Maximum drawbar power, firm soil	= max eng power x 0.86 ³
Usable drawbar power, firm soil	= max eng power x 0.86 ⁴
Usable drawbar power, tilled soil	= max eng power x 0.86 ⁵
Usable drawbar power, soft soil	= max eng power x 0.86 ⁶

The expected usable drawbar power can be determined for any tractor with a known power rating if the soil conditions are known. It should be noted that Bowers de-rates the maximum power by 14 percent in going from a maximum power to a usable power for each soil type, or operating condition. This would give a normal operating load of 86 percent of the maximum available power under each condition.

Larsen (10) makes use of Nebraska Tractor Test Data (11) in the prediction of available drawbar horsepower. The available drawbar power can be determined from the following formula:

$$\text{DBHP in the field} = Z \times \text{DBHP on concrete, Nebraska Tractor Test} \quad [1.14]$$

where $Z = 0.58$ for soft soils,

$Z = 0.70$ for filled soils,

$Z = 0.85$ for firm soils, and

$Z = 1.00$ for concrete.

These numbers are quite close to the values shown by Bowers (6). They are, however, related to the maximum power that should be available for each soil condition and should be derated to usable power to be comparable with the information from Bowers.

If the Nebraska Tractor Test Data was not available, Larsen used maximum continuous power with accessories as published in the Implement and Tractor Red Book (8) as an estimate of the available engine power. The estimating formula was then expressed as:

$$\text{DBHP in the field} = Y \times \text{continuous engine HP with accessories} \quad [1.15]$$

where $Y = 0.45$ for soft soils,

$Y = 0.55$ for tilled soils,

$Y = 0.66$ for firm soils, and

$Y = 0.78$ for concrete.

The recommendations set forth by Bowers and Larsen may be used in matching implements to tractors, or used as a guide to determine if farmers are operating with properly matched tractor-implement units.

A comparison of the maximum drawbar power from the Nebraska Tractor Tests with Maximum Engine Horsepower from the Implement and Tractor Red Book shows a wide range of variability. Data was compared for engines in 4WD tractors which were tested between 1976 and 1979. The ratio of maximum DBHP from the Nebraska Test to the maximum engine horsepower varied over the range of 0.59 to 0.83. The average value was 0.73.

This would indicate that prediction of drawbar power as a percentage of Nebraska Tractor Test power is quite valid since the Nebraska Test is run under standard conditions. Prediction of drawbar power as a percentage of maximum engine power is questionable due to the variability either in the procedures used by the manufacturers to rate the engines or in the performance of the engines when placed in a tractor.

2. TRACTORS AND IMPLEMENTS TESTED

SELECTION OF UNITS

The tractor-implement units used in these tests were owned by farmer-cooperators throughout Montana. County agents and equipment dealers were contacted, and through them a list of potential cooperators was obtained. These farmers were contacted, and appointments were made with those interested in the study. No effort was made to choose farmers with particular brands of tractors or implements. There was an effort, however, to locate cooperators over a wide area within the state.

TRACTORS

All tractors tested were 4WD units. Figure 2.1 shows a typical 4WD tractor. Most of the tractors were of the articulated frame type. Four of the tractors were a solid frame type, with individual steering for front and rear wheels. Twelve tractors were equipped with dual tires, while four tractors were operated with singles. Two of the wheel steer tractors were equipped with single tires.

Power ratings for the tractors based on maximum engine power ratings ranged from 104 to 448 kilowatts. Static weights of the tractors varied from 8.3 to 24.5 metric tons. Static weight distribution varied from 53 percent of the total weight on the front axle to 65 percent of the total weight on the front axle.

Accessories on the tractors were limited to air conditioning units and dozer blades. All the tractors tested were equipped with air condi-

tioning. Frames for dozer blades were mounted on six of the tractors. The dozer blades were not mounted during field work, but were used for winter snow blowing and light grading work during the summer.

IMPLEMENTS

The tractors involved in this project were often used with a variety of implements for general field work. For the performance test, however, in all cases they were operated with towed, tool bar type field cultivators. Figure 2.2 shows a typical tool bar field cultivator.

All cultivators tested were towed implements. No three point hitch mounted implements were encountered. The actual tillage tools were primarily sweeps mounted on 30.5 centimeter centers. The sweep width ranged from 35.5 to 40.6 centimeters. One cultivator was equipped with twisted shank chisels rather than sweeps. Tillage tools were connected to the implement frame by spring shanks. No rigid shanks were encountered. Overall implement widths ranged from 6.4 to 16.6 meters. Implement weights ranged from 2.4 to 6.4 metric tons.

Accessories on the implements were limited to spring tooth harrows or rod weeders, mounted to the rear of the implement. Five of the sixteen implements tested were equipped with spring tooth harrows. One of the implements was equipped with a rod weeder.

Most of the farmers were operating the implements at depth of 10 to 12.5 centimeters, with one farmer operating at tillage depth of 20 centimeters.

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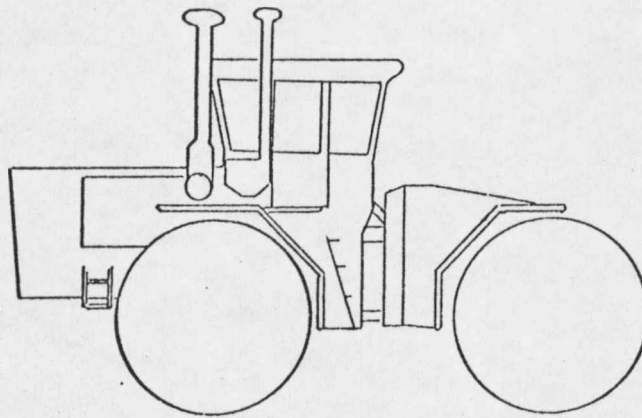


Figure 2.1. Typical four wheel drive tractor

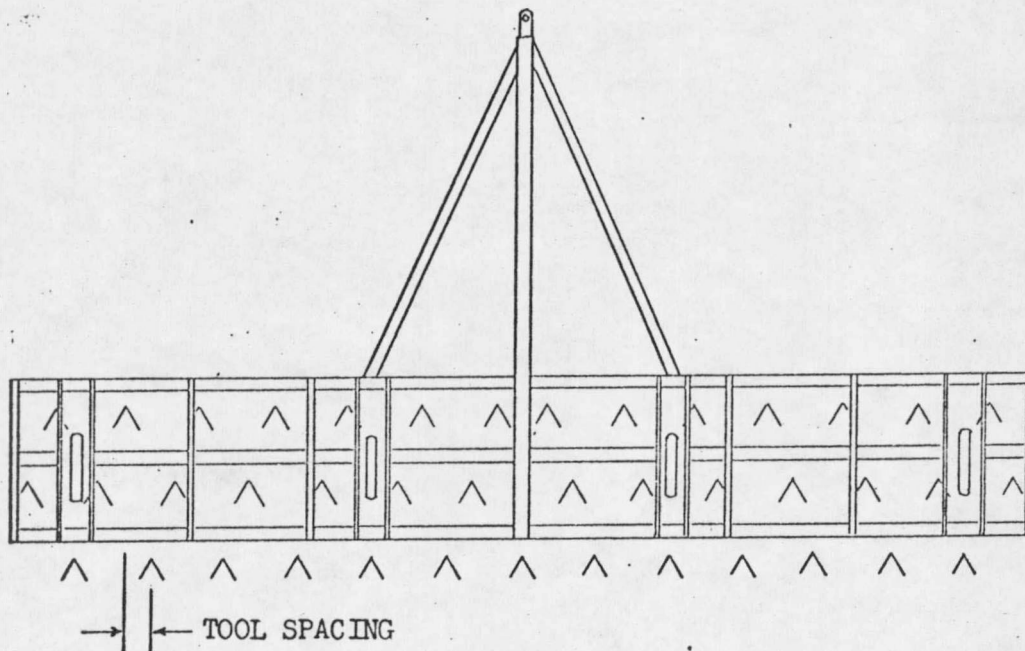


Figure 2.2. Typical towed, tool bar type field cultivator, plan view

3. TEST EQUIPMENT DEVELOPMENT

TRACTOR PERFORMANCE MEASUREMENT

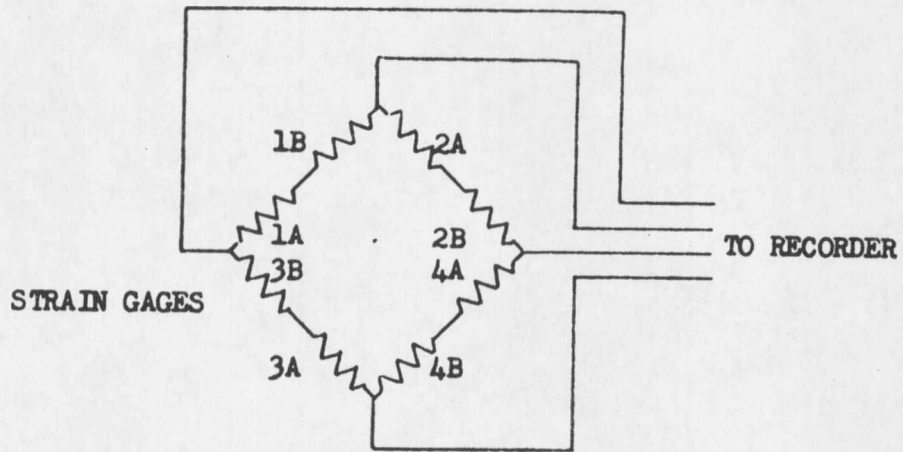
The parameters used in evaluating the performance of the tractors were drawbar power, ground speed, wheel slip, and coefficient of net traction. These parameters cannot be measured directly. The field data gathered for each tractor was drawbar pull, test distance, elapsed time for each test, number of tractor wheel revolutions for each test, and static weight of the tractor.

Three tractors were tested in 1977 to evaluate the test equipment. These preliminary tests were conducted as follows:

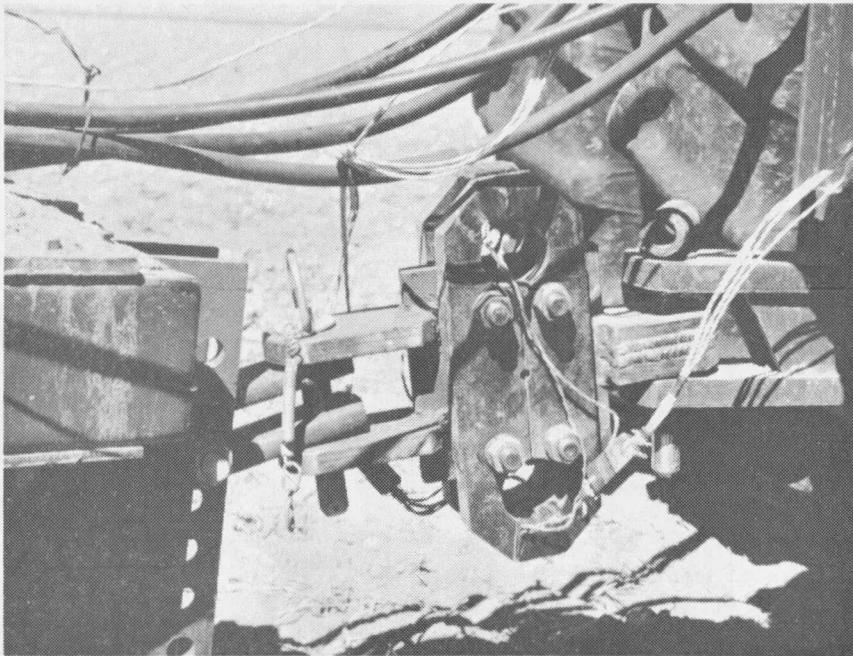
Drawbar pull was measured using the pull meter shown in Figure 3.1. This pull meter used two extended ring strain gage transducers. The strain gages were wired to form a Wheatstone bridge. The two transducers were used in parallel and the strain gages placed at corresponding positions of the two transducers were wired in series. In this way, the output from the two transducers was summed. The signal from the pull meter was recorded on a Hewlett Packard 321 Dual Channel Carrier-Amplifier Recorder. The recorder was carried in an instrument shed in a pickup which was driven alongside the tractor during the test. Power was supplied to the recorder by a portable generator in the pickup.

A land measuring wheel was used to measure an arbitrary test distance of 150 meters. Stakes were used to mark off this distance.

Tractor wheel revolutions over the test distance were counted by the pickup driver. A piece of tape on the tractor wheel was used to facili-



(a)



(b)

Figure 3.1. Extended ring strain gage transducers. (a) Arrangement of strain gages in Wheatstone bridge. Gage 1A is in the #1 position on transducer A, 1B is in #1 position on transducer B, and so on. (b) Transducers arranged as pull meter between implement and tractor.

tate counting.

During a test, the pickup was driven beside the tractor while it was in operation. The run began some distance before the start of the measured test course to allow the farmer to set the tillage implement at the proper depth, and to allow the tractor to stabilize speed at the given load. The tractor operator signalled the beginning of the run when the first stake was passed. The pickup driver used a stopwatch to record the time for each run. He was also responsible for counting tractor wheel revolutions. The recorder operator recorded the start and end of each run by means of an event marker on the recorder. The tractor operator signalled the end of each run when the second stake was passed.

Dust kicked up by the tractor and implement created many problems with this test method. Many times, the tractor wheel was almost obscured by dust, making wheel revolution counting almost impossible. The tractor driver's signals were often difficult to see.

Two other problems were encountered during the preliminary tests. After each run, the operations had to stop while the recorder operator and pickup driver compared and recorded information. Then conversation with the farmer was necessary to discuss the conditions of the next run. These stops slowed the testing operation. Driving the pickup alongside the tractor was also difficult. Bouncing in the pickup was severe and much worse than that felt by the tractor operator. This was due to the

difference in the sizes of the tires of the two vehicles. Difficulties were also encountered with the wires connecting the pull meter to the recorder. If the wires did not have enough slack, they could be torn loose. If they had too much slack, they could snag on the ground or be run over.

Problems caused by dust and by the coordination and operation of two vehicles were circumvented by redesigning the equipment and mounting all equipment on the tractor and implement. Equipment was developed to record tractor wheel revolutions and test distance directly on the recorder. Automatically recording the data on the recorder eliminated the problems of poor visual contact between the tractor and pickup operators.

The distance covered during each run was measured with the system shown in Figure 3.2. A land measuring wheel with a 3.05 meter (10 foot) circumference was towed behind the implement. A cam on the inner hub of the wheel opened and closed a microswitch, providing one signal to the recorder for each revolution of the wheel.

The wheel revolution counter which was used is shown in Figure 3.3. The counter was clamped inside the tractor wheel by means of the threaded rods. These rods were screwed out until they wedged tightly inside the tractor wheel. A pendulum with a microswitch was suspended from the axle at the center of the counter. A cam activated the microswitch to give one signal per tractor wheel revolution. The signal was recorded on an event marker.

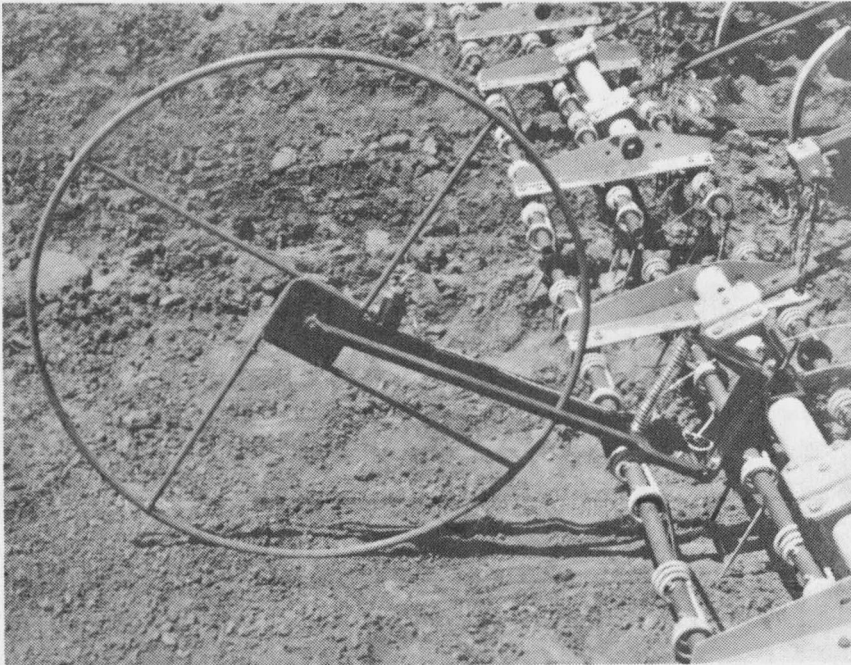


Figure 3.2, Distance measurement wheel

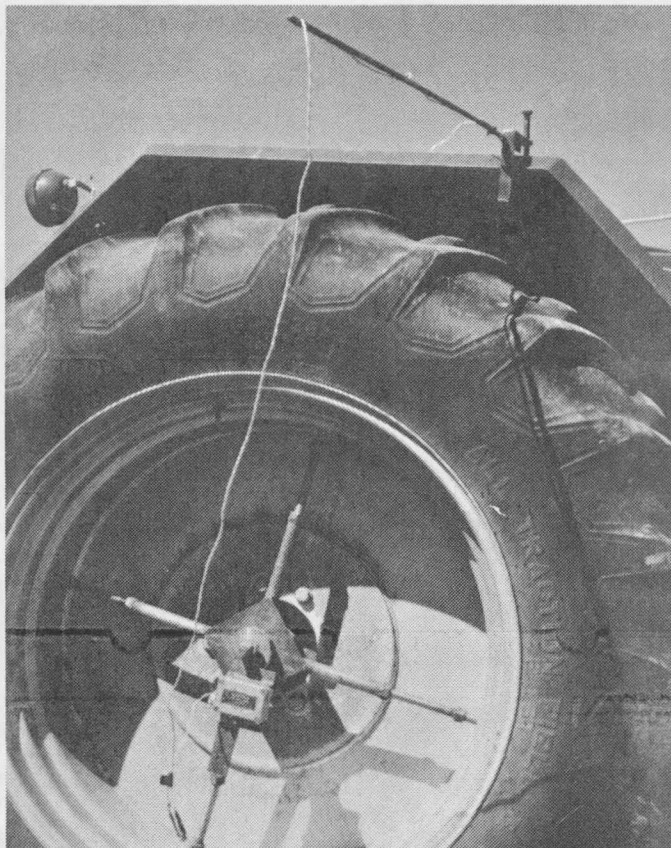


Figure 3.3. Tractor wheel revolution counter

Two wheel revolution counters were made to record both right and left wheel revolutions on the rear axle. Any differential slip between the wheels could be discovered. After several tractors were tested, however, it was discovered that the differential slip was negligible. Therefore, only one unit was used for the majority of the tests.

A rod was clamped on the fender of the tractor to support the wires from the counter unit and keep them from becoming tangled in the wheel of the tractor.

To solve the problems associated with communication between recorder operator, pickup driver, and tractor operator, the recorder was mounted in the cab of the tractor. This system also eliminated the problems associated with driving the pickup alongside the tractor. With the recorder in the cab of the tractor, the pickup was no longer needed. The generator was mounted in a universal frame which clamped onto the implement frame as shown in Figure 3.4.

The same pull meter was used in 1978 as was used in the preliminary tests in 1977.

Elapsed time for the tests was indicated by the recorder chart paper speed. Paper advance speed was known, and provided a convenient measurement of time. Also, the recorder had a timer mode for the right-hand event marker which was used as a check on chart paper speed.

Channeling all the information into the recorder reduced the chances for error. All information for a particular run was on the same

piece of chart paper. Previously, some of the information was recorded on the chart paper, and some was kept in a record book. Confusion could conceivably result when the two sets of records were combined. With all information concerning the performance on one piece of paper, this confusion was eliminated.

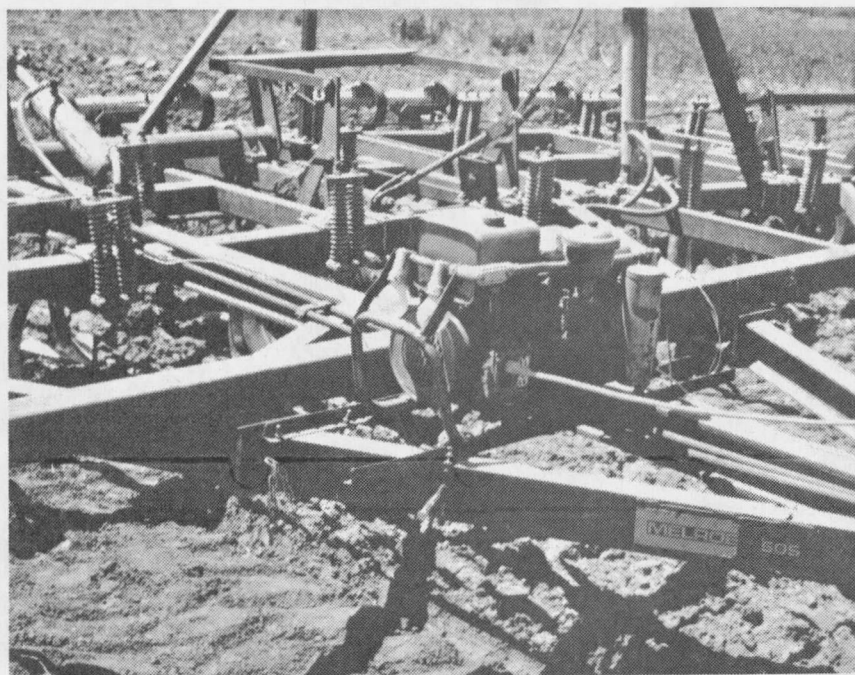


Figure 3.4. Portable generator mounted on tool bar frame

Improved communication between recorder operator and tractor driver also improved the system. If a problem occurred, it was possible to correct the problem, or stop operation if necessary, before the problem became serious.

The need for stopping after each run was also eliminated. This greatly speeded up the test process. Reducing down time for the tractor was considered very important to the success of the project. Many farmers would be unwilling to work with the project if they thought their tractor would be tied up, unproductively, for too great a time period.

The tests conducted during the summer of 1978 used the equipment and procedures described above. This test process worked effectively during the test period. One problem was encountered, however, as some of the tractor cabs were too small for the tractor driver, recorder operator, and recorder. On several tests, the recorder operator had to sit on the steps of the tractor, with the recorder on the floor of the cab beside him, as shown in Figure 3.5. By necessity, the door of the tractor cab was open. This allowed a large quantity of dust, kicked up by the tires, to surround the recorder operator and recorder. Besides being fairly uncomfortable for the recorder operator, the dust caused problems with the recorder. The chart feed rolls were particularly sensitive to dust. This caused some problems since the chart speed was used as the time measurement. Any change in chart speed made a test worthless. When possible, the timer mode for the right-hand event marker was used to check chart speed.

For a short period, the left-hand channel of the recorder, which was normally used to record the distance measurement, was inoperative. Until the unit was repaired, the distance wheel signal was recorded on the

right-hand event marker. This made use of the timer impossible. Problems with paper speed during this period caused one test to be discarded.

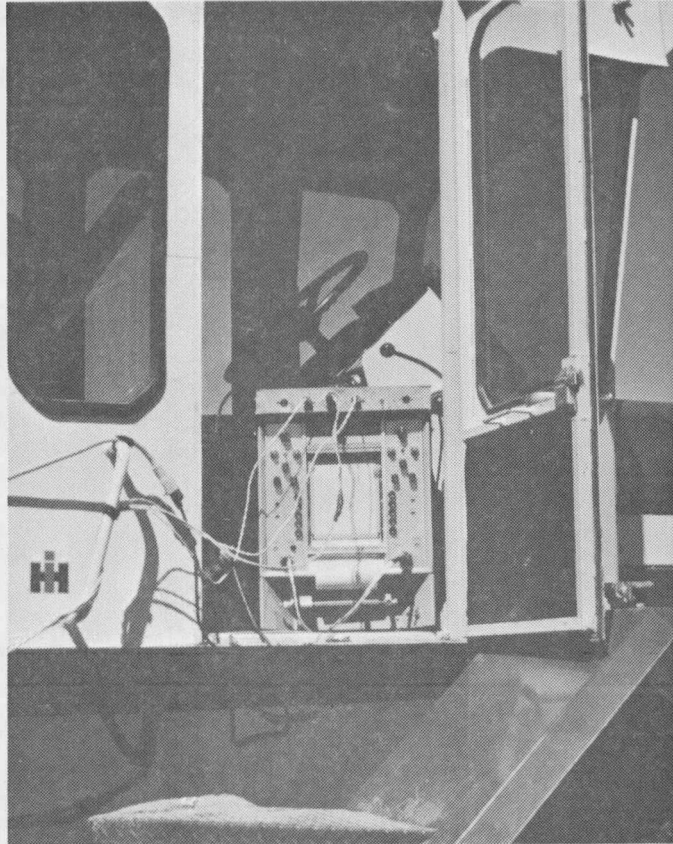


Figure 3.5. Recorder in cab of tractor

Because of the dust problems, efforts were made to bring the recorder into the cab whenever possible. A plastic dust cover was included in the supplies for cases where the dust could not be controlled.

Problems were also encountered with the strain gages on the transducers. Although protected by padding and several layers of tape, they were easily damaged. Care was necessary to ensure that the transducers did not rest on the gages or wires during transport and handling.

TRACTOR AND IMPLEMENT WEIGHTS

The tractors and implements were weighed with a scale built from the same transducers as were used in the pull meter. The pull meter was unbolted, and the transducers separated from the hitch assembly.

Weights of the three tractors tested during 1977 and the first two tractors tested during 1978 were determined as follows. One end of the tractor at a time was lifted with hydraulic jacks placed on the strain gage transducers. The weight was recorded on the recorder. This system was fairly time consuming as it required crawling under the tractor with the heavy transducers, jacks, and wooden blocking, and then jacking up the tractor. This process was repeated for both front and rear axles. Also, there was a danger of the tractor slipping off the jacks during weighing and injuring the operator. This was particularly a problem on tractors with dozer frames mounted on the underside of the tractor, as there was little room to get out of the way if the tractor did slip.

Figures 3.6 and 3.7 show the system which was constructed for the remainder of the tests. A platform scale was used to weigh one tire, or set of duals, at a time. The scale was set in the ground with the top

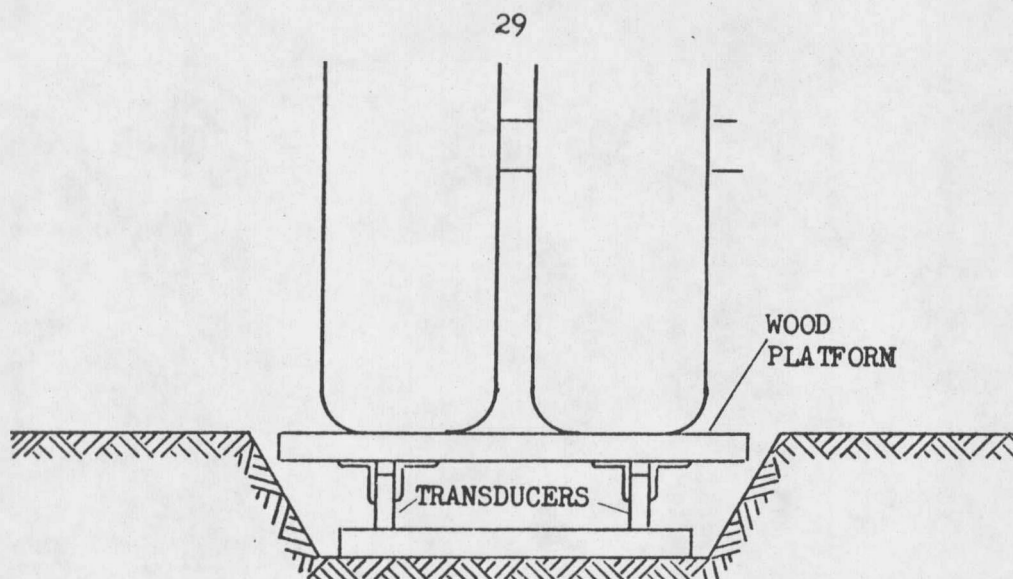


Figure 3.6. Platform scale weighing one pair of duals

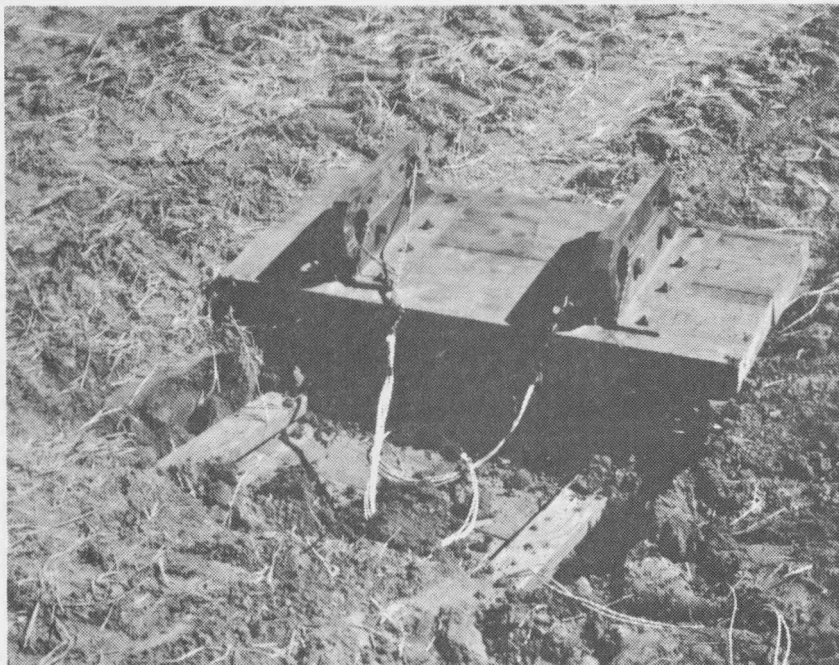


Figure 3.7. Platform scale, inverted to show position of strain gage transducers

even with the soil surface. The platform scale reduced down time for the farmer, as very little time was required to drive onto the scale, stop for several seconds, and drive another wheel onto the platform. The recorder operator had to take the time to dig a pit large enough for the scale, but this did not contribute to down time for the farmer.

In addition to the time and safety advantages, the platform scale was somewhat more accurate. Jacking the tractor up five or six inches to take all the weight off the wheels caused some weight transfer to the axle that was not being weighed. With the platform, the tractor was setting in a normal attitude, with both axles level.

The implement was usually weighed by driving the unit over the platform, then jacking it up until half the weight was supported by the scale. Wheel spacings on the implements made it difficult to position the wheels on the platform, but the jacks could be used easily and safely to lift the implements.

Tongue weight was determined by maneuvering the hitch over the platform, and jacking the tongue up until the scale was supporting the weight of the tongue.

SOIL CONE INDEX MEASUREMENT

Soil strength was measured using cone index as the basic soil parameter. Figure 3.7 shows the soil cone penetrometer which was used to measure cone index. The cone design follows the recommendations set

forth in "Soil Cone Penetrometer," ASAE R313.1 (14). A hydraulic cylinder provided the force necessary to drive the cone into the ground. This cylinder was matched to the pump-motor unit to provide the recommended 182.9 centimeters per minute penetration speed.

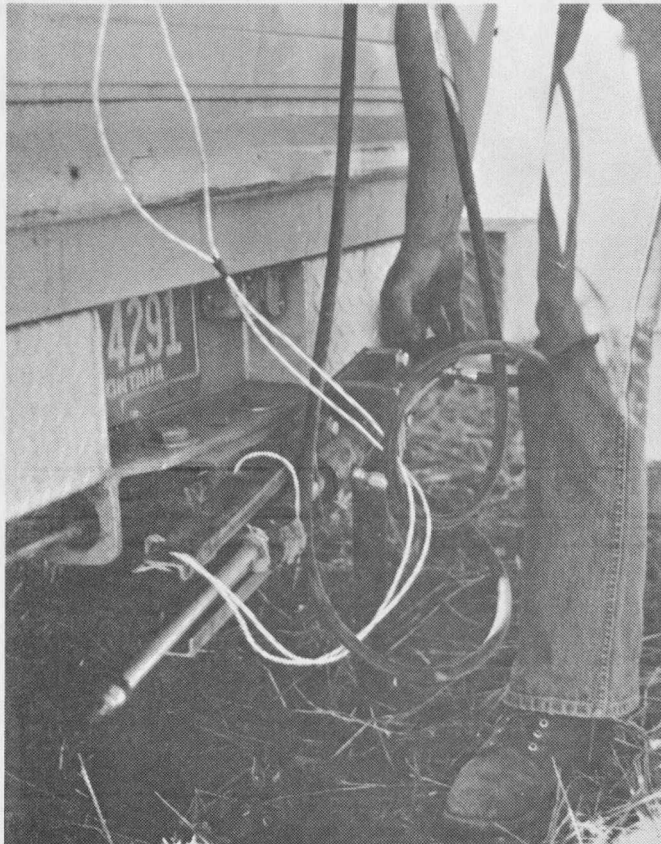


Figure 3.8. Penetrometer mounted on bumper, shown in traveling (horizontal) position

A strain gage ring transducer was used to measure the force on the cone. The recorder provided a reading of force versus time. The speed of extension of the cylinder was known, therefore, the depth of penetration was proportional to distance on the recorder chart. Data from the recorder was read as force versus depth.

Bumper jacks were installed on the pickup to ensure that the extension of the cylinder was the same as the soil penetration depth. The bumper jacks are shown in Figure 3.9. Without the bumper jacks supporting part of the weight of the pickup, the hydraulic cylinder could have

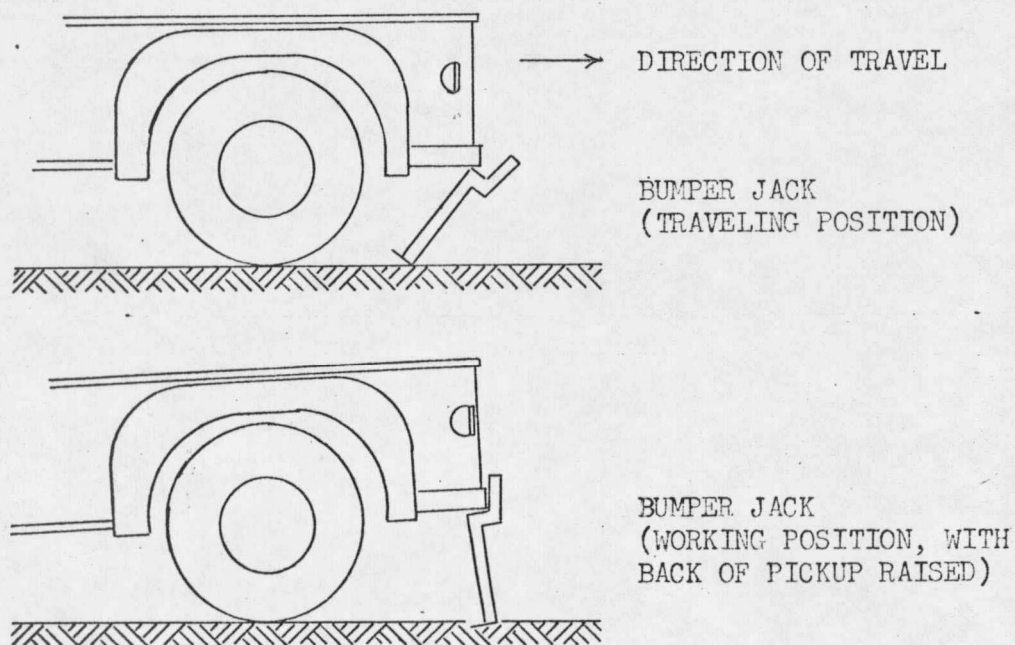


Figure 3.9. Bumper jacks used with penetrometer

provided enough force to lift the back of the pickup on the springs. If this occurred, the depth measurement would have been inaccurate.

The bumper jacks were clamped onto the bumper of the pickup. Driving the pickup forward raised the bumper onto the jacks. To travel between sites, the pickup was backed up, which automatically lowered the jacks. The jacks were allowed to drag as the pickup was backed to a new site.

The penetrometer was built to rotate about the bumper mount. While traveling between sites, the penetrometer was rotated to a horizontal position. It was held in a vertical position while readings were being taken.

A pressure relief valve prevented damage to the penetrometer by limiting cylinder force in case a rock was encountered.

The system described was used for all tests conducted during 1977 and 1978. A slightly revised version has been built for future use. The new unit is a free standing model, which will be more mobile than the bumper mounted unit. Figure 3.10 shows the new unit. The operator stands on the foot platforms while a reading is being made. The foot platforms are spaced widely to prevent the weight of the operator from compressing the soil which is to be tested.

In addition to speeding up the cone index measurements, the new unit will be able to take readings between the front and rear wheels of the tractors. This information will be useful in determining the difference

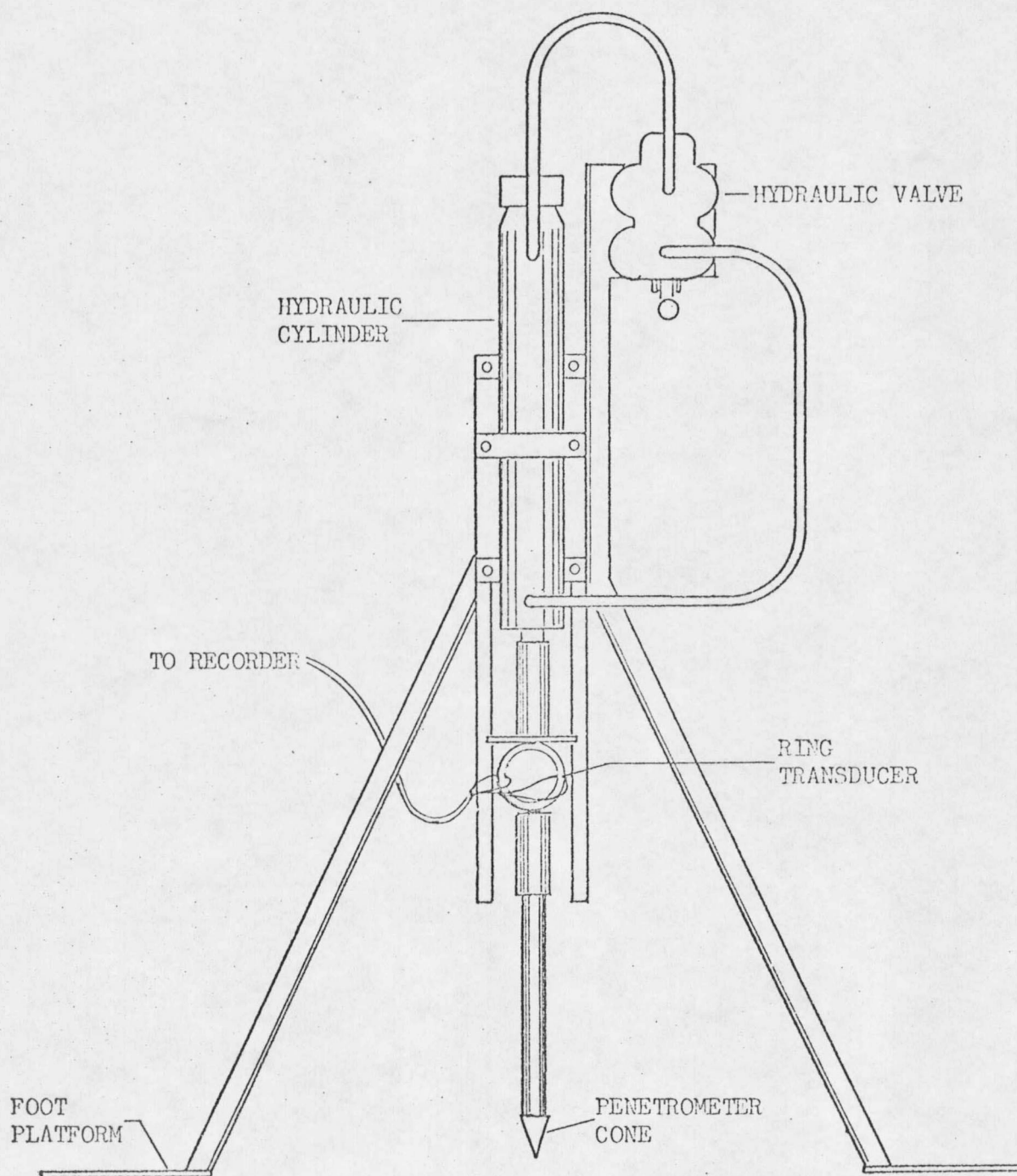


Figure 3.10. Revised, free-standing penetrometer

in strength of the soils "seen" by the front and rear wheels.

4. FIELD TESTS

TRACTOR SPEEDS AND LOADS

Field tests were conducted on a level area of the field to eliminate the effect grade might have on the tests. Slip and drawbar pull could be expected to vary depending on whether the travel was uphill or downhill. The runs were made back and forth over adjacent paths. If there were a grade, some of the runs would be on an uphill grade, while others were downhill. Comparison of the tests would be more difficult if the grade was included as a variable.

The field test for each tractor consisted of six runs. Each run extended over a time period of 120 to 150 seconds. The distance covered during this time at field speeds was in the range of 300 to 450 meters.

Sufficient time was allowed between runs to allow the tractor and implement to stabilize at the new condition. No stop was necessary between runs, as the start and end of each run could be clearly marked on the chart paper. Each run and each test was identified by a number placed on the chart paper.

The first run was made under no-load conditions to determine no-load wheel advance per revolution. This run was performed by travelling over the distance with the implement raised completely out of the ground. The no-load wheel advance per revolution was necessary as a basis for slip calculations for the other runs.

The second run was called the normal run. For this run, the tractor operator set the implement at the depth at which he usually worked.

The tractor was placed in the gear which the farmer considered his normal operating gear. This run provided data for comparing the actual tractor usage to the general recommendations described in Chapter 1.

All other runs were set up as variations from the normal run. All references to "normal speed" or "normal depth" refer to the tractor gear used and the implement depth used for the normal run.

The remaining four runs expanded the operating range around the farmer's normal operation by utilizing faster and slower speeds and greater and lesser drawbar loads. The high-speed run was one gear faster than normal and the low-speed run was one gear slower than normal. The implement was maintained at the normal operating depth for both runs. In several cases, the high-speed run was not possible as the next higher gear either overloaded the tractor or was too fast for field conditions. Information gathered from these two runs and the normal run gave indications of relative performance of the tractor at different speeds. It also indicated trends of drawbar pull and energy input to the soil as a function of speed.

Two runs with drawbar load greater and lesser than normal finished the test. These runs were performed by operating the tractor in the "normal" gear, while operating the implement at greater and shallower depths, respectively. These runs provided information on tractor performance under varied loading. In several cases, the greater load run could not be performed, as the implement was already set at its maximum

depth.

Approximately 45 minutes were usually required to install the test equipment on the tractor. Fifteen to twenty minutes were required to dismantle the system. This time loss did not seem objectionable to most of the farmers. Time spent during the actual test was not considered unproductive down time by the farmers, as they were performing a productive function.

Tractor and implement weights, and cone index of the soil, were determined as described in the chapter on equipment development. Five penetrometer readings were taken from each field, from which the average cone index was determined.

DATA ANALYSIS TECHNIQUES

Data gathered in the field was recorded on the strip chart as distance, time, number of wheel revolutions, and drawbar pull for each run. This data was used to calculate speed, drawbar power, slip, field capacity, pull/weight ratio, and loaded weight distribution.

Ground speed of the tractor, expressed as an average for the run, was determined by dividing the distance of the run, in meters, by the time of the run, in seconds. A conversion factor of 3.6 was used to convert the meters per second to kilometers per hour.

$$S' = (D \times 3.6) / T$$

[4.1]

where S' = speed, km/hr;

D = run distance, m; and

T = run time, s.

Drawbar power is the product of drawbar pull and the ground speed.

The basic equation for calculating the drawbar power is given by:

$$DBP = S' \frac{(\text{km})}{(\text{hr})} \times P(N) \times \frac{\text{hr}}{3600 \text{ s}} \quad [4.2]$$

where DBP = drawbar power, KW; and

P = drawbar pull, N.

Slip, which is more correctly termed travel reduction, is defined as follows:

$$S = \frac{\text{No-load advance per wheel revolution} - \text{Loaded advance per revolution}}{\text{No-load advance per wheel revolution}} \quad [1.1]$$

For these tests, the number of wheel revolutions for a given distance were known. If the same distance is used for both the no-load and loaded runs, the slip equation can be simplified to:

$$S = \frac{\text{Number of wheel revolutions, loaded} - \text{Number of wheel revolutions, no-load}}{\text{Number of wheel revolutions, loaded}} \quad [1.12]$$

The term loaded refers to the run for which slip is being measured, and no-load refers to the reference no-load, or zero slip, run. Run distance varied, so it was necessary to convert each run to an equivalent constant length. An arbitrary distance of 300 meters was used for all conversions.

The number of wheel revolutions per 300 meters was determined from the equation:

$$R' = (R \times 300)/D \quad [4.3]$$

where R' = wheel revolutions per 300 meters,

R = actual number of wheel revolutions for the run, and

D = run distance, m.

Field capacity, in hectares per hour, was calculated from the basic equation:

$$C = S' \frac{(\text{km})}{(\text{hr})} \times W' (\text{m}) \times \epsilon \times \frac{1000 \text{ m}}{\text{km}} \times \frac{\text{ha}}{10,000 \text{ m}^2} \quad [4.4]$$

where C = effective field capacity, ha/h;

S' = speed, km/h;

W' = implement width, m; and

ϵ = field efficiency.

The field efficiency term is a fraction which accounts for lost time, as for conducting maintenance work, and for overlap between successive passes. Theoretical field capacity is determined by setting field efficiency equal to one. Equation 4.4 reduces to:

$$C = S' \times W' \times \epsilon/10 \quad [4.5]$$

Energy input to the soil was expressed as the ratio of power to capacity. The units are kilowatt-hours per hectare. Energy input is

determined by the following equation:

$$E = \frac{DBP (S' \times P/3600)}{C (S' \times P/10)} \quad [4.6]$$

where E = energy input to the soil, KW-h/ha; and

S', W', P as previously defined.

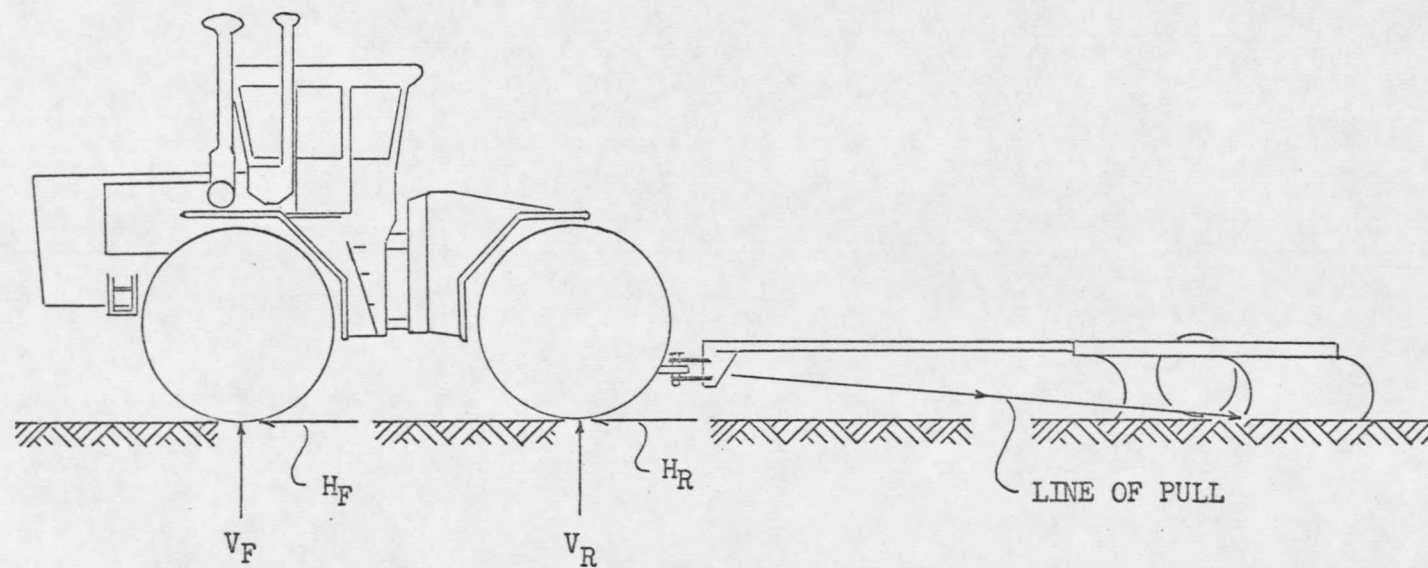
Because the speed terms cancel, energy input to the soil reduces to the following equation:

$$E = \frac{P}{360 W'} \quad [4.7]$$

which shows that energy input to the soil is proportional to the unit draft of the implement.

Coefficient of net traction is a dimensionless term used to show what portion of the tractor weight is being converted into effective drawbar pull. It is determined by dividing the drawbar pull by the total dynamic support force on the tractor. The dynamic support force on the tractor is the static support force plus the downward component of force which the toolbar exerts on the drawbar. Figure 4.1 illustrates this effect. Assuming the pullmeter is a free link between the tractor and implement, the measured pull is the force in the direction of the line of pull. The downward component at the drawbar is given by:

$$P_y = P \sin \alpha \quad [4.8]$$



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Figure 4.1. External forces acting on a four wheel drive tractor during tillage operations

where P = drawbar pull, N;

P_y = vertical component of the drawbar pull, N; and

α = the angle of the line of pull, positive downward from the horizontal.

In all cases, the angle of the line of pull from the horizontal was between four and six degrees. At the extreme case of α equals six degrees, the vertical component of the drawbar pull was ten percent of the drawbar pull. Assuming a coefficient of net traction of 0.3, the vertical component contributes three percent to the total tractor dynamic support force.

For calculations concerning the coefficient of net traction, the horizontal component of drawbar pull is required. Again assuming the extreme of six degrees for the angle α , the horizontal component of pull is within one half percent of the pull measured by the pull meter. The pull meter reading can therefore be used for calculating the coefficient of net traction while remaining within the accuracy limits of the equipment.

Loaded weight distribution was determined by calculating the wheel reaction forces, V_F and V_R , as shown in Figure 4.1. The vertical and horizontal components of drawbar pull both tend to increase the load carried by the rear wheels, and decrease the load on the front wheels. The reaction at the rear wheels was determined by summing moments about the area of contact of the front wheels. Similarly, summing moments

about the area of contact of the rear wheels was used to determine the load on the front wheels. As previously noted, this method, according to Smith, et. al. (13), is not an exact method of determining loaded weight distribution. However, for this project, the approximation was considered satisfactory.

The ratio of loaded engine rpm to the no-load engine rpm at the given throttle setting was used as an indicator of engine loading. The engine rpm during the run was recorded as the loaded rpm. After the run was completed, the operator depressed the clutch pedal of the tractor. This high idle engine speed, at the same throttle setting, was recorded as the no-load engine rpm.

The cone index value which was used to represent the soil condition was determined as follows. The depth of the hardpan or tillage layer could be determined by inspecting the force-depth curve. Values of the force at each 2.5 centimeters of depth were averaged, to a depth corresponding to the depth of the hardpan. The average of the values at each 2.5 centimeter increment of depth for each of the five curves for a given field was then divided by the area of the base of the cone (1.29 centimeters squared in all cases). This was the value used as the cone index for that field.

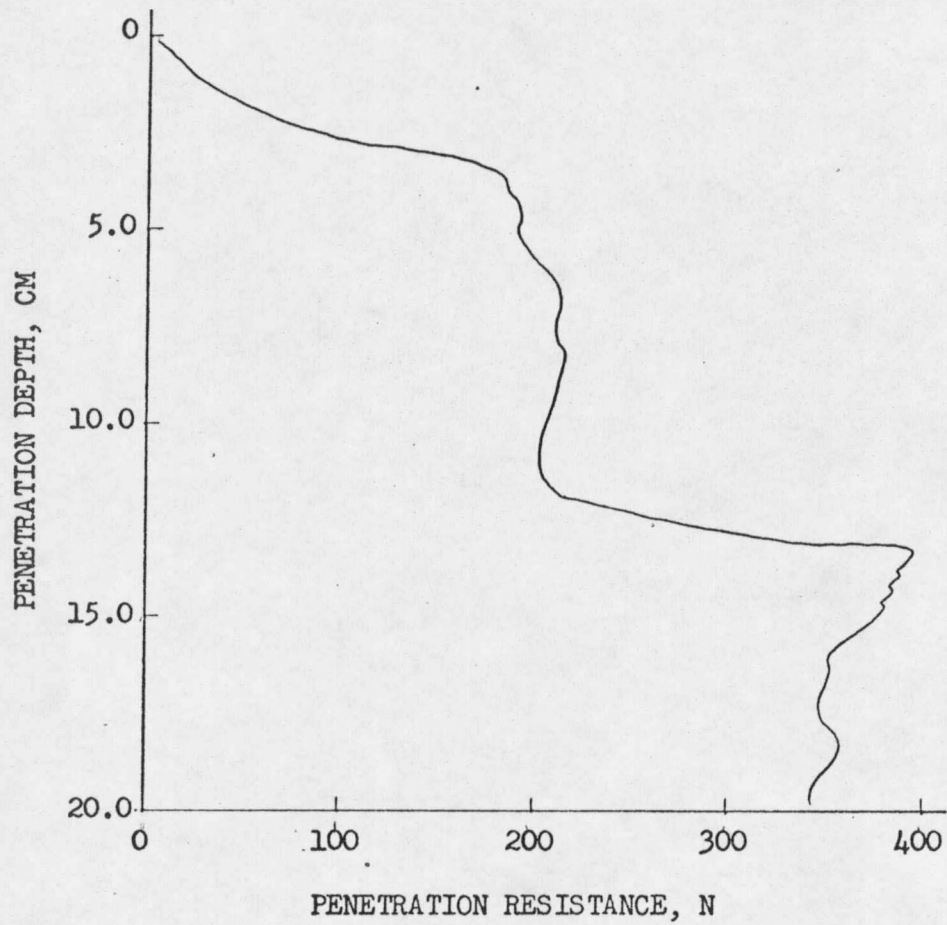


Figure 4.2. Typical recorder output for penetrometer

5. COOPERATOR INTERVIEWS

An interview was conducted with each cooperator. Information was gathered concerning how he operates his tractor. Questions were also asked to determine features he liked or disliked about his tractor, and features he would like to see on tractors he purchased in the future.

Annual use of the tractors varied from 330 to 1500 hours per year. In general, the larger farms reported the greater annual tractor use. There were three tractors with an annual use in excess of 1000 hours. These three tractors were on the two largest farms.

All the tractors involved in this research were used primarily for summer fallow work. Secondary uses were operating discs, drills, mold-board plows, and snow plows. Smaller farming operations, where the tractor tested was the only large horsepower tractor on the farm, used the tractor in a variety of operations. Larger farms were able to concentrate the use of the tractor on one implement, using other tractors for the other field work.

Six of the tractors were equipped with frames to which a dozer blade could be attached. Snow plowing was the primary purpose of the dozers, although some tractors were used for light grading work.

Increased power and increased traction were the two most common reasons cited for purchasing the 4WD units. These reasons were expressed in every case. Labor savings was another common reason. Updating the farming operation was cited as a reason in several cases.

In most cases, the 4WD units replaced one or two two-wheel drive units. Two operators were adding extra equipment, without replacing any older tractors. One cooperator replaced three 4WD's with two larger 4WD tractors. In most cases, an increase in the total power available to the farmer occurred as a result of the purchase.

Very few of the tractors were equipped with power take-off units, and none with three point hitches. Two of the tractors had power take-offs, although neither of them were used. Five farmers expressed a desire for a power take-off on a future tractor. These would be used with large corn choppers or tub grinders. One farmer wanted a power take-off solely to increase the resale value of the tractor. Two farmers expressed a desire for a three point hitch on a future 4WD tractor. Several other farmers indicated they might want one if there were equipment available to match the power of the tractor.

Farmers indicated that future tractors in most cases will be more powerful tractors. Eight farmers said they would increase the power rating when buying a new tractor. Five farmers said they would purchase another tractor of approximately the same size when this tractor was replaced. The remainder of the farmers were undecided. Use of the future tractor would be the same, plus operation of power take-off operated equipment by some of the farmers.

Methods of operation of the tractor was somewhat varied. Nine of the farmers started tillage operations with the toolbar in the ground,

while eight started with the toolbar out of the ground, and lowered it after the engine had reached operating speed. All except three of the farmers started the loads at full throttle. One farmer performed the turns with the toolbar out of the ground, while the rest remained loaded during turns. Most turned at full speed, although six farmers reduced speed on turns.

6. RESULTS AND DISCUSSION

DATA NORMALIZATION

During each test, one run was conducted under the conditions of speed and load which the tractor operator considered his normal operating conditions. This was called the normal run. The remainder of the test consisted of runs conducted under conditions which varied a small amount from the normal operating conditions. For these runs, one variable (tractor speed or implement depth) was changed and all other variables were held as constant as possible. These runs provided information on how variation from the normal operating conditions affected performance.

Direct comparison between tractors must be done with care, due to extreme variations between fields, sizes of tractors and implements, and tractor operators. It was possible to directly compare the data from the six runs of each individual test. These six runs were all conducted under the same field conditions, with the same tractor and implement, and with the same tractor operator.

Normalized data provides one means of comparing the data from the various tests. Data from the normal runs were used as a basis for data normalization and were designated the 100 percent value. Other data was normalized by expressing it as a percentage of the normal run data.

Most variable interactions are cancelled when normalizing data since all but one of the independent variables remain the same between the test runs. The effect of a single independent variable on an inde-

pendent variable may be determined.

Variation between field or test sites may be quite extreme. Soil types, moisture levels and equipment all vary. A normal run measurement is only typical of that particular situation. For this reason, normalizing data is not an exact method for comparing between test, and any mathematical function which may be derived would probably be marginally accurate. For example, a ten percent increase in draft may occur with a twenty percent increase in speed in some conditions. In other conditions, a twenty percent increase in speed may not show an increase in draft.

A reason for using normalized data is that trends in the data may be determined. Relationships between independent and dependent variables can be observed over the operating ranges used for testing.

NORMAL PERFORMANCE

The data presented in this section describes tractor and implement performance for the normal runs. These are the field speeds and tool depths which the farmers were using during their normal day-to-day operation.

Normal field speeds ranged from 6.1 to 9.8 kilometers per hour. Most of the tractors were being operated at speeds below eight kilometers per hour. Average speed for all tractors tested was 6.9 kilometers per hour.

Normal drawbar pull varied from 17.8 to 97.8 kilo-newtons. Drawbar

power ranged from a minimum of 45.3 kilowatts to a maximum of 311.8 kilowatts. The highest drawbar power was being produced by the largest tractor. The lowest drawbar power, however, was not associated with the smallest tractor.

Draft on the tillage tools ranged from 2.09 to 6.06 kilo-newtons per meter of implement width. Shallow tillage with sweeps in most cases required approximately 3 kilo-newtons per meter of implement width. Draft per sweep was approximately 890 newtons, with sweeps spaced on 0.30 meter centers.

Energy input to the soil varied from 6.0 to 18.2 kilowatt-hours per hectare. The average was 9.9 kilowatt-hours per hectare. This measurement was based on the effective width of the implement rather than the full width. The effective width is the full implement width minus the overlap of successive passes. Using the effective width results in an average value for the field.

Theoretical field capacity (no allowance for overlap of successive passes or lost time) of the tractor-implement units ranged from a low of 4.90 to a high of 12.58 hectares per hour.

Slip varied from negligible slip in two cases to a maximum of 24.9 percent. Average slip for the tractors tested was 7.3 percent.

EFFECT OF SPEED ON PULL

Sial and Harrison (11), among others, have shown that the pull

which must be developed at the drawbar will increase with speed if other factors remain constant. This effect is thought to be partially due to an increase in forces necessary to accelerate the soil in an upward direction. This lifting action is due to the lift on the blade of the sweep.

Data from the tractors tested in the study are presented in Figure 6.1 and Table 6.1. The data in some cases follows the expected trend of increased pull with increased speed. In other cases, there is extreme variation from the expected trend.

Figure 6.1 shows the data from 14 tractors tested. The results are shown on four graphs according to the speed of the normal run. The tests were arbitrarily grouped on the graphs, with an arbitrary limit of four tests on each graph. The limit was chosen for ease and clarity of presentation. The speed range for the normal runs of the tests on each graph is indicated on each graph. The data normalization procedure dictates that, for each test, the normal run is designated by the point (100,100). Two of the tests (32-611 on Figure 6.1 (a) and 3-111 on Figure 6.1 (d)) have no point for the high-speed run. These tractors could not be operated in a gear higher than the normal operating gear.

The data for the high-speed and low-speed runs are also shown in Table 6.1. The runs are listed in order by increasing percentages of the normal speed. This will give increments of deviation from the normal speed and not necessarily similar changes in actual speed. The "H"

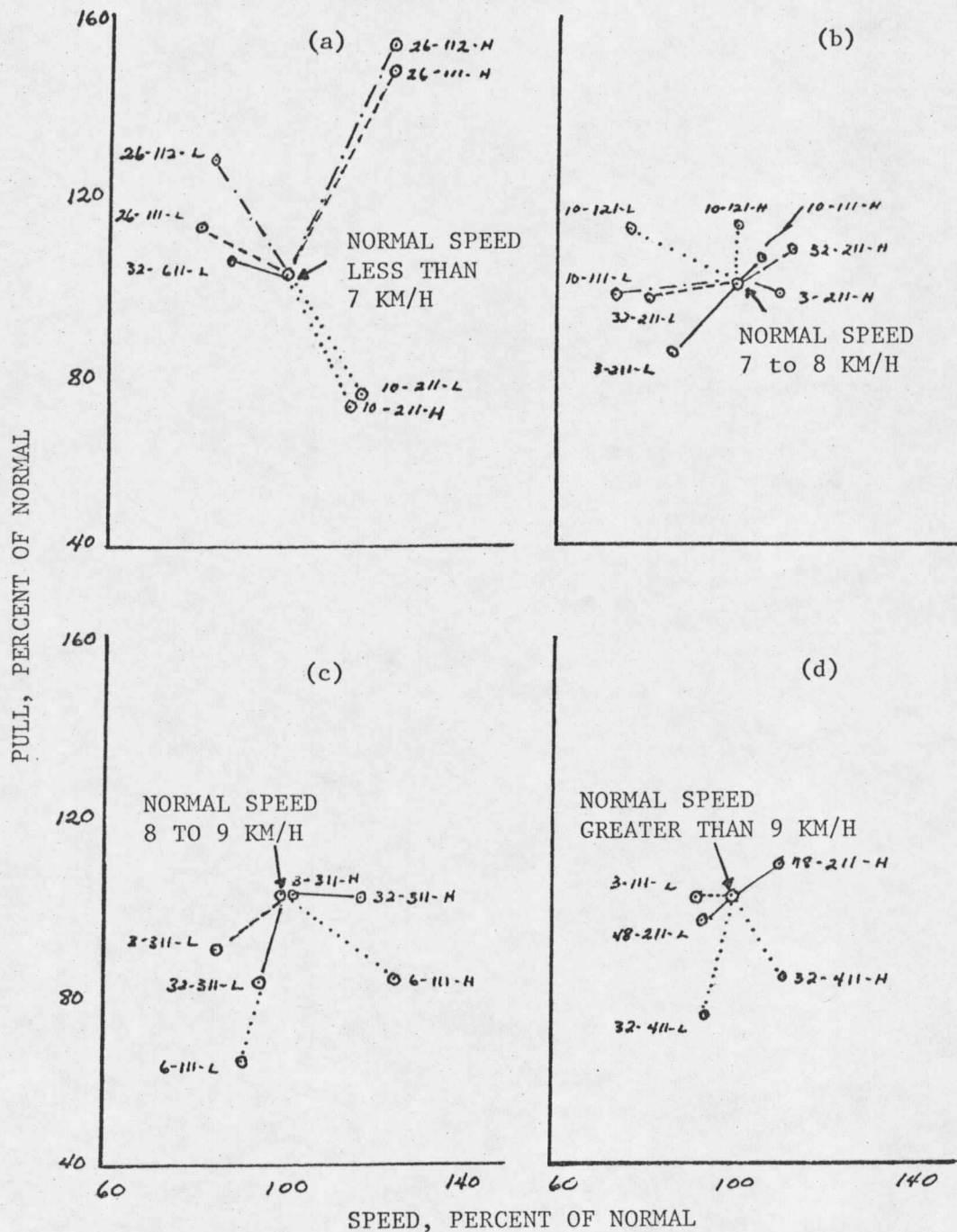


Figure 6.1. Effect of speed on draft, normalized data
 Numbers refer to the code number of the given test. "H" refers to high-speed run. "L" refers to low-speed run.

TABLE 6.1

PULL AND ENERGY INPUT TO THE SOIL VERSES SPEED, NORMALIZED DATA

CODE #	SPEED % NORMAL	PULL % NORMAL	ENERGY % NORMAL
10-111-L	73.6	97.7	EXACTLY EQUAL TO PULL, % OF NORMAL
10-121-L	77.3	112.8	
32-211-L	80.2	96.7	
26-111-L	81.3	113.0	
26-112-L	84.0	125.0	
3-311-L	85.1	88.2	
3-211-L	86.1	84.3	
32-611-L	86.3	104.3	
6-111-L	90.4	61.5	
3-111-L	92.3	100.0	
32-411-L	93.1	73.5	
32-311-L	94.0	81.3	
48-211-L	95.0	95.2	
10-121-H	100.0	112.8	
3-311-H	101.6	100.0	
10-111-H	105.8	106.8	
3-211-H	109.4	97.1	
48-211-H	110.3	107.1	
32-411-H	111.6	82.4	
32-211-H	112.2	108.3	
10-211-H	114.0	70.8	
10-211-L	116.6	72.9	
32-311-H	119.3	100.0	
26-112-H	122.9	153.6	
26-111-H	123.2	147.8	
6-111-H	124.3	82.1	

or "L" after the code number refers to high-speed or low-speed runs. The relatively fast speed of the low-speed run, 10-211-L, was probably due to the closeness of the gear ratios in the transmission of the tractor. Operation in a gear very close to the normal gear, combined with less slip, could account for an increase in speed in a lower gear. The slip for the low-speed run was 13.2 percent compared to 24.9 percent slip for the normal run.

Scattering of the data may in part be due to variations in tillage depth. The vertical forces on the tillage tool may be large enough to raise the implement and reduce tillage depth at the higher speeds. This would account for reduced drawbar pull at higher speeds. No measurement of the depth of tillage was made during the test, except for visual observation. Due to the usual dusty conditions, and the unevenness of the soil surface, small variations in the tool depth could easily have gone unnoticed.

Increased draft, relative to the normal, at any speed may be caused by a slightly increased tillage depth. The farmers in many cases are operating the tillage tools very near to a hardpan layer in the soil. An increase in tillage depth of a centimeter or less may cause the tool to enter the hardpan layer. A significant increase in draft could then occur. A change in tillage depth may occur due to the operator's depth adjustment or speed change.

Additional data may help to establish definite trends for the data. Additional speed ranges may also be needed to show valid relationships between speed and pull. In some cases there may be no valid relationship between speed and pull.

The effect of speed on pull per meter of width is shown graphically in Figure 6.2. This data is from runs which were all made at a ten centimeter tillage depth. The soil characteristics are indicated by a cone index number for each point on the graph. The total data is very scattered but the data for a particular soil, as indicated by cone index, generally shows an increase in unit draft with increase speed.

Another trend which appears in Figure 6.2 seems to relate higher speeds with soils having higher cone index values. Perhaps the farmers are operating at higher speeds on the harder soils. This may be related to better traction on harder soils but no definite relationship was observed.

ENERGY INPUT TO THE SOIL

Most tractors involved in this study were observed to be operating at ground speeds below eight kilometers per hour. This is a speed recommended by Bowers (6) as the low end of the operating range for high horsepower wheel tractors. The slow speeds were in most cases associated with light engine loadings, which generally result in poor fuel use. Higher fuel use efficiency would be expected if the tractors were opera-

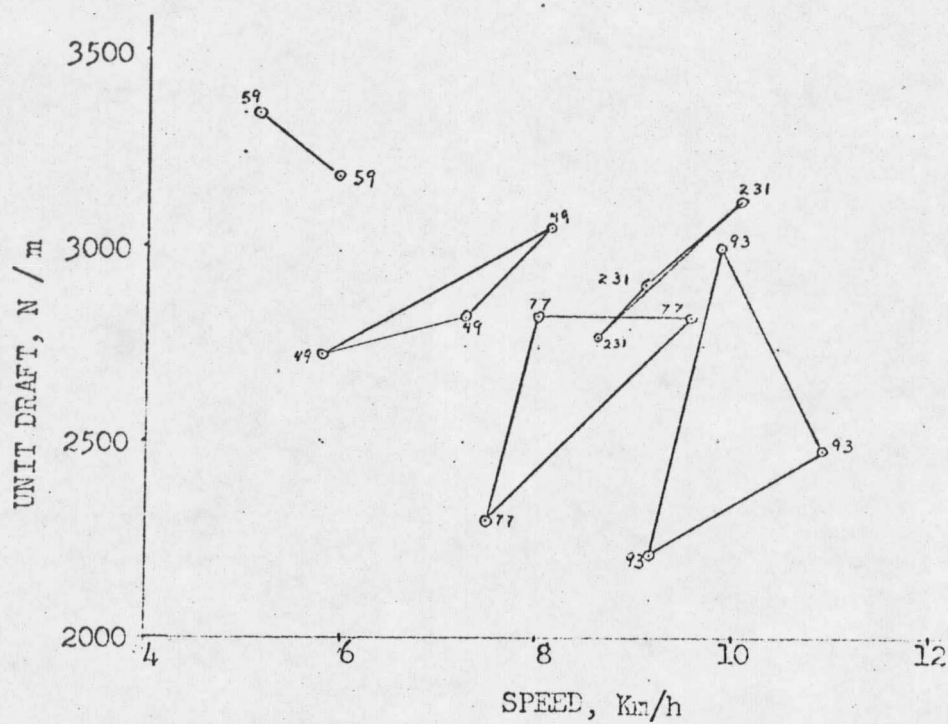


Figure 6.2. Draft per meter of implement width verses speed, all data at 10 centimeter tillage depth. Numbers refer to CI of soil where test was run.

ted at higher speeds, due to increased capacity and more efficient fuel conversion by the engine. Care must be taken to avoid overloading, however.

Higher speeds may be more efficient for the tractor but could cause excessive soil pulverization. Soil structure deterioration may result from operating at high field speeds due to increased energy input to the soil. Energy input to the soil, measured in kilowatt-hours per hectare, is independent of machine speed unless the drawbar pull changes with speed. It is directly proportional to the unit draft of the implement, as shown in the section on Data Analysis. Therefore, energy input to the soil may be obtained independently of a power test.

In several cases, there was a significant increase in energy input to the soil with an increase in speed. The increased energy demand in such a case may negate any fuel savings obtained from more efficient engine loading at the higher speed. With other tractors, however, there was a significant decrease in energy demand at the higher speed. This occurrence is counter-intuitive. Further research is necessary before such data can be fully understood.

The average of the normalized data indicate there is an increase in energy input to the soil with increased speed. The runs with speeds less than the normal speed averaged a speed of 86.05 percent of the normal speed, with energy input of 94.88 percent of the energy input of the normal run. The average of the runs which were faster than the

normal runs was 113.17 percent of the normal speed, with energy input to the soil averaging 103.28 percent of the energy input of the normal run. These averages were determined from the data presented in Table 6.1.

COEFFICIENT OF NET TRACTION

The coefficient of net traction is the ratio of the force which the tractor is developing in a forward direction at the drawbar to the force necessary to support the dynamic weight of the tractor. This ratio is useful in comparing the performance of tractors of different weights. If drawbar pull and the tractor support force are in the same units, the ratio is dimensionless. The coefficient of net traction is called the pull/weight ratio by Wismer and Luth (17).

The coefficient of net traction for the tractors tested ranged from 0.217 to 0.414 for the farmers' normal operations. The average for all the tractors was 0.304.

Unit draft for the implements tested averaged 3 kilo-newtons per meter of implement width. The tractors apparently are operating with an average dynamic tractor support force of 10 kilo-newtons per meter of implement width to yield an average coefficient of net traction of 0.30.

EFFECT OF SLIP ON THE COEFFICIENT OF NET TRACTION

The coefficient of net traction and the slip experienced by the tractor are interrelated and dependent on soil properties. The pressure of the tire against the soil surface also enters into the relation.

Wismer and Luth (17) developed the following equation for predicting the coefficient of net traction for a given slip and soil wheel numeric:

$$\frac{P}{W} = 0.75[1 - e^{(-0.3 C_n S)}] - [\frac{1.2}{C_n} + 0.04] \quad [1.7]$$

This equation is plotted in Figure 6.3 for various values of the wheel numeric, C_n . This data was developed for two-wheel drive tractors. The figure indicates that, for two-wheel drive tractors, the coefficient of net traction will never exceed 0.71. This limit may not apply to four-wheel drive tractors, due in part to the increase pull associated with four-wheel traction.

Figures 6.4, 6.5, and 6.6 compare Equation [1.7] to the data from the work being reported. The wheel numeric varies from 10 to 25, 25 to 50, and 50 to 100, respectively, for each figure. The general trend of the data follows the prediction values fairly well. There is quite a variation for individual values.

An interesting trend shows up when comparing Figures 6.4, 6.5, and 6.6. At the lower range of wheel numeric, Figure 6.4 (generally softer soils), the data shows a consistently lower slip for four-wheel drive tractors for given values of the coefficient of net traction. In Figure 6.5, the data is fairly well centered on the range bounded by the prediction equations. Slip for a given coefficient of net traction is consis-

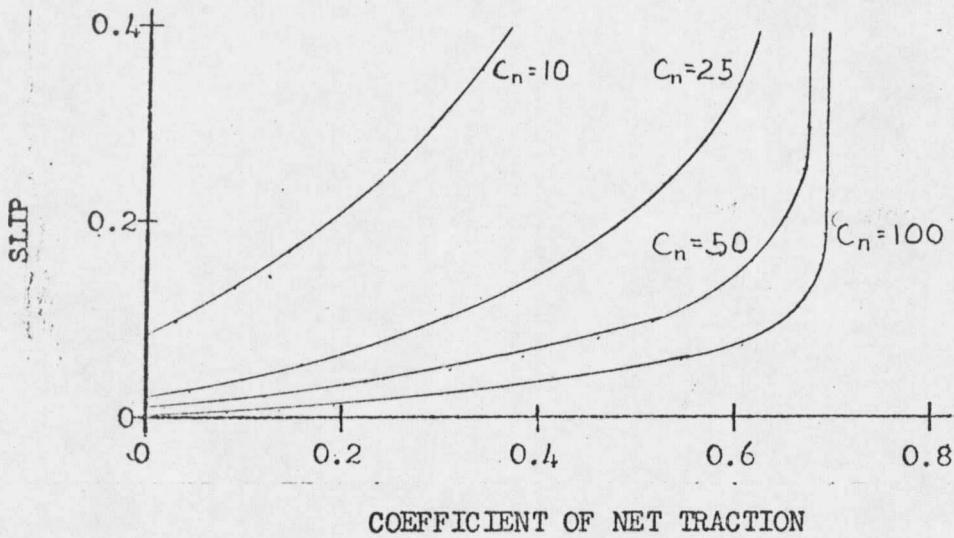


Figure 6.3. Wismer and Luth prediction equation plotted for various values of the wheel numeric

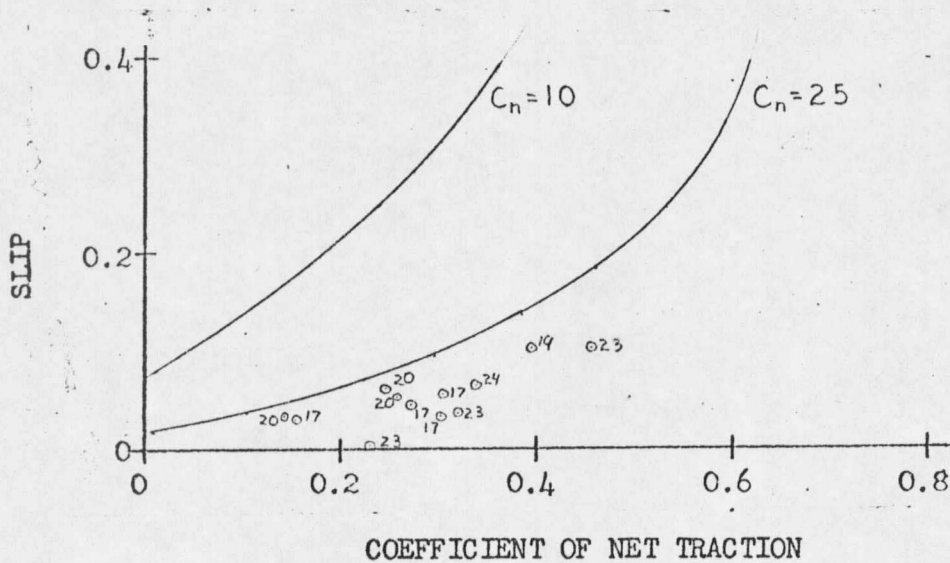


Figure 6.4. Test data compared to Wismer and Luth prediction equation for C_n from 10 to 25

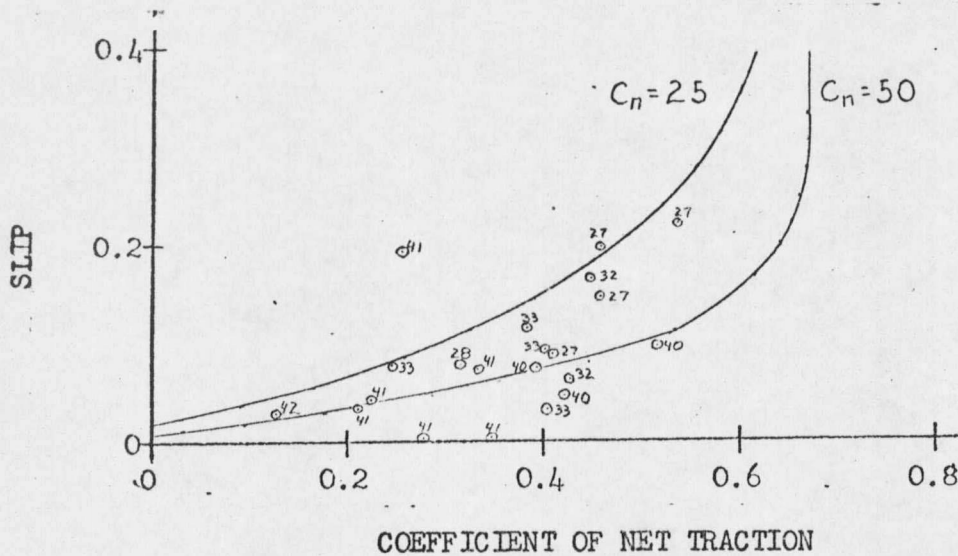


Figure 6.5. Test data compared to Wismer and Luth prediction equation for C_n from 25 to 50.

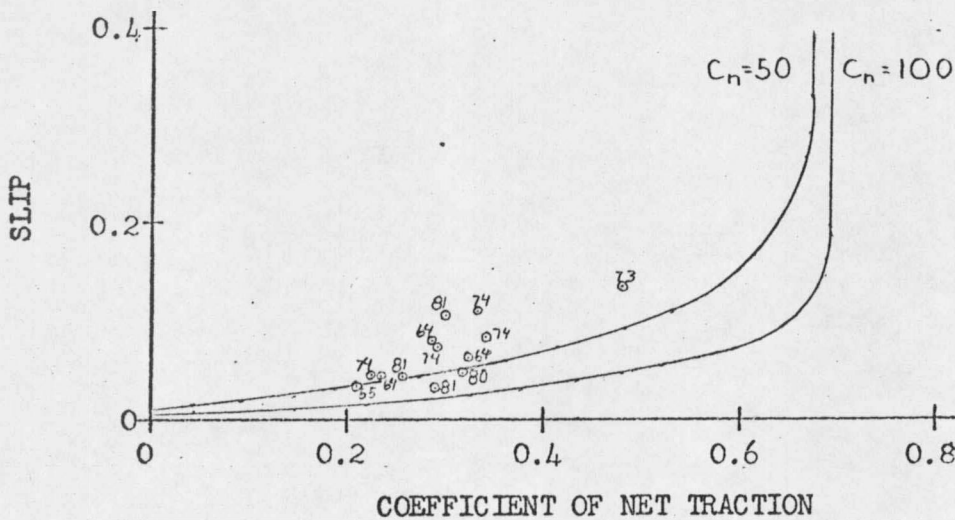


Figure 6.6. Test data compared to Wismer and Luth prediction equation for C_n from 50 to 100

tently higher with the higher range of wheel numeric, which corresponds to the harder soils.

An expected trend would be to have lower slip for the 4WD tractors than a two-wheel drive tractor, at a given coefficient of net traction and wheel numeric. This would be due to the tandem effect. The front wheel tracks of a 4WD tractor provides a much firmer surface for the rear traction wheels, contributing to a lower slip.

The data presented in Figure 6.4 follows the expected trend of less slip than the prediction equation. Variation from the trend in Figure 6.6 may be due to the brittleness of the soil. A harder, more brittle soil may not increase in strength, or may even weaken somewhat, when a loaded tire is driven over it.

An adjustment of Equation [1.7] for 4WD tractors may be accomplished as follows. The wheel numeric is determined by the tractor support force, tire dimensions, and cone index. The cone index used in calculating wheel numeric for Figures 6.3 to 6.6 was for undisturbed soil condition. However, the rear wheels experience a more compacted soil because they follow in the track of the front wheels. For improved accuracy, the cone index of the soil in the track immediately behind the front wheels should be determined. A wheel numeric for the entire tractor would be easy to calculate from a weighted average of the front and rear wheel numerics. The dynamic weights on front and rear axles would be the basis for the weighted average.

With the data available, wheel numeric can be calculated in two ways. The total dynamic tractor support force was used with tire dimensions from all eight tires (four tires for tractors equipped with singles) to determine the "total wheel numeric." The "front axle wheel numeric" was determined by using the dynamic support force on the front wheels only, combined with the tire dimensions of the front wheels. The front axle wheel numeric would correspond to the wheel numeric of a two-wheel drive tractor on the soil. On the average, the front axle wheel numeric was within one percent of the total wheel numeric, although variations of up to ten percent were encountered. The variations were due to the different weight distributions which the tractors experienced under the various loadings.

Another method of adjusting Wismer and Luth's equation for application to 4WD tractors is to look at the effect that slip has on the soil. Slip within the soil is the strain element of a stress strain loading cycle. It is necessary to have slip to create the soil resistance to thrust. The greater the slip, prior to soil failure, the greater the soil's resistance to thrust. The soil strain can be measured by the soil deformation. If the soil deformation is considered plastic deformation, then the soil will not recover from this deformation after the first tire has passed. Two tires traveling in the same track, each with the same slip per tire, would create twice the soil deformation as a single tire with the same slip.

The effect of slip of a 4WD tractor can be accounted for in Wismer and Luth's equation by modification of the coefficient, $(-0.3 C_n S)$, in the exponential term. The first tire travels over soil which has not been deformed. The equation developed by Wismer and Luth applies to this condition. The second tire, however, travels over soil which has been previously deformed. Because the rear tire has the same slip as the front tire, it will deform the soil by the same amount as the front tire. The soil deformation after the second tire has passed will be twice the deformation caused by the first tire. The rear tire is effectively operating as if it had twice as much slip as it actually has. This effect can be accounted for in Equation [1.7] by doubling the coefficient, -0.3 , the exponent of e . The equation which would be appropriate for the rear tire is:

$$\frac{P}{W} = 0.75(1 - e^{(-0.6 C_n S)}) - \left(\frac{1.2}{C_n} + 0.04\right) \quad [6.1]$$

An average of Equation [1.7] as developed by Wismer and Luth, and Equation [6.1] would result in an equation which would take into account effects of both front and rear tires. This equation is:

$$\frac{P}{W} = 0.375[2 - e^{(-0.3 C_n S)} - e^{(-0.6 C_n S)}] - \left(\frac{1.2}{C_n} + 0.04\right) \quad [6.2]$$

Figure 6.7 shows a comparison between the curves for the original prediction equation and the modified prediction equation, Equation [6.2], for wheel numerics of 10 and 25. As expected, the curves are shifted to

a lower slip for a given coefficient of net traction.

Figures 6.8, 6.9, and 6.10 show the test data compared to the modified prediction equation. The wheel numeric for each data point is given. On softer soils, with wheel numerics from 10 to 25, as shown in Figure 6.8, the modified equation fits the data more closely than the original equation. Figure 6.9 shows the test data compared to the modified equation for the medium strength soils, with wheel numerics of 25 to 50. The data fits this curve slightly better than the original prediction equation as shown in Figure 6.5. On the harder soils, with wheel numerics of 50 to 100, the modified equation follows the data less closely than the original equation. Neither equation fits the data well for these soils. As with the original equation, this may be due to the brittleness of the soil. The equation may not be valid for the harder soils. However, for the softer soils, the modified equation appears to be a better prediction equation for 4WD tractors than the original equation.

POWER UTILIZATION

The efficiency of power utilization was determined by comparing the actual drawbar power to an estimated power that should be available at the drawbar. When possible, the maximum drawbar power from the Nebraska Tractor Test was used as the basis for the comparison. If no Nebraska Tractor Test was available, maximum engine power was used as the basis

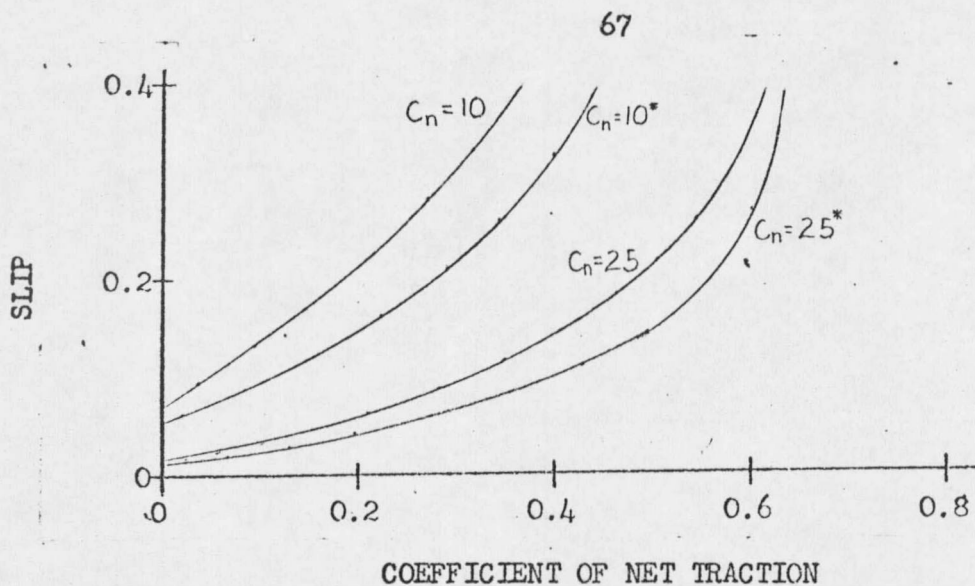


Figure 6.7. Wismer and Luth prediction equation compared to modified prediction equation for C_n equal to 10 and 25. Modified equation designated by an * by the wheel numeric

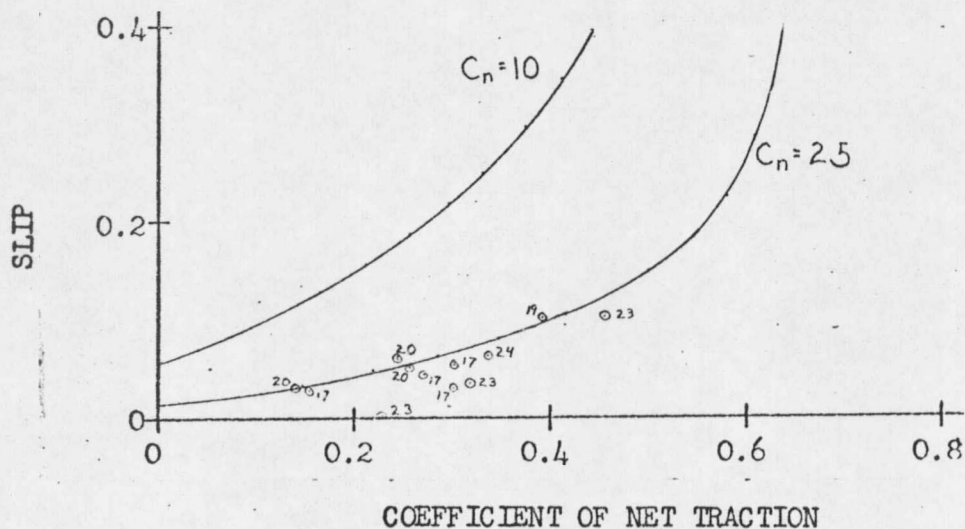


Figure 6.8. Test data compared to modified prediction equation for C_n from 10 to 25

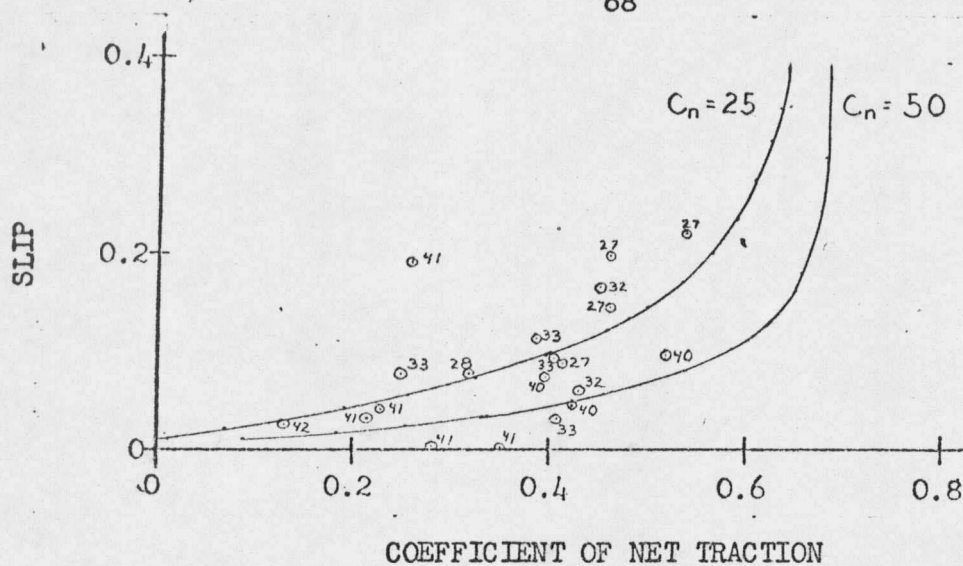


Figure 6.9. Test data compared to modified prediction equation for C_n from 25 to 50

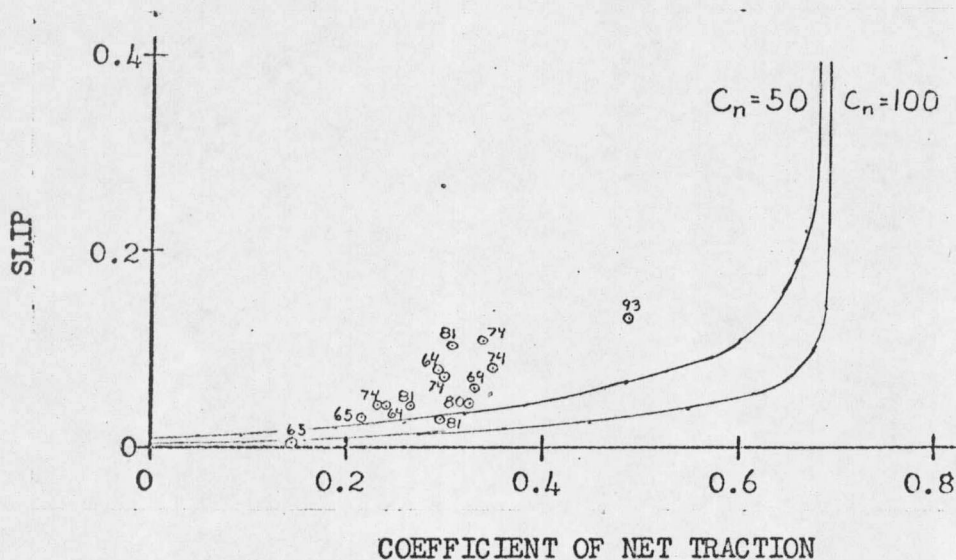


Figure 6.10. Test data compared to modified prediction equation for C_n from 50 to 100

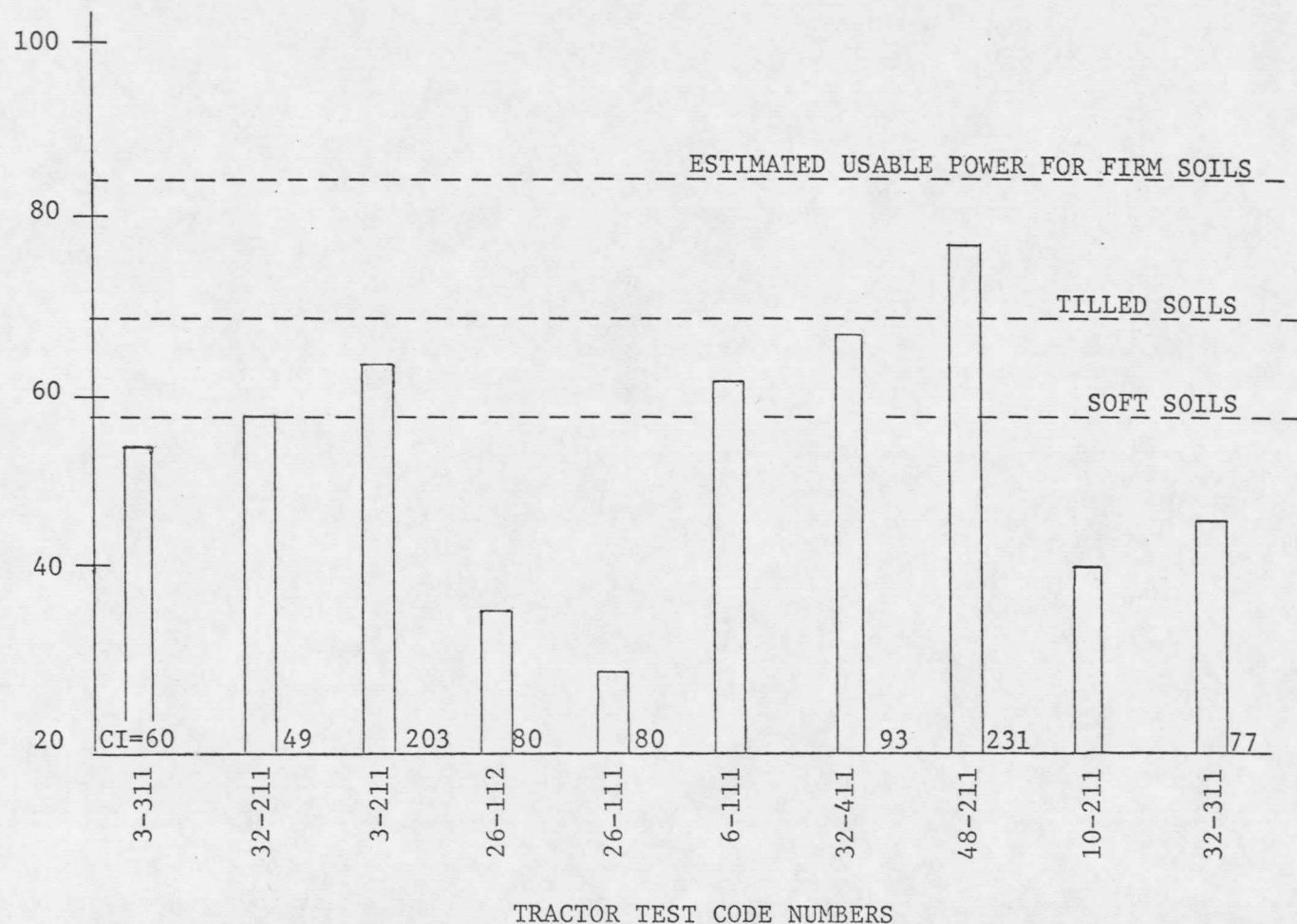
for the comparison.

Figure 6.11 shows the measured values of drawbar power as ratios of the measured value to the maximum drawbar power from the Nebraska Tractor Test for the particular tractor. The data is arranged according to continuous engine power ratings, in increasing order from left to right. The estimated usable power for various soil conditions, according to Larsen's (10) method based on percentages of the maximum drawbar power from the Nebraska Tractor Test, are indicated on the figure for comparison. Cone index for the soils is also indicated. Cone index was not available for two tests.

The four tractors for which Nebraska Tractor Tests were not available are shown in Figure 6.12. The measured values for these tractors are shown as ratios of the measured values to the maximum engine power rating. The estimated usable power for various soil conditions, according to methods developed by Bowers (6), are indicated on the figure. Cone index of the soils is also indicated. Cone index for one test was not available.

The data from Figures 6.11 and 6.12 show that, in general, the tractors are being under-utilized. Most of the tractors would realize higher fuel efficiencies and greater capacity if they were operated at higher speeds or with wider implements.

PERCENT OF MAXIMUM DRAWBAR POWER FROM NEBRASKA TRACTOR TESTS



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Figure 6.11. Measured drawbar power compared to estimated usable power, based on maximum drawbar power from Nebraska Tractor Tests.

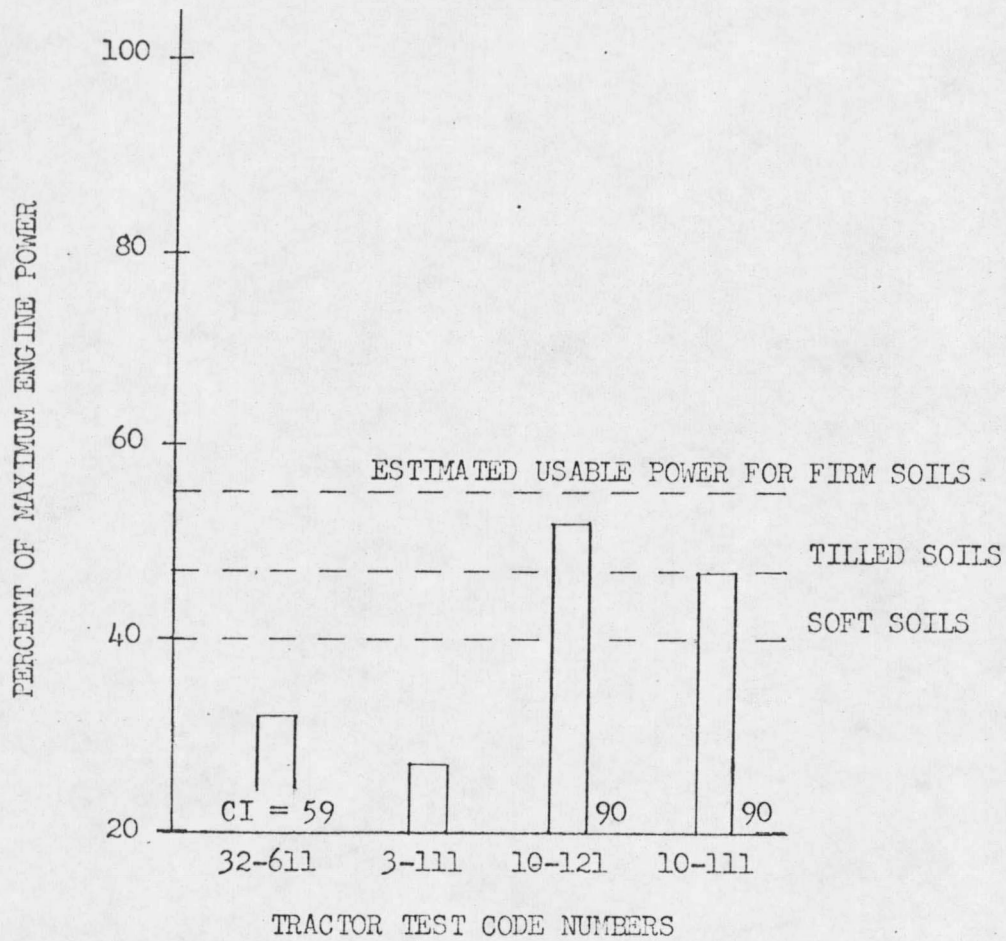


Figure 6.12. Measured drawbar power compared to estimated usable power, based on maximum engine power.

7. RECOMMENDATIONS FOR FUTURE WORK

Further work is necessary to expand on the findings of this research. More data may define the trends better, which would improve confidence in the conclusions. The range of the data may also be increased as more tractors are tested. Data from tractors being operated at high speeds and high slips may help to define the trends.

The testing equipment and procedure has been well refined in the two seasons of work. Use of the new penetrometer unit should speed up that part of the test. The recorder should be kept dust free by either placing it in the cab of the tractor and closing the doors, or wrapping it in plastic. Some means of further protecting the strain gages on the transducers would be helpful. The gages on the ends of the transducers are particularly susceptible to damage. It would also be advisable to carry a spare transducer.

Accuracy of the slip measurements may be improved if the location of the land measuring wheel is changed. In its present location, the wheel rolls over untilled ground during the no-load run, and is rolling over tilled ground during the remainder of the test. Placing the wheel on the implement in front of the tillage tools would ensure that the wheel rolls on untilled ground for all the runs. Any possible variation due to changes in the ground surface would be eliminated.

8. CONCLUSION

Research conducted on four-wheel drive tractors in Montana during the summers of 1977 and 1978 indicate that many of the farmers are operating with larger tractors than they need. In almost all cases, the drawbar power during normal operation is less than the estimated available power under the given conditions.

Farmers are also operating their tractors at relatively low speeds. Most of the cooperators were operating in the five to eight kilometer per hour range, as opposed to the eight to ten kilometer per hour range which has been suggested (6). Increasing the speed would increase the drawbar power, helping the tractors to operate more efficiently. Tractor life would not suffer, as torques on the drive train would presumably remain fairly constant. Life of the implements may be decreased, however.

Interviews with the farmers indicate that, in general, they do not desire power take-off units, or three-point hitches. If equipment to match the tractor's power were available, these accessories would be more popular.

Drawbar pull and energy input to the soil showed poor correlation with speed. In some cases, they increased with increases in speed. A decrease occurred with an increase in speed in a few cases. On the average, however, both pull and energy input to the soil increased with increased speed.

Coefficient of net traction showed a rough correlation with slip. This relation generally followed the prediction equation. Variation from the prediction equation can be partially explained by the fact that the data was taken from four-wheel drive tractors, while the prediction equation was developed for a single drive wheel. Relocation of the land measuring wheel as suggested in Chapter 7 may lead to more accurate slip measurements, which may change these results.

Modification of the prediction equation resulted in a closer fit of the data to the equation for soft and medium strength soils. Hard soils showed poor correlation between data and equation for both the original equation and were even poorer for the modified equation. This effect may be due in part to the brittleness of the soils.

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APPENDIX

SAMPLE CALCULATIONS

The following are sample calculations based on the raw data from tractor test number 32-411. The data is presented in Table A.2. Symbols used to represent the variables are listed in Table A.1.

SPEED

$$S' = (D \times 3.6) / T \quad [4.1]$$

Normal	$S' = (369 \times 3.6) / 135 =$	9.8 km/h
High speed		11.0
Low speed		9.2
Greater load		9.4
Less load		11.0

DRAWBAR POWER

$$DBP = (S' \times P) / 3.6 \quad [4.2]$$

Normal	$DBP = (9.8 \times 30.2) / 3.6 =$	82.2 kW
High speed		76.1
Low speed		56.7
Greater load		90.6
Less load		46.1

Note: The pull as presented in the data is in kilonewtons rather than newtons. The constant used is 3.6 rather than 3600 as given in the text.

SLIP

$$S = \frac{\left[\begin{array}{c} \text{Number of wheel} \\ \text{revolutions, loaded} \end{array} \right] - \left[\begin{array}{c} \text{Number of wheel} \\ \text{revolutions, no-load} \end{array} \right]}{\left[\begin{array}{c} \text{Number of wheel revolutions, loaded} \end{array} \right]} \quad [1.12]$$

$$R' = (R \times 300) / D \quad [4.3]$$

No-load	$R' = (75 \times 300) / 358 =$	62.8 revolutions
Normal		68.3
High speed		65.8
Low speed		65.0
Greater load		67.3
Low load		62.5

SLIP (continued)

Normal	$S = (68.3 - 62.8) / 68.3 = 0.080$
High speed	0.046
Low speed	0.034
Greater load	0.067
Less load	0.005

FIELD CAPACITY

$$C = S' \times W' \times \xi / 10 \quad [4.5]$$

Normal	$C = 9.9 \times 10.05 \times 0.94 / 10 = 9.26 \text{ ha/h}$
High speed	10.35
Low speed	8.64
Greater load	8.85
Less load	10.35

Note: Assuming ξ equal to 0.94 accounts for an overlap between passes of 0.60 meters. This does not take into account lost time.

ENERGY INPUT TO THE SOIL

$$E = P / (0.36 \times W') \quad [4.7]$$

Normal	$E = 30.2 / (0.36 \times 9.45) = 8.87 \text{ kW-h/ha}$
High speed	7.35
Low speed	6.52
Greater load	10.20
Less load	4.44

Note: Energy input to the soil, for an average over a field, is based on the effective width of the implement. Therefore, an implement width of 9.45 meters is used rather than the actual width of 10.05 meters. Because the pull is given in kilo-newtons rather than newtons, the coefficient of 0.36 is used rather than 360.

LOADED WEIGHT DISTRIBUTION

$$P_y = P \times \sin \alpha \quad [4.8]$$

Normal	$P_y = 30.2 \times \sin 6^\circ = 2.84 \text{ kN}$
High speed	2.34
Low speed	2.09
Greater load	3.26
Less load	1.42

LOADED WEIGHT DISTRIBUTION (continued)

$$V_T = W_T + P_y / 9.807 \quad [A.1]$$

Normal	$V_T = 10.3 + 2.84 / 9.807 = 10.6 \text{ t}$
High speed	10.5
Low speed	10.5
Greater load	10.6
Less load	10.4

$$V_F = W_F - (P / 9.807) \times (y / w) \quad [1.8]$$

Normal	$V_F = 5.3 - (30.2 / 9.807) \times (0.368 / 3.175)$ $= 4.9 \text{ t}$
High speed	5.0
Low speed	5.0
Greater load	4.9
Less load	5.1

$$\% \text{ front} = (V_F / V_T) \times 100\% \quad [A.2]$$

Normal	$\% \text{ front} = (4.9 / 10.6) \times 100\%$ $= 47$
High speed	48
Low speed	48
Greater load	47
Less load	50

Note: The constant 9.807 is used in these calculations as a conversion factor between force in kilo-newtons and the equivalent mass in metric tonnes.

COEFFICIENT OF NET TRACTION

$$CNT = (P / 9.807) / V_T \quad [A.3]$$

Normal	$CNT = (30.2 / 9.807) / 10.6$ $= 0.292$
High speed	0.241
Low speed	0.216
Greater load	0.333
Less load	0.147

NORMALIZED DATA

Actual data		Normalized data	
Normal:	P = 30.2	$30.2 / 30.2$	= 1.00
	E = 8.87	$8.87 / 8.87$	= 1.00
	S' = 9.8	$9.8 / 9.8$	= 1.00
High speed:			
	P = 24.9	$24.9 / 30.2$	= 0.82
	E = 7.35	$7.35 / 8.87$	= 0.82
	S' = 11.0	$11.0 / 9.8$	= 1.12
Low speed:			
	P = 22.2	$22.2 / 30.2$	= 0.74
	E = 6.52	$6.52 / 8.87$	= 0.74
	S' = 9.2	$9.2 / 9.8$	= 0.94

TABLE A.1

EXPLANATION OF SYMBOLS USED IN SAMPLE CALCULATIONS

Symbol

C	= Field capacity, ha/h
CNT	= Coefficient of net traction, dimensionless
D	= Run distance, m
DBP	= Drawbar power, kW
E	= Energy input to the soil, kW-h/ha
% front	= Percent of total dynamic weight supported by the front wheels, dimensionless
P	= Drawbar pull, kN
P _y	= Vertical component of the drawbar pull, kN
R	= Number of tractor wheel revolutions in run distance
R'	= Number of tractor wheel revolutions per 300 meters
S	= Slip, dimensionless
S'	= Speed, km/h
T	= Run time, s
V _F	= Dynamic load on front axle, t
V _T	= Total dynamic tractor weight, t
w	= Tractor wheelbase, m
W'	= Implement width, m
W _F	= Static weight on front axle, t
W _T	= Total static tractor weight, t
y	= Drawbar height
α	= Angle of line of pull, positive down from horizontal
ϵ	= Field efficiency

TABLE A.2

DATA USED IN SAMPLE CALCULATIONS

Test Code No. 32 - 411

Run	No-Load	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Distance, m	358	369	442	369	352	396
Time, s	135	135	145	145	135	130
Wheel revolutions	75	84	97	80	79	82 $\frac{1}{2}$
Pull, kW	---	30.2	24.9	22.2	34.7	15.1

83

Tractor:

Brand and Model: John Deere 7520
 Front axle weight: 5.3 t
 Rear axle weight: 5.0 t
 Total weight: 10.3 t

Drawbar height: 0.368 m
 Centerline of rear axle
 to centerline of drawbar pin: 0.965 m
 Wheelbase: 3.175 m

Implement:

Brand and Model: Melroe
 Weight: 4.0 t
 Tongue weight: 0.0 t
 Angle of line of pull: 6°

FOUR WHEEL DRIVE TRACTOR PERFORMANCE DATA

The tables which follow list the data for the field performance for each tractor tested. In several cases, there are blanks in the tables due to lack of data. Two tractors were operating in the highest gear possible for the conditions during the normal run, so no high speed run was possible. Two implements were being operated at maximum depth for the normal run, so a greater load run was not possible. Data on the slip for one tractor is missing, due to operator errors which were not noticed during the test. The depth measurement for one test was not recorded, again due to operator error.

The test code numbers were developed as follows. The number or numbers before the hyphen refer to the number of the county in which the test was run. The first number after the hyphen refers to the first, second, etc., cooperator in the particular county. Next is the number of the tractor tested. The last number refers to the implement. Thus test number 26-1112 was a test performed with the first cooperator in county number 26 (Teton County). It was the first tractor tested at his farm, and the second implement tested at his farm.

Test Code No. 3 - 111

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	5th		4th	5th	5th
Depth, cm	---		---	---	---
Speed, km/h	9.40	TRACTOR COULD NOT OPERATE IN HIGHER GEAR	8.68	8.85	9.40
Pull, kN	17.8		17.8	28.4	10.7
Slip, %	5.5		5.5	8.2	3.7
Coefficient of Net Traction	0.217		0.217	0.347	0.130
Drawbar power, kW	46.4		42.8	69.9	27.8
Capacity, ha/h	7.76		7.15	7.31	7.76
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	6.24		6.24	9.96	3.75
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.98		0.98	0.93	0.98
Loaded Wt. Distr. (% Front/% Rear)	55/45		55/45	51/49	59/41

85

Tractor: Brand and Model IHC 4100

Front axle weight, t: 5.2

Rear axle weight, t: 3.0

Total weight, t: 8.2

Drawbar height, m: 0.533

Centerline of rear axle to centerline of drawbar pin, m: 0.965

Implement: Brand and Model: Melroe-Gysler

Weight, t: 3.2

Tongue weight, t: 0.0

Wheelbase, m: 2.616

Test Code No. 10 - 111

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3-L	4-L	2-L	2-H	3-L
Depth, cm	13	13	13	13	10
Speed, km/h	7.76	8.21	5.71	7.84	7.99
Pull, kN	97.7	104.3	95.5	108.8	59.9
Slip, %	9.2	5.9	11.4	16.7	7.6
Coefficient of Net Traction	0.410	0.435	0.388	0.453	0.250
Drawbar power, kW	210.6	238.0	151.4	236.9	133.0
Capacity, ha/h	11.59	12.28	8.52	11.72	11.92
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	17.46	18.64	17.07	19.44	10.70
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	1.00	0.66 - 0.85	1.00	0.85	1.00
Loaded Wt. Distr. (% Front/% Rear)	46/54	45/55	46/54	44/56	51/49

98

Tractor: Brand and Model Woods Copeland 600C Implement: Brand and Model: Friggstad 5-43
 Front axle weight, t: 14.4 Weight, t: 6.4
 Rear axle weight, t: 9.9 Tongue weight, t: 2.6
 Total weight, t: 24.3
 Drawbar height, m: 0.660 Wheelbase, m: 3.568
 Centerline of rear axle to centerline of drawbar pin, m: 0.990

Test Code No. 10-121

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3-L	2-H	1-H	3-L	3-L
Depth, cm	13	13	13	13	10
Speed, km/h	7.28	7.28	5.63	6.06	7.44
Pull, kN	86.6	97.7	97.7	115.4	66.6
Slip, %	9.8	14.9	20.0	22.2	7.5
Coefficient of Net Traction	0.414	0.464	0.464	0.544	0.322
Drawbar power, kW	175.1	197.5	152.8	194.3	137.6
Capacity, ha/h	10.87	10.87	8.40	9.05	11.10
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	15.48	17.46	17.46	20.62	11.90
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	1.00	0.85	1.00	----	----
Loaded Wt. Distr. (% Front/% Rear)	52/48	52/48	46/54	43/57	51/49

87

Tractor: Brand and Model Woods Copeland 450C Implement: Brand and Model: Friggstad 5-43
 Front axle weight, t: 12.6 Weight, t: 6.4
 Rear axle weight, t: 7.6 Tongue weight, t: 2.6
 Total weight, t: 20.2
 Drawbar height, m: 0.660 Wheelbase, m: 3.568
 Centerline of rear axle to centerline of drawbar pin, m: 0.990

Test Code No. 48 - 211

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	4th	5th	3rd	NORMAL RUN AT MAXIMUM DEPTH SET IMPLEMENT	4th
Depth, cm	10	10	10.		7
Speed, km/h	9.06	9.99	8.61		9.88
Pull, kN	37.3	40.0	35.5		32.0
Slip, %	10.6	4.8	3.3		4.5
Coefficient of Net Traction	0.306	0.327	0.292		0.264
Drawbar power, kW	93.9	110.9	85.0		87.7
Capacity, ha/h	10.79	11.90	10.25		11.76
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	8.72	9.35	8.30		7.48
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.91	0.82	0.91		0.91
Loaded Wt. Distr. (% Front/% Rear)	46/54	46/54	46/54		47/53

88

Tractor: Brand and Model John Deere 7520

Front axle weight, t: 6.3

Rear axle weight, t: 5.6

Total weight, t: 11.9

Drawbar height, m: 0.444

Centerline of rear axle to centerline of drawbar pin, m: 0.952

Implement: Brand and Model: John Deere 1600

Weight, t: 4.4

Tongue weight, t: 0.3

Wheelbase, m: 3.175

Test Code No. 10 - 211

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	5th	6th	4th	5th	5th
Depth, cm	15	15	15	20	10
Speed, km/h	6.18	7.04	7.20	5.81	6.85
Pull, kN	42.6	30.2	31.1	62.2	23.1
Slip, %	24.9	32.0	13.2	26.6	17.0
Coefficient of Net Traction	0.292	0.208	0.214	0.420	0.160
Drawbar power, kW	73.2	59.0	62.2	100.3	43.9
Capacity, ha/h	8.08	9.25	9.45	7.27	8.97
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	9.47	6.71	6.91	13.83	5.13
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	1.00	1.00	1.00	0.85 - 0.97	1.00
Loaded Wt. Distr. (% Front/% Rear)	56/44	57/43	57/43	53/47	58/42

89

Tractor: Brand and Model Steiger Panther ST310 Implement: Brand and Model: Melroe 503
 Front axle weight, t: 8.8 Weight, t: 5.1
 Rear axle weight, t: 5.7 Tongue weight, t: 0.2
 Total weight, t: 14.5
 Drawbar height, m: 0.387 Wheelbase, m: 3.251
 Centerline of rear axle to centerline of drawbar pin, m: 1.168

Test Code No. 32 - 211

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	4th	5th	3rd	4th	4th
Depth, cm	10	10	10	15	5
Speed, km/h	7.22	8.10	5.79	6.22	7.44
Pull, kN	26.6	28.9	25.8	39.1	19.1
Slip, %	3.5	6.5	2.7	9.1	0.0
Coefficient of Net Traction	0.32	0.34	0.30	0.46	0.23
Drawbar power, kW	53.4	64.9	41.4	67.5	39.5
Capacity, ha/h	6.63	7.43	5.52	5.70	6.83
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	8.36	9.08	8.11	12.29	6.00
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.98	0.95	1.00	0.95	1.00
Loaded Wt. Distr. (% Front/% Rear)	51/49	51/49	52/48	48.52	54/46

96

Tractor: Brand and Model Case 1470 TK

Front axle weight, t: 4.9

Rear axle weight, t: 3.4

Total weight, t: 8.3

Drawbar height, m: 0.457

Centerline of rear axle to centerline of drawbar pin, m: 0.890

Implement: Brand and Model: Melroe-Gysler

Weight, t: 3.3

Tongue weight, t: 0.2

Wheelbase, m: 2.591

Test Code No. 32 - 311

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	4th	5th	3rd	4th	4th
Depth, cm	10	10	10	15	5
Speed, km/h	7.97	9.51	7.49	6.13	6.19
Pull, kN	28.4	28.4	23.1	32.0	23.1
Slip, %	--	--	--	--	--
Coefficient of Net Traction	0.260	0.260	0.220	0.299	0.220
Drawbar power, kW	62.9	75.1	48.0	54.4	39.7
Capacity, ha/h	7.27	8.73	6.75	5.62	5.66
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	8.35	8.35	6.79	9.41	6.79
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.91	0.82	0.93	0.79	0.95
Loaded Wt. Distr. (% Front/% Rear)	58/42	58/42	60/40	58/42	60/40

Tractor:	Brand and Model	Stieger Bearcat	Implement:	Brand and Model:	Melroe 505
	Front axle weight, t:	6.9		Weight, t:	4.0
	Rear axle weight, t:	3.6		Tongue weight, t:	0.0
	Total weight, t:	10.5			
	Drawbar height, m:	0.482		Wheelbase, m:	2.997
	Centerline of rear axle to centerline of drawbar pin, m:				1.270

Test Code No. 32 - 411

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	4-Hi	5-L0	4-L0	4-Hi	4-Hi
Depth, cm	10	10	10	15	5
Speed, km/h	9.8	11.0	9.2	9.4	11.0
Pull, kN	30.2	24.9	22.2	34.7	15.1
Slip, %	8.0	4.6	3.4	6.7	0.5
Coefficient of Net Traction	0.292	0.241	0.216	0.333	0.147
Drawbar power, kW	82.2	76.1	56.7	90.6	46.1
Capacity, ha/h	9.26	10.35	8.64	8.85	10.35
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	8.87	7.35	6.52	10.20	4.44
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.97	0.97	1.00	0.83 - 0.93	1.00
Loaded Wt. Distr. (% Front/% Rear)	47/53	48/52	48/52	47/53	50/50

92

Tractor: Brand and Model John Deere 7520

Front axle weight, t: 5.3

Rear axle weight, t: 5.0

Total weight, t: 10.3

Drawbar height, m: 0.368

Centerline of rear axle to centerline of drawbar pin, m: 0.965

Implement: Brand and Model: Melroe

Weight, t: 4.0

Tongue weight, t: 0.0

Wheelbase, m: 3.175

Test Code No. 3 - 211

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3rd	4th	2nd	3rd	3rd
Depth, cm	11	11	11	15	7
Speed, km/h	7.17	7.84	6.18	5.04	7.78
Pull, kN	31.1	30.2	26.2	43.5	20.4
Slip, %	8.1	11.3	7.2	13.5	4.6
Coefficient of Net Traction	0.350	0.340	0.300	0.490	0.235
Drawbar power, kW	61.9	65.8	45.0	60.9	44.1
Capacity, ha/h	5.45	5.98	4.73	3.84	5.94
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	12.32	11.97	10.38	17.24	8.08
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.83	0.64 - 0.75	0.90	0.60	0.90
Loaded Wt. Distr. (% Front/% Rear)	50/50	50/50	51/49	46/54	52/48

93

Tractor: Brand and Model IHC 4166
 Front axle weight, t: 4.9
 Rear axle weight, t: 3.7
 Total weight, t: 8.6
 Drawbar height, m: 0.394
 Centerline of rear axle to centerline of drawbar pin, m: 1.143

Implement: Brand and Model: Hess
 Weight, t: 2.5
 Tongue weight, t: 0.2

Wheelbase, m: 2.591

Test Code No. 32 - 611

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	2nd aux. 1st main		1st aux. 2nd main	2nd aux. 1st main	2nd aux. 1st main
Depth, cm	10		10	15	5
Speed, km/h	5.95		5.13	5.28	5.98
Pull, kN	20.4		21.3	33.3	11.5
Slip, %	5.9		5.0	10.4	3.1
Coefficient of Net Traction	0.246		0.257	0.395	0.141
Drawbar power, kW	33.8		30.4	48.8	19.2
Capacity, ha/h	3.45		2.98	3.06	3.47
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	9.79		10.22	15.97	5.52
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.94		0.95	0.90	1.00
Loaded Wt. Distr. (% Front/% Rear)	54/46		53/47	51/49	56/44

94

Tractor: Brand and Model	Versatile D118	Implement: Brand and Model:	Gysler
Front axle weight, t:	5.2	Weight, t:	2.3
Rear axle weight, t:	3.4	Tongue weight, t:	0.0
Total weight, t:	8.6		
Drawbar height, m:	0.356	Wheelbase, m:	3.048
Centerline of rear axle to centerline of drawbar pin, m:	0.914		

Test Code No. 3 - 311

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3rd under	3rd over	2nd over	RUN	3rd under
Depth, cm	14	14	14	FOR NORMAL	8
Speed, km/h	7.97	8.10	6.78	DEPTH	8.26
Pull, kN	29.7	30.2	26.6	AT MAXIMUM	15.1
Slip, %	3.4	5.5	4.6	IMPLEMENT SET	3.4
Coefficient of Net Traction	0.302	0.306	0.271		0.155
Drawbar power, kW	65.9	67.9	50.2		34.6
Capacity, ha/h	6.57	6.67	5.59		6.81
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	10.03	10.19	8.98		5.10
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.95	0.77	1.00		1.00
Loaded Wt. Distr. (% Front/% Rear)	57/43	57/43	58/42		61/39

95

Tractor: Brand and Model Massey Fergusson 1500
 Front axle weight, t: 6.2
 Rear axle weight, t: 3.4
 Total weight, t: 9.6
 Drawbar height, m: 0.508
 Centerline of rear axle to centerline of drawbar pin, m: 1.041

Implement: Brand and Model: John Deere 1600
 Weight, t:
 Tongue weight, t:
 Wheelbase, m: 3.048

Test Code No. 6 - 111

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	4th	5th	3rd	4th	4th
Depth, cm	11	11	11	18	7
Speed, km/h	8.05	10.01	7.28	6.03	8.74
Pull, kN	34.6	28.4	21.3	37.3	23.1
Slip, %	8.9	7.7	1.8	28.2	4.1
Coefficient of Net Traction	0.330	0.275	0.208	0.360	0.225
Drawbar power, kW	77.4	79.0	43.1	62.5	56.1
Capacity, ha/h	8.11	10.08	7.34	6.08	8.81
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	9.56	7.84	5.88	10.30	6.38
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.96	0.96	0.96	0.88	0.96
Loaded Wt. Distr. (% Front/% Rear)	47/53	49/51	51/49	46/54	50/50

Tractor: Brand and Model IHC 4366
 Front axle weight, t: 5.8
 Rear axle weight, t: 4.3
 Total weight, t: 10.1
 Drawbar height, m: 0.609
 Centerline of rear axle to centerline of drawbar pin, m: 1.168

Implement: Brand and Model: IHC 55
 Weight, t: 3.0
 Tongue weight, t: 0.0

Wheelbase, m: 2.997

Test Code No. 26 - 111

Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3rd	4th	2nd	3rd	3rd
Depth, cm	9	8	8	13	5
Speed, km/h	6.16	7.59	5.00	6.19	6.32
Pull, kN	20.4	30.2	23.1	35.5	11.5
Slip, %	4.0	7.2	18.8	7.5	2.2
Coefficient of Net Traction	0.234	0.342	0.264	0.400	0.134
Drawbar power, kW	34.9	63.7	32.1	61.0	20.2
Capacity, ha/h	4.51	5.56	3.67	4.54	4.63
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	7.75	11.47	8.77	13.48	4.37
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.96	0.96	0.98	0.94	0.96
Loaded Wt. Distr. (% Front/% Rear)	51/49	48/52	50/50	46/54	54/46

97

Tractor: Brand and Model IHC 4366

Front axle weight, t: 4.9

Rear axle weight, t: 3.7

Total weight, t: 8.6

Drawbar height, m: 0.457

Centerline of rear axle to centerline of drawbar pin, m: 1.167

Implement: Brand and Model: Anderson

Weight, t: ---

Tongue weight, t: ---

Wheelbase, m: 2.589

Test Code No. 26 - 112

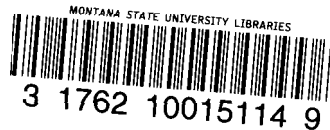
Run	Normal Conditions	Higher Speed	Lower Speed	Greater Load	Less Load
Gear	3rd	4th	2nd	3rd	3rd
Depth, cm	8	8	8	13	5
Speed, km/h	6.53	8.02	5.49	6.08	6.67
Pull, kN	24.9	38.2	31.1	47.1	18.6
Slip, %	0.2	4.5	0.0	9.4	3.1
Coefficient of Net Traction	0.284	0.430	0.352	0.525	0.214
Drawbar power, kW	45.1	85.1	47.4	79.5	34.6
Capacity, ha/h	6.18	7.59	5.19	5.75	6.31
Energy input, $\frac{\text{kW-h}}{\text{ha}}$	7.32	11.32	9.14	13.85	5.47
$\frac{\text{Loaded RPM}}{\text{No Load RPM}}$	0.96	0.94	0.98	0.93 - 0.94	0.96
Loaded Wt. Distr. (% Front/% Rear)	50/50	46/54	48/52	43/57	51/49

86

Tractor: Brand and Model IHC 4366
 Front axle weight, t: 4.9
 Rear axle weight, t: 3.7
 Total weight, t: 8.6
 Drawbar height, m: 0.457

Implement: Brand and Model: Gysler
 Weight, t: 3.6
 Tongue weight, t: 0.2

Wheelbase, m: 2.591
 Centerline of rear axle to centerline of drawbar pin, m: 1.168



N378

Oh6

cop.2

Ohrmann, John W

Four wheel drive
tractors

DATE	ISSUED TO
2 WEEKS	INTERLIBRARY LOV
	INTERLIBRARY
	MARTIN W
NOV 10	Rob Daile

N378
Oh6
cop 2