Pertanika J. Sci. & Technol. **1(1)**: 51-64 (1993)

ISSN: 0128-7680

Draft and Fuel Requirements Measurement Using Tractor On-Board Data Acquisition System

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Received 28 February 1992.

ABSTRAK

Keperluan kuasa tarikan alat-alat pertanian atau draf adalah faktor penting di dalam pemilihan traktor dan alat pertanian didalam pengurusan jentera. Draf adalah digunakan untuk menentukan keperluan bahanapi didalam sesuatu operasi ladang. Sistem perolehan data di atas traktor telah di rekabentuk bagi memudahkan pengumpulan dan penanalisisan data. Pengukuran bagi keperluan-keperluan draf dan bahanapi dari ladang ditentusahkan menggunakan persamaan-persamaan dari ASAE standards.

ABSTRACT

The implement drawbar power requirement or draft is an important factor to determine tractor and machinery selection in machinery management. The implement draft is used to determine the fuel consumed for an operation. The tractor on-board data acquisition system was developed to ease in field data collection using the established equations from the ASAE standards.

Keywords: Draft, fuel, computer model, data acquisition system, tillage implements, planting implements, drawbar power, transducers, regression analysis.

INTRODUCTION

Machinery contributes a major capital input cost in most farm businesses (Chen 1986; Ozkan and Edwards 1986; Singh and Holtman 1979; Mayfield *et al.* 1981). Tractor and machinery selection is an important part of machinery management. To adequately evaluate crop production and to be able to choose alternative crop production or tillage systems, information needs to be collected. Implement draft requirement is an important consideration in selecting implements, tillage systems and a tractor size that is compatible with the operation. In addition to the required tractor size, implement draft will also be used to determine the fuel consumed for an operation.

Implement draft and power requirements were reported by various researchers (White 1977 and 1978; FMO 1987; Hunt 1983; Self *et al.* 1983; Zwilling and Hummel 1988). Draft requirements of various machines under Michigan conditions were also reported by a group of scientists at Michigan State University (Rotz and Black 1985). Draft is the major component of forces between the tractor and implement, and in parallel to the soil surface and to the direction of travel. ASAE standard EP391.1 presents draft and power requirements for most field machines for various soil types.

Microcomputers are increasingly utilized in the acquisition and processing of implement-tractor performance data. Thomson and Shinners (1987) reported using a portable instrument system to measure draft and speed of tillage implements. Measurements were taken and stored using a data logger, then transferred via magnetic cassette tape to a microcomputer for further processing. Microcomputer-based data acquisition systems have emerged as relatively inexpensive alternatives to instrumentation-type tape recorders or strip chart systems. Carnegie *et al.* (1983), Clark and Adsit (1985), and Bowers (1986), are examples of researchers who developed microcomputer-based data acquisition systems for measuring in-field tractor performance. Carnegie *et al.* (1983) reported the use of an Apple IIe personal microcomputer for data collection and analysis. They concluded that the Apple IIe personal microcomputer was versatile, yet inexpensive, and performed well under adverse field conditions.

Research was carried out to determine the field measurements for draft and fuel requirements for major crop production tillage and planting operations. The tests for measuring power and energy requirements were conducted on the farms at Michigan State University and in Clinton County, Michigan using various types of tillage and planting equipment. Experiments were conducted on different soil series at different depths and speeds using various conservation tillage and conventional tillage implements. The draft and fuel consumptions were determined for the mouldboard plough, chisel plough, disc harrow, field cultivator, row crop planters, and grain drills at various numbers of test runs and also consecutive operations (e.g. chisel plough followed by disc harrow twice).

INSTRUMENTATION

The system designed for this research used an Apple IIe[1] microcomputer for collecting data on-board the tractor and an IBM microcomputer for data processing. The Apple IIe data acquisition system was developed by earlier researchers (Tembo 1986; Guo 1987 and Mah 1990) at Michigan State University. A commercially available Dickey John Tractor Performance Monitor II (DjTPMII) was employed to measure the engine speed and ground speed. A commercial engine rpm sensor was used for determining the engine speed. A single beam Doppler radar unit was used for determining true ground speed. A magnetic pickup sensor was used to

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

measure the front and rear wheel rotational speed. The fuel consumption was measured using an EMCO pdp-1 fuel flow meter attached to the engine fuel line. The amount of fuel and time consumed was recorded directly by the data acquistion system. The draft of the tillage and planting equipment was determined using strain gauges attached to the drawbar of the tractor. The draft was also recorded directly using the data acquisition system.

The data acquisition system is powered by 12DC-120VAC, 60 Hz, 500 watt sinusoidal voltage converter. Input power to the converter is supplied by a 12 VDC battery with free-floating ground. The signal from each sensor is passed through a signal conditioner and through an analog-to-digital converter. The data were stored as ASCII code in the Random Access Memory (RAM) of a microcomputer which was later transferred to a floppy disc. A second computer was used to convert the data from ASCII code to numerical values for analysis.

TABLE 1

Regression equations for transducers.

Channel	Gain Code	Transducer	Equations	R^2
6	0	Engine Rpm	Hz = mv*0.08914 + 1.6936	0.9998
7	0	Ground Speed	Hz = mv*0.0978 + 2.2774	0.9992
8	0	Rear Wheel Rpm	Hz = mv*0.0835 + 2.7575	0.9988
9	0	Front Wheel Rpm	Hz = mv*0.0902 + 1.1103	0.9986
10	0	Draft	N = v*24000.664 - 12.857	0.9991
11	0	Fuel Consumption	Hz = mv*0.2036 + 0.8803	0.9999

Calibration of the transducers to obtain the regression equations as in Table 1 were carried out prior to the field experimentation that was conducted between September and November 1989. Calibration of the strain gauges for draft measurement was done using a Universal Testing Machine with a maximum load of 4627 kg (10200 lb). The calibration of the other transducers such as engine rpm sensor for the engine rpm, magnetic pickup sensor for the wheel speeds and fuel meter for the fuel consumption were carried out at the Agricultural Engineering Laboratory using a frequency function generator. Regression equations for each transducer were obtained.

The method used to arrive at the calibration equations was through estimating the maximum load expected for each of the transducers. The maximum expected loads (i.e., engine rpm, fuel consumption, ground speed, rear wheel speed and front wheel speed) were converted into frequencies for their respective transducers which were later fed into the signal conditioner to obtain analogous voltages. The computer then provided coefficients and constants for calibration equations to convert the computer outputs (mv) to the analog parameters. The respective equations and the coefficients of determination for each channel are listed in Table 1. Depending on the range of the voltage, a suitable gain code was selected. All six transducers were calibrated for a gain code of 0 viz for a voltage of 0 - 5 volts.

The calibration of the fuel flow meters was done using a custom-made frequency simulator that was designed to expand the narrow signal obtained from the sensor to one that the conditioner could display. The frequency simulator had four preset frequency levels of 100, 250, 500, and 1000 Hz. The frequencies, Hz were fed into the signal conditioner to obtain analogous voltages as explained above, which were later used to determine the calibration equation for the fuel consumption.

MODEL EQUATIONS

The equations for the draft and fuel consumption used in the computer model were obtained from ASAE (ASAE D230.4, 1990) and Machinery Management (FMO 1987). The implement draft was estimated based on the operation speed, operation depth and implement width. The implement drawbar power was calculated using the implement draft and operation speed. The operation speed and depth used were obtained from the experiment. The fuel required by each implement operation was estimated based on the implement equivalent power take-off power (EPTOP) and the tractor available power take-off power (APTOP). The implement EPTOP was calculated using the drawbar power and tractive efficiency. The tractive efficiency was estimated from the wheel slippage and soil cone index obtained from the field experiments. The tractor used in the experiment produced APTOP of 64.1 kW.

Equation 1 shows an example to determine the draft for a mouldboard plough used on coarse soil. The experimental draft obtained from the field experiment was compared to the draft obtained from the CPMS Model using the above equation. Using the calculated valus of slippage (SL) and dimensionless ratio (CN) from Equations 2 and 3, an individual TE can be estimated as in Equation 4. CN is a function of the Cone index (CI) of the soil. The values for the CI were obtained from the research using a cone penetrometer. SL was calculated using the rear and front wheel speeds, and the ground speed. These speeds are experimental data and were obtained from the on-board computer data acquisition system. Based on the individual values of TE, the power required by the implement was calculated as in Equation 5. Based on the implement equivalent power take-off power (EPTOP) and tractor available power take-off power (APTOP), the predicted fuel was obtained as in Equation 6. The experimental fuel consumption was compared with the fuel requirement estimated by the model using the above equations.

$$D=(2.80+0.013*S^2)*WD*W*10 \qquad (1)$$

where

D = Draft, kN
S = Operation speed, Km/h
WD = Operation Depth, m
W = Implement width (Mouldboard plough), m

$$CN=\frac{CI*B*D}{W_L} \qquad (2)$$

where

CN = Dimensionless ratio
CI = Cone Index (from cone penetrometer reading)
B = Unloaded tyre section width (34.5cm), cm
D = Unloaded overall tyre diameter (131 cm)
W_L = Dynamic wheel load

$$SL=\frac{S_w - S_g}{S_w} \qquad (3)$$

where

SL = Wheel slippage
S_w = Wheel speed
S_g = Ground speed

$$TE=(1-SL)\left(1-\frac{\frac{1.2}{CN}+0.04}{0.75\,(1-e^{0.3}*CN*SL)}\right) \qquad (4)$$

$$EPTOP=\frac{DBP}{0.96*TE} \qquad (5)$$

$$FCN = \left(2.64 * \frac{EPTOP}{APTOP} + 3.91 - 0.203 \sqrt{7.38 * \frac{EPTOP}{APTOP} + 173} \right) * EPTOP \tag{6}$$

FIELD EXPERIMENTS

This paper focused on the research to determine the average draft and fuel consumption for various tillage and planting implements at various field speeds, and depths of operation. The tractor used in this research was a Ford[1] agricultural tractor, model 7610, with front wheel assist. The nominal PTO power of this tractor was 64.1kW (86 hp).

The field tests for the first season were carried out in the summer and fall of 1989 at the MSU farms. The field tests for the second season were carried out in the summer and fall of 1990 at the MSU farms and at Clinton County, Michigan.

Experiments at MSU were carried out on Capac loam which is fine-textured soil. The experiments using chisel plough, mouldboard plough, disc harrow and field cultivator were carried out using different operation speeds and depths. A single depth was used for the grain drill experiments. The experiments using a semi-mounted mouldboard plough were carried out at different depths, but no draft was recorded. The experiments using a disc harrow were carried out on an untilled area, a previously mouldboard-ploughed area and a previously chisel-ploughed area. The field cultivator experiments were carried out on an untilled area, after mouldboard and disc harrow operations, and after chisel plough and disc harrow operations. The grain drill was tested on an untilled area, a previously mouldboard-ploughed area and a previsously chisel-ploughed area. The John Deere grain drill was tested on a chisel-ploughed area and a mouldboard-ploughed area.

Experiments on farms at Clinton County were carried out on four different soils, namely, Owosso-Marlette Sandy loam, Metamora Capac loam, Granby loamy soil, and Palms Muck soil. The chisel plough, mouldboard plough and disc harrow experiments were carried out for different operation speeds and depths. The disc harrow experiments were carried out for single and double passes on an unploughed area and previously ploughed area. The grain drill was tested on unploughed area, previously chisel-ploughed area, previously mouldboard-ploughed area, and previously mouldboard-ploughed and disc-ploughed area. The corn planter was tested on an untilled area and after a disc harrow operation.

At the beginning of the experiment, the operator entered the number of data sets to be collected. The operator initiated the data collection procedure when the tractor reached steady state operation during an experimental run. The data were stored temporarily in RAM memory during each experimental run of the tractor. After each experimental run, the data were verified before being saved an a floppy disc. The data were stored as an ASCII file in order to provide ease in transferability to other computers for analysis. About 500 to 1000 data sets at 20 Hz frequency sampling were obtained for each experimental run. Each data set contained one data point for each of the six measured parameters. These data sets were used to calculate the engine rpm, ground speed, rear wheel revolution, front wheel revolution, wheel slip, implement draft, implement power requirement and fuel consumption.

The data recorded using the on-board data acquisition system were then retrieved and transferred to an IBM computer. The transfer of the data was carried out using cross-over RS232 wires connecting the modem ports of the Apple IIe and IBM computers. The ASCII Express program was used with the Apple IIe computer to send the files. The Modem 7 PC program was used with the IBM computer to receive the files from the Apple IIe computer. The data saved in IBM format were then changed to ASCII files by adding the .PRN extension. The extension PRN files were then imported to the LOTUS 1-2-3 program for analysis. LOTUS 1-2-3 was used to determine the average values of the voltages for each transducer. These average voltage values were then converted by the appropriate equation to calculate the parameters measured by each sensor. These parameter values were then stored on discs for later analysis and for use by the simulation model.

RESULTS AND DISCUSSION

Simple regression analysis was performed to find the relationship between computer model outputs and experimental outputs. A perfect model would provide a line passing through the origin with a slope of 1 i.e. a 1:1 correspondence. For this study, the general form of the regression model is $Y = a + bX + e$ where Y is the predicted or model value, X is the experimental value, a is the intercept, b is the slope of the regression equation and e is the error term. The estimated value of b must be one or close to one indicating the model value is equal or close to the experimental value.

A student's t test is used to determine whether a and b are significantly different from zero. The calculated t is compared with the tabular at 5% level of significance. If the calculated t is greater than the tabular t, the null hypotheses of $a = 0$ and $b = 0$ are rejected and the coefficients are said to be "statistically significant". An F-statistic is used to determine whether the relation expressed by the regression line is statistically significant.

A coefficient of determination, R^2 is computed to measure the goodness of fit of the regression equation. R^2 can be interpreted as the proportion of varation in predicted values explained by variation in experimental values. An R^2 value of 1 occurs if the experimental and predicted values all lie on a straight line, so that the residuals are zero. A correlation coefficient R is computed to give a quantitative measure of how close the association is between the experimental value, X and model value, Y. A value of R near + 1 indicates a very close correlation.

TABLE 2
Experimental and model draft and fuel requirements for mouldboard plough on Owosso - Marlette sandy loam.

Speed, km/h	Depth, cm	Expt. Draft, KN	Expt. Fuel, L/h	Model Draft,KN	Model Fuel, L/h
4.42	28	22.63	19.70	23.08	18.23
3.63	28	24.13	17.52	22.21	18.81
3.79	28	23.16	17.69	22.36	16.54
5.23	20	18.86	14.96	17.24	15.22
7.39	13	13.54	15.57	12.92	14.17
6.73	20	17.15	18.70	18.98	17.83

Location : Clinton County, Michigan
Implement : Mouldboard Plough Size: 6-Bottom Width: 2.43m

Data gathered from the experiments carried out on the farms at MSU and Clinton County, Michigan were used to test the predictions of this computer model. The tractor size, type and size of implement, soil texture, operation speed, operation depth and tractive efficiency were used as inputs to the model to generate the predicted draft and fuel requirements. The model's predicted drafts for the chisel plough and field cultivator were calculated based on the number of blades or tines at 0.305 metres spacing as indicated by the equation from ASAE (ASAE D230.4, 1990).

The example below shows the data recorded for the mouldboard plough operation on Owosso-Marlette sandy loam soil carried out at Clinton County. Table 2 shows the experiments carried out using mouldboard plough at different operation depths and ground speeds. Table 4 shows the summary of the regression analysis for the above mouldboard plough. The regression equation for the draft requirement is $Y = 1.631 + 0.896X$. From the t tests, the intercept is not significantly different from zero at the 0.05 level. The slope of the draft requirement equation is 0.896, and it is statistically significant at the 0.05 level. We can say that model output for the draft requirement does not differ significantly from field data. R^2 for the above equation is 0.886. This indicates that the variation of the predicted draft requirements is highly explained by the experimental draft requirement. The correlation coefficient was calculated to be 0.941, showing a very close association between the experimental draft and the predicted draft. The regression equation for the fuel requirement is $Y = 2.527 + 0.822X$. From the t tests, the intercept is not significantly different from zero at 0.05 level. The slope of the fuel requirement equation is 0.822, and it is statistically significant at the 0.05 level. The model output for the fuel requirement does not differ significantly from field data. About 66.7 per cent of the predicted fuel requirements' variability is explained by the experimental fuel requirement. The experimental fuel and the model fuel values showed a correlation of 0.816. There was high correlation across the range of conditions tested between measured and predicted values.

Table 3 shows the regression analysis for the draft and fuel requirements for the mouldboard plough, chisel plough, disc harrow, field cultivator, row crop planter and grain drill. Tables 4 to 9 shows the summary of the regression analysis for each experiment carried out using the mouldboard plough, chisel plough, disc harrow, field cultivator, row crop planter, and grain drill, respectively. These tables provide the regression equations for the draft and fuel consumption and the coefficient of correlation for each experiment and for each implement. A student's t test was carried out to determine the significance of the intercept and the slope of the regression line. The * beside each coefficient denotes the

TABLE 3

Summary of the regression analysis for the implements.

Implement Types	Regression	Regression Equation	Coefficient of Correlation, R
Mouldboard Plough	Draft	$Y^{@} = 0.743 + 0.937X^{*}$	0.943
	Fuel	$Y^{@} = 2.167 + 0.44X^{*}$	0.935
Chisel Plough	Draft	$Y^{@} = 2.539^{*} + 0.668X^{*}$	0.974
	Fuel	$Y^{@} = 8.913^{*} + 0.312X^{*}$	0.742
Disc Harrow	Draft	$Y = 8.358 + 0.753X$	0.362
	Fuel	$Y^{@} = 6.600^{*} + 0.656X^{*}$	0.776
Field Cultivator	Draft	$Y^{@} = 7.759^{*} + 0.849X^{*}$	0.869
	Fuel	$Y^{@} = 10.814 + 0.215X^{*}$	0.572
Row Crop Planter	Draft	$Y^{@} = 4.560^{*} + 0.697X^{*}$	0.831
	Fuel	$Y^{@} = 8.839^{*} + 0.324X$	0.399
Grain Drill	Draft	$Y^{@} = -4.401^{*} + 2.048X^{*}$	0.847
	Fuel	$Y^{@} = 1.946^{*} + 0.601X^{*}$	0.860

@ Model-output does not differ significantly from field data (F-statistic).

* Significant difference at 95 per cent level of confidence (t-test)

TABLE 4
Summary of the regression analysis for the mouldboard plough

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Metamora Capac Sandy Loam	Draft	$Y^{@} = 1.631 + 0.896^{*}$	0.941
	Fuel	$Y^{@} = 2.527 + 0.822X^{*}$	0.816
Owosso-Marlette Sandy Loam	Draft	$Y = -0.243 + 0.991X$	0.919
	Fuel	$Y = 1.768 + 0.872$	0.990

TABLE 5
Summary of the regression analysis for the chisel plough

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Metamora Capac Sandy Loam	Draft	$Y^{@} = 0.048 + 0.856^{*}$	0.982
	Fuel	$Y^{@} = 9.628^{*} + 0.247X^{*}$	0.948
Capac Loam Soil	Draft	$Y^{*} = 3.029 + 0.637X^{*}$	0.975
	Fuel	$Y^{@} = 7.552^{*} + 0.429^{*}$	0.723

[@] Model-output does not differ significantly from field data (F-statistic)
[*] Significant difference at 95 per cent level of confidence (t-test)

TABLE 6
Summary of the regression analysis for the disc harrow

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (After chisel plough operation)	Draft	$Y^{@} = -23.048 + 3.300X^{*}$	0.835
	Fuel	$Y^{@} = 9.017^{*} + 0.443X^{*}$	0.959
Granby Loamy Sand Soil (no-till area)	Draft	$Y = -4.116 + 1.868X$	0.674
	Fuel	$Y^{@} = O.224 + 1.140X^{*}$	0.979
Palms Muck Soil (after mouldboard plough operation)	Draft	$Y = 12.671^{*} - 0.086X$	0.064
	Fuel	$Y^{@} = 8.793^{*} + 0.605X^{*}$	0.958
Granby Loamy Sand Soil (after mouldboard plough operation)	Draft	$Y^{@} = 0.990^{*} + 0.874X^{*}$	0.894
	Fuel	$Y = 6.785 + 0.519X$	0.790
Palms Muck Soil (no-till area)	Draft	$Y = 0.792 + 1.419X$	0.610
	Fuel	$Y = 17.814^{*} - 0.127X$	-0.486

[@] Model-output does not differ significantly from field data (F-statistic).
[*] Significant difference at 95 per cent level of confidence (t-test)

significant difference at 95 per cent level of confidence. An F-statistic was used to determine the relationship expressed by the regression lines. The @ beside the dependent variable y indicates that the model-output does not differ significantly from the field data. For each regression equation, a correlation of coefficient was determined to measure the closeness of the association between the experimental value, X and model value, Y.

TABLE 7

Summary of the regression analysis for the field cultivator.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (after chisel plough & d.harrow)	Draft	$Y^{@} = 7.363^{*} + 0.801X^{*}$	0.921
	Fuel	$Y^{@} = 7.568^{*} + 0.409X^{*}$	0.800
Capac Loam Soil (after mb plough & d.harrow)	Draft	$Y^{@} = 5.973 + 1.102X^{*}$	0.860
	Fuel	$Y = 10.513^{*} + 0.263X^{*}$	0.595
Capac Loam Soil (no-till area)	Draft	$Y^{@} = 8.960 + 0.683X^{*}$	0.942
	Fuel	$Y = 12.245^{*} + 0.116X$	0.646

[@] Model-output does not differ significantly from field data (F-statistic)

[*] Significant difference at 95 per cent level of confidence (t-test)

TABLE 8

Summary of the regression analysis for the row crop planter

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Palms Muck Soil	Draft	$Y^{@} = 9.300^{*} + 0.407E\text{-}05X^{*}$	1.000
	Fuel	$Y = 9.290^{*} + 0.096X$	0.891
Capac Loam Soil	Draft	$Y^{@} = 12.000^{*} - 0.421E\text{-}05X^{*}$	1.000
	Fuel	$Y^{@} = 8.010^{*} + 0.451X^{*}$	0.849
Gilford Sandy Loam	Draft	$Y^{@} = 9.300 + 0.328E\text{-}04X^{*}$	1.000
	Fuel	$Y^{@} = 12.268^{*} + 0.0712X^{*}$	0.953

[@] Model-output does not differ significantly from field data (F-statistic).

[*] Significant difference at 95 per cent level of confidence (t-test).

TABLE 9
Summary of the regression analysis for the grain drill.

Soil Types	Regression	Regression Equation	Coefficient of Correlation, R
Capac Loam Soil (after mouldboard plough)	Draft	$Y^{@} = 6.751^{*} - 0.101\text{E-}03X^{*}$	1.000
	Fuel	$Y = 8.600 + 0.068X$	0.173
Capac Loam Soil (after chisel plough)	Draft	$Y^{@} = 6.750^{*} - 0.199\text{E-}05X^{*}$	1.000
	Fuel	$Y = 8.206^{*} + 0.421\text{E-}01X$	0.219
Granby Loamy Sand Soil (after mb plough & d.harrow)	Draft	$Y = 2.340 + 0.204\text{E-}05X^{*}$	1.000
	Fuel	$Y = -0.529 + 0.741^{*}$	0.959
Granby Loamy Sand Soil (no-till)	Draft	$Y^{@} = 2.900^{*} + 0.158\text{E-}05X^{*}$	1.000
	Fuel	$Y^{@} = 2.910^{*} + 0.395X^{*}$	0.995

@ Model-output does not differ significantly from field data (F-statistic)
* Significant difference at 95 per cent level of confidence (t-test)

CONCLUSION

In summary, the model outputs of the operations for mouldboard plough, chisel plough, field cultivator, row crop planter and grain drill for the draft requirements do not differ significantly from the field data. There was very close association between the experimental draft and the predicted draft for the experiments of the above implements.

The model output of the disc harrow operations for the draft requirement is statistically different from the field data. There was a low association between the experimental draft and the model draft for the disc harrow operations. The low coefficient of determination indicates that the variation of the predicted draft requirement is not well explained by the experimental draft requirement. Research should be carried out to determine the disc harrow draft equation that also depends on the depth of operation.

The model draft regression equations for the row crop planter and the grain drill show a zero or almost zero slope. The drafts stay constant which is independent of the operation speed. There was a perfect association between the experimental draft and the model draft for the individual row crop planter and grain drill operations. The correlation of coefficient was reduced when all the experiments were combined. Research should be carried out to determine the row crop planter and grain drill draft equations to reduce the variability among the experiments.

The model outputs of the mouldboard plough, chisel plough, field cultivator, disc harrow and grain drill operations for the fuel requirements do not differ significantly from the field data. There was very close association between the experimental fuel requirement and the predicted fuel requirement for the above implements. There was a low correlation between the experimental fuel requirement and the model fuel requirement for the overall row crop planter experiment. There was a high correlation between the experimental fuel and the model fuel for the individual row crop planter experiments. The variations of the experimental draft affect the model fuel consumption.

The acquisition and processing of implement tractor performance data can now be easily carried out using microcomputers. Apple IIe personal microcomputer performed well under adverse field condition and is reliable for data collection. The draft and fuel requirements measurements using tractor-on-board data acquisition system were validated and verified using the equations that were established in the ASAE standards. The close association between the experimental data and the predicted data conclude the reliability of the tractor-on-board data acquisition system developed at Michigan State University, USA.

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