

Development and Evaluation of Tractors and Tillage Implements Instrumentation System

S.A. Al-Suhaibani, A.A. Al-Janobi and Y.N. Al-Majhadi
Department of Agricultural Engineering, Collage of Food Science and Agriculture,
King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia

Abstract: Problem statement: Field machines contribute a major portion of the total cost of crop production. Proper selection and matching of farm machinery is essential in order to reduce the cost of crop production. Performance data for tractors and implements are, therefore, essential for farm machinery operators and manufacturers alike. The aim of this study was to develop and evaluate an instrumentation system for tractor and agricultural implements. **Approach:** An instrumentation system was developed and mounted on an MF 3090 tractor to measure and record data for the various performance parameters of the tractor and attached tillage implements. The system was designed to measure: drawbar pull, three-point linkage forces, rear and front wheel forces, PTO torque, ground speed, tillage depth, fuel consumption, engine speed and fluid temperatures. **Results:** The system performed well during the field operations and the results obtained showed that the accuracies of the transducers were acceptable. The wheel torque and weight transducers measured the torque and forces acting on the tractor wheels with high accuracy. The other transducers measured the vertical and the horizontal forces on mounted implements of categories II (40-100 hp) and III (80-225 hp). The field tests showed significant increase in the draft with increases in the depth and speed. A general regression equation to predict draft of the implements was developed. **Conclusion:** The system was capable of measuring the draft of primary tillage implements on sandy loam soils at various speeds and depths with high accuracy. The data was recorded, displayed and analyzes simultaneously.

Key words: Instrumentation, transducers, dynamometer, torque meter, strain gauge, data logger, tractor, implement, drawbar, PTO, temperature, fluids

INTRODUCTION

Field machines contribute a major portion of the total cost of crop production. The proper operation is essential for any system to be reasonably profitable. Thus, efficient operation of farm tractors includes: (a) maximizing fuel efficiency of the engine and mechanical efficiency of the drive train, (b) maximizing attractive advantage of traction devices and (c) selecting an optimum travel speed for a given tractor-implement system (Grisso *et al.*, 2008). Therefore, performance data for tractors and implements are essential for farm machinery operators and manufacturers alike. Proper selection of tractors and implements for a particular farm operation need to be based on these performance parameters (Al-Suhaibani, 1992).

A number of instrumentation systems, based on data loggers and microcomputers, have been developed and used to determine the performance of agricultural tractors and implements. Al-Suhaibani *et al.* (1994)

developed a mobile instrumentation package for monitoring tractor performance. Al-Janobi and Al-Suhaibani (1996) developed a three linkage-implement transducer. Al-Suhaibani and Al-Janobi (1996) developed an instrumentation system for monitoring tractor performance. Al-Janobi *et al.* (1997) developed a precision wheel torque and weight transducer for common agricultural tractors. Al-Janobi *et al.* (1998) developed a computer based data acquisition system for monitoring the performance of agricultural tractors. Al-Janobi (2000) developed a data acquisition system for monitoring the performance of fully mounted implement. Al-Suhaibani and Al-Janobi (1997) made an extensive review on various instrumentation systems to measure the performance parameters of tractors and implements. The majority of these systems were designed exclusively for particular tractors and cannot, therefore, be easily adopted to other tractors. Most of these systems were used to measure one of the major performance parameters such as: drawbar pull, ground

Corresponding Author: S.A. Al-Suhaibani, Department of Agricultural Engineering Collage of Food Science and Agriculture, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia

speed and drive wheel speed. They, also, lack the ability to monitor and analyze fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant and engine fuel), Power Take Off (PTO) torque, position of front wheel steering and angular position the lifting position of the three-point linkage.

The objective of this study was develop and evaluate a mobile instrumentation system for agriculture tractors (up to 250 hp) and implements, covering the range of the most common agricultural wheel tractor in use in Saudi Arabia.

MATERIALS AND METHODS

Development of a tractor instrumentation system:

An instrumentation system was developed and installed on a Massey Ferguson (MF) 3090 tractor to measure tractor and implement performance parameters. The instrumentation system consisted of: (a) a drawbar dynamometer, to measure drawbar pull (b) two wheel torque transducers, to measure wheel forces (c) a three-point linkage-implement force and depth transducer, to measure three-point linkage forces, (d) other transducers, to monitor ground speed, fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant and engine fuel), Power Take Off (PTO) torque, right and left position of front wheel steering and angular position and indication of the lifting position of the three-point linkage, (d) a data logger, to monitor and record data from various parameters and (e) a computer, for processing and analyzing data. The

block diagram of the instrumentation system is shown in Fig. 1.

Drawbar dynamometer: The drawbar dynamometer consists of two load sensing clevis bolts. The force exerted by the implement was measured by a strain gauge bridge within the clevis bolts.

Wheel torque and weight transducers: Most of the wheel torque and weight transducers available on the market are designed to work on specific tractors for specific precision and are quite expensive. Thus, there is need for a general precision wheel torque transducer suitable for the most common agricultural tractors in the field. To fulfill this need, two wheel torque and weight transducers (one for the front wheel and the other for the rear wheel) suitable for common agricultural tractors were developed. These transducers were used to measure the torque and weight acting on the tractor wheels. The developed transducer replace the standard wheel center of the tractor under consideration and connected the wheel hub to the wheel rim. Figure 2 shows the tractor wheel fitted with the developed wheel torque and weight transducer. The transducer incorporated three load sensing clevis bolts. Its force measurement on the revolving wheel were combined with the measurement of angular position of the wheel by a position transducer. A shaft encoder was used to determine the total horizontal and vertical components of forces.

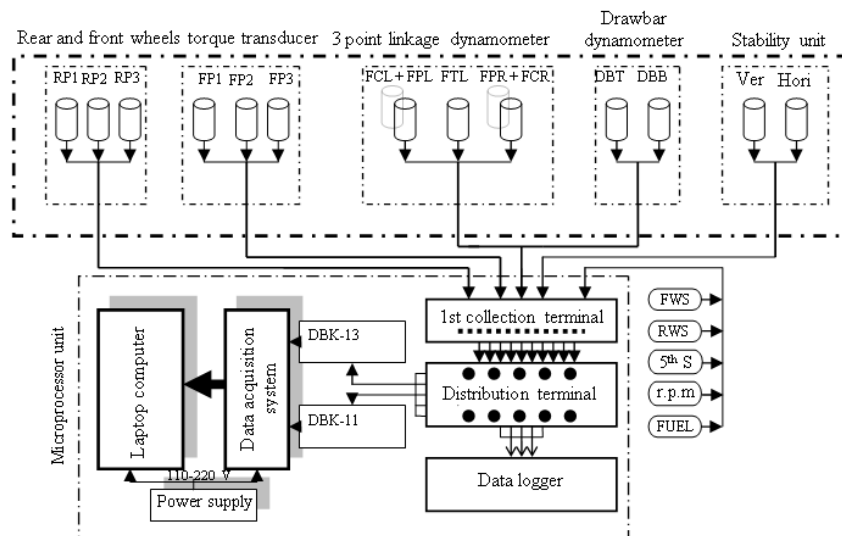


Fig. 1: The microprocessor unit



Fig. 2: The tractor wheel fitted with the wheel torque and weight transducer



Fig. 3: The 5th wheel for measuring speed

Three-point linkage-implement force and depth transducer: A three-point linkage-implement force and depth transducer was developed for the MF 3090 tractor as a tool for measuring the draft forces. It was designed specifically for use with mounted implements of categories II (40-100 hp) and III (80-225 hp) as specified by ASAE Standard (1985), measuring forces in the longitudinal and vertical planes. The lower links of the three-point linkage dynamometer were modified to accommodate the sensing elements by preserving the original geometry and the use of the Power Take Off (PTO) shaft was not restricted.

Other sensors: The tractor ground speed was measured using a fifth wheel attached to a suitable position underneath the tractor as shown in Fig. 3. An RS shaft encoder (360 pulses/revolution) was mounted on the fifth wheel and used to measure the distance traveled and hence the actual ground speed. Fuel consumed was measured by a fuel flow unit. The unit gave a single output pulse per revolution of the wheels. Engine speed

was measured by an RS optical proximity sensor mounted at the front of the tractor near to the crankshaft pulley. Fluid temperatures were measured using platinum resistance thermometers. A torque meter was used to measure the torque required to operate the Power Take Off (PTO) driven implements. Two inductive proximity sensors mounted on brackets attached to the left and right bump stops on the front axle were used to indicate the right and left position of front wheel steering.

Data logger: A data logger mounted on a platform to the left of the tractor operator was used to scan and record the output signals from the transducers. The strain gauge transducers in the instrumentation system were connected to the data logger through amplifier boxes, which also provided a regulated power supply to give excitation to the transducers. The activity unit was used to provide excitation to both the data logger and transducers with input supply from the tractor battery (12 V). It was, also, used to indicate the activity performed during field tests.

Transducer calibrating rig: A Transducer calibration rig was designed and fabricated to calibrate the major transducers in the instrumented tractor. The rig was used to calibrate the force transducers: drawbar dynamometer, wheel torque meters, Power Take Off (PTO) torque meter and three-point linkage-implement force and depth transducers. The rig could be assembled in three different modes to accommodate and calibrate the various force transducers of the instrumentation system. In the first mode, the load sensing clevis bolts (two for the drawbar dynamometer and three for each wheel torque meter) could be calibrated against a 100 kN standard load cell. In the second mode, the PTO torque meter) could be calibrated against a 5 kN standard load cell on a torque arm. In the third mode, the two EORTs and the top link load cell of the three-point linkage-implement force and depth transducer could be calibrated against a 100 kN standard load cell. The calibration procedure was similar to that reported by Al-Janobi and Al-Suhaibani (1995).

Mobile instrumentation laboratory: A self-contained mobile instrumentation laboratory was designed to accommodate all the transducers in the instrumentation system and the calibration rig for the calibration of the transducers on site. The instrumentation laboratory included a personal computer for the development of test programs and for the analysis of data on site. Figure 4 shows the mobile instrumentation laboratory with the MF 3090 tractor.

Table 1: Specifications of tillage implements

Implement	Width (mm)	Specifications
Chisel plow 1	2100	Massey Ferguson (Denmark), model MF 38. Serial No. L4078. A heavy duty type accommodating 13 shanks arranged in two rows with 355 mm between shanks in each row and 450 mm between rows. The width of shank is 60 mm and shank stem angle is 60°.
Chisel plow 2	2100	Massey Ferguson (Denmark), model MF 38. Serial No. L4078. A heavy duty type accommodating 13 shanks arranged in two rows with 355 mm between shanks in each row and 450 mm between rows. The width of shank is 70 mm and shank stem angle is 55°.
Chisel plow 3	2100	Massey Ferguson (Denmark), model MF 38. Serial No. L4078. A heavy duty type accommodating 13 shanks arranged in two rows with 355 mm between shanks in each row and 450 mm between rows. The width of shank is 223 mm and shank stem angle is 57°.
Offset disk harrow	1800	Massey Ferguson (Denmark), model MF 38. Serial No. L4082. A disk harrow with thirty six disks, 18 in each row with 210 mm between disks in each row. Each disk is 510 mm in diameter and is inclined to the direction of travel with a 45° angle.
Moldboard plow	1150	Overum-S (Sweden), model 7073331. A general purpose type with three bodies in the frame, each of 360 mm.
Disk plow	1115	EBRO (Spain), model ADE 300. A plow with three disks with 600 mm between disks and a tilt angle of 22°. Each disk is 660 mm in diameter with a disk angle of 45°.

Table 2: Operating parameters

Implement	Depth (mm)	Speed (km h ⁻¹)
Chisel plow 1	115, 160, 230	0.75, 1.20, 1.75, 2.30
Chisel plow 2	115, 160, 230	0.75, 1.20, 1.75, 2.30
Chisel plow 3	100, 150, 200	0.75, 1.20, 1.75, 2.30
Offset disk harrow	70, 115, 170	0.85, 1.30, 1.70, 2.00, 2.25, 2.50
Moldboard plow	70, 115, 170	0.85, 1.30, 1.70, 2.00, 2.25, 2.50
Disk plow	70, 115, 170	0.86, 1.30, 1.70, 2.00, 2.25, 2.50



Fig. 4: The mobile instrumentation lab and the MF-3090 instrumented tractor

Calibrating procedure: The transducers were calibrated using the relevant standard load cell and a Novatech indicator as described reported by Al-Janobi and Al-Suhaibani (1995). For each calibration test, load was applied in equal steps from zero to the maximum allowed load for the transducer under test and then reduced in approximately the same steps back to zero. A linear regression analysis was carried out on the data collected for each transducer under calibration using the lotus software package.

Field experiment: Experiments were conducted using the fully instrumented MF 3090 tractor to measure the

draft requirements of commonly used primary tillage implements on sandy loam soils over a wide range of speed and depths at the Agricultural Research and Experimental Farm of King Saud University in Dirab. A set of primary tillage implements consisting of: Three chisel plows of different shanks, an offset disk harrow, a moldboard plow and a disk plow were used in the experiments. The specifications of these implements are presented in Table 1. These implements are representative of the standard primary tillage implements most commonly used for seed bed preparation in Saudi Arabia. For the three chisel plows, four speeds and three depths were tested resulting in a total of 36 treatments. For the other three implements, six speeds and three depths were tested resulting in a total of 54 treatments. The values of the operating parameters are presented in Table 2. All treatment were replicated.

RESULTS

The developed instrumentation system consisted of: (a) a drawbar dynamometer, to measure drawbar pull (b) two wheel torque transducers, to measure wheel forces (c) a three-point linkage-implement force and depth transducer, to measure three-point linkage forces, (d) other transducers, to monitor ground speed, fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant and engine fuel), Power Take Off (PTO) torque, right and left position of front wheel steering and angular position and indication of the lifting position of the three-point linkage and (d) a data logger, to monitor and record data from various parameters.

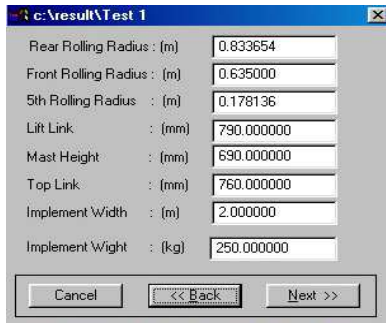


Fig. 5: A screen showing input data

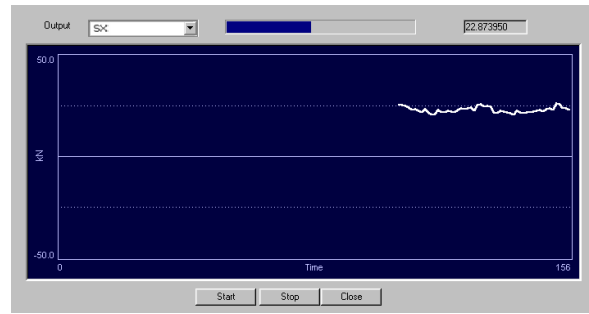


Fig. 8: A screen showing the results of a performance components (SX) presented in a curve

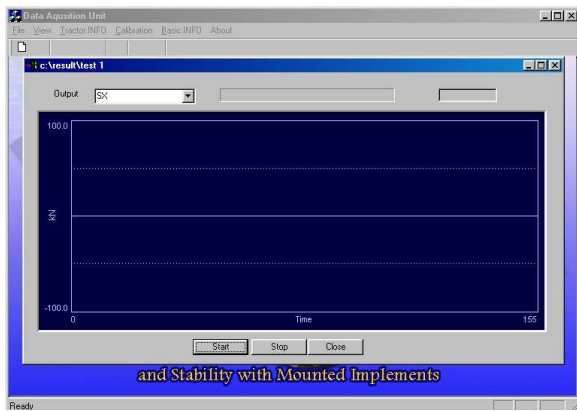


Fig. 6: A screen from the results file before requesting a specific data presentation

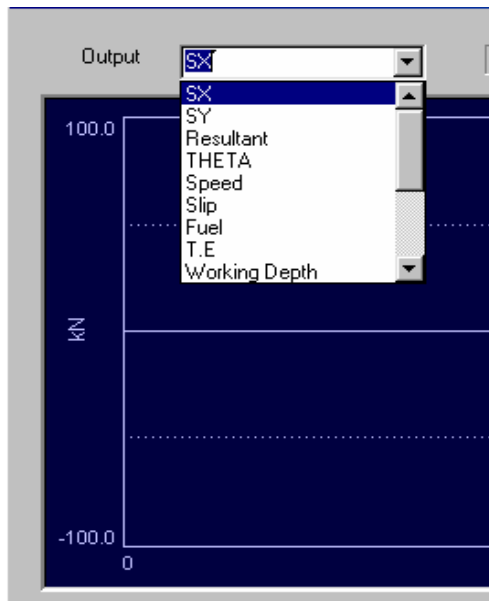


Fig. 7: A screen showing the requested performance components (SX)

Other developments included: (a) designing an electric circuit to determine the angle of the first transducer on front and rear wheels, (b) changing the design of the fifth wheel to become smaller and wider, (c) increasing the number of pulses from 20-360 pulses/turn in order to increase the accuracy of reading of the actual tractor speed and (d) developing a microprocessor unit (which included a laptop computer, two data acquisition cards and a speed signal conditioning circuit) with an interactive screen for monitoring the performance of the tractor and the mounted implement using Visual C++ programming tools.

The wheel torque and weight transducers measured the torque and forces acting on the tractor wheels with high accuracy. The other transducers measured the vertical and the horizontal forces on mounted implements of categories II (40-100 hp) and III (80-225 hp). The on-board data logger recorded the implement draft and working depth and tractor speed during field operations.

The laptop displayed the values of the measured parameters and analyzed the data simultaneously in a well-designed format. It, also, provided information on faulty transducers (signals) and on the stability of the tractor. The computer program consisted of three sub-programs to: (a) scan sensors (up to 10 scans sec^{-1}), (b) convert signals to engineering values and (c) process the data and presenting the results (digital values or curves). A screen showing input data is presented in Fig. 5 while Fig. 6 shows a screen before requesting a specific data presentation. Figure 7 shows a screen in which a specific performance component (SX) is requested. Figure 8 shows the results of a specific performance component (SX) presented in a curve.

The average values of draft for all the implements obtained during the tillage experiments are presented in Table 3. These results presented in Fig. 9 and 10 showed a significant increase in draft with increases in tillage depth and speed for all tillage implements.

Table 3: Draft (KN) measurements made during the field experiment

Implement	Average speed (m sec ⁻¹)	First depth		Second depth		Third depth	
		Mean	SD	Mean	SD	Mean	SD
Offset disk harrow	0.84	2.15	0.517	3.08	0.060	5.62	0.456
	1.39	3.26	0.440	4.39	0.410	6.91	0.388
	1.76	4.81	1.735	5.53	0.617	7.40	0.835
	2.02	5.46	0.156	6.57	0.587	9.56	0.656
	2.31	6.25	0.412	7.43	0.637	10.57	0.596
Moldboard plow	2.50	6.78	0.498	7.88	0.520	11.37	0.788
	0.80	4.08	0.110	5.29	0.111	8.03	0.115
	1.32	4.51	0.219	5.99	0.071	8.56	0.364
	1.68	4.99	0.250	6.69	0.298	9.01	0.241
	1.94	5.36	0.093	7.29	0.165	10.02	0.348
Disk plow	2.23	5.98	0.705	7.97	0.240	11.40	0.172
	2.53	6.79	0.594	9.21	0.100	13.00	0.398
	0.86	3.50	0.102	5.34	0.134	6.76	0.078
	1.27	4.15	0.146	5.51	0.173	7.15	0.059
	1.60	5.10	0.185	6.25	0.113	8.09	0.661
Chisel plow 1	1.90	6.11	0.174	6.96	0.168	8.76	0.308
	2.18	7.30	0.617	7.99	0.449	9.56	0.532
	2.54	8.96	0.225	9.91	0.229	11.13	0.305
	0.73	3.14	0.521	5.54	0.377	8.33	0.625
	1.23	3.76	0.139	6.56	0.378	9.60	0.841
Chisel plow 2	1.74	4.11	0.236	7.41	0.142	10.58	0.103
	2.37	4.59	0.247	8.01	0.684	11.92	1.113
	0.74	3.01	0.235	5.38	0.338	8.19	0.146
	1.17	3.61	0.172	6.44	0.279	9.47	0.178
Chisel Plow 3	1.82	3.74	0.161	7.11	0.221	10.51	0.754
	2.30	4.37	0.264	7.85	0.296	11.33	0.427
	0.72	7.52	0.593	11.00	0.717	15.9	0.841
	1.19	7.86	0.285	11.49	0.421	16.58	0.652
	1.75	8.13	0.112	11.84	0.513	17.13	0.579
	2.30	8.41	0.673	12.34	0.597	18.31	0.979

SD: Standard Deviation

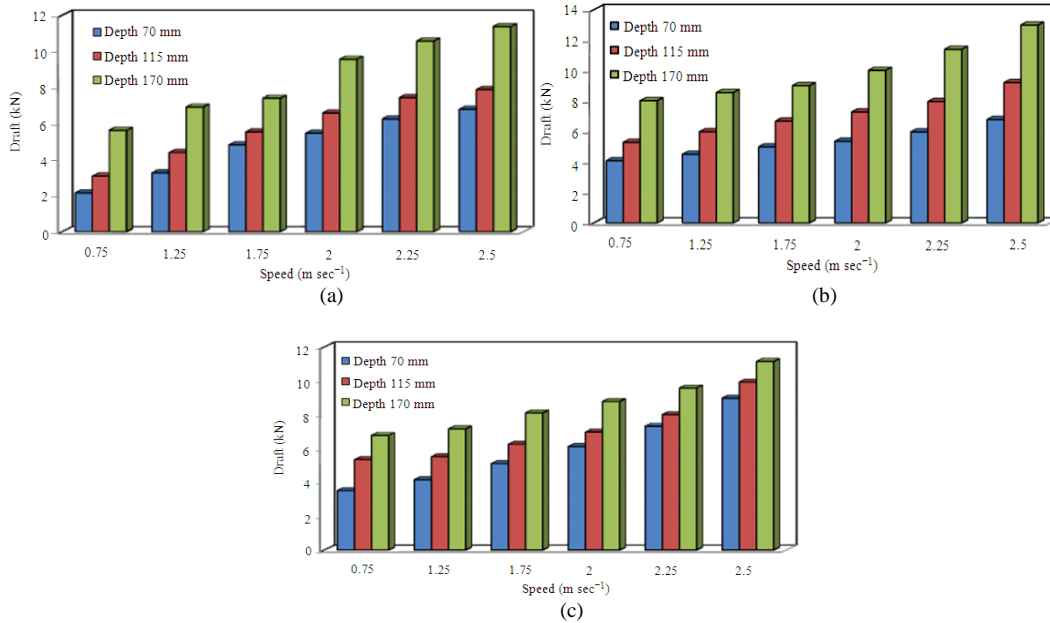


Fig. 9: Effects of tillage depth and speed on the draft of offset disk harrow, moldboard plow and disk plow (a) offset disk harrow; (b) moldboard plow; (c) disk plow

Table 4: Regression coefficients

Implement	Draft unit	Regression coefficients symbol	Probability value	(P)	R ²
Offset disk harrow	N mm ⁻¹	β ₀	3.08990		0.9873
		β ₁	-0.43580	0.0001	
		β ₂	0.01920	0.0001	
		β ₃	0.02290	0.0001	
		β ₄	0.02510	0.0577	
Moldboard plow	N mm ⁻¹	β ₅	0.01070	0.0654	0.9939
		β ₀	0.46400		
		β ₁	-0.38300	0.0001	
		β ₂	0.01990	0.0003	
		β ₃	-0.84210	0.0001	
Disk plow	N mm ⁻¹	β ₄	0.07520	0.0001	0.9958
		β ₅	0.03140	0.0001	
		β ₀	1.39270		
		β ₁	0.11370	0.0001	
		β ₂	0.00790	0.0161	
Chisel plow 1	N/tool	β ₃	-0.01382	0.0001	0.9995
		β ₄	0.09060	0.0001	
		β ₅	0.01730	0.0011	
		β ₀	-19.54600		
		β ₁	21.68400	0.0000	
Chisel plow 2	N/tool	β ₂	0.43620	0.0646	0.9961
		β ₃	16.90800	0.0000	
		β ₄	-1.77300	0.0017	
		β ₅	2.97500	0.0000	
		β ₀	-63.18800		
Chisel	N/tool plow 3	β ₁	26.06700	0.0000	0.9989
		β ₂	0.41290	0.5827	
		β ₃	20.05100	0.0000	
		β ₄	-1.66400	0.1600	
		β ₅	2.34200	0.0078	
		β ₀	94.18500		0.9989
		β ₁	40.18300	0.0000	
		β ₂	0.23630	0.5855	
		β ₃	-14.34900	0.0000	
		β ₄	0.20230	0.2261	
		β ₅	1.97480	0.0027	

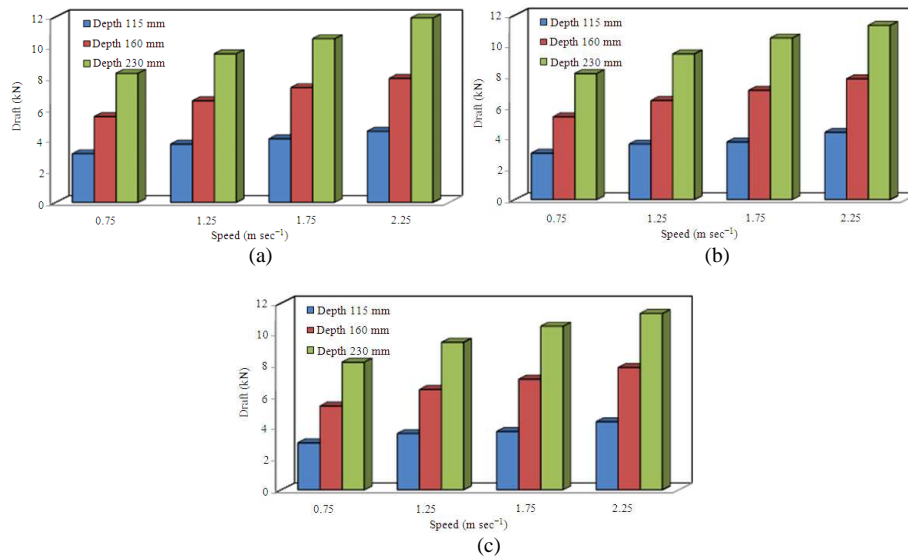


Fig. 10: Effects of tillage depth and speed on the draft of various chisel plows (a) Chisel Plow 1; (b) Chisel Plow 2; (c) Chisel Plow 3

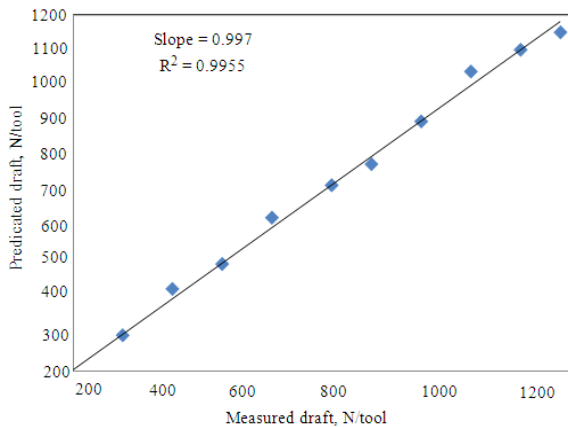


Fig. 11: Predicted and measured values of chisel plow 1

For all tillage implements (except the chisel plows), the draft was divided by the implement width to obtain the specific draft (draft per unit width), whereas the draft was divided by the number of tools to obtain the specific draft (draft per tool) for the chisel plows. A multiple regression analysis was performed on the calculated values of specific drafts of all implements using the General Linear Model (GLM) procedure of Brocklebank and Dickey (1986). The general form of the equation used in this analysis was a function of travel speed and tillage depth. The regression equation that that gave the best fit with a maximum coefficient of regression (R^2) is as follows:

$$UD = \beta_0 + \beta_1 D + \beta_2 D^2 + \beta_3 S + \beta_4 S^2 + \beta_5 DS \quad (1)$$

Where:

- UD = Unit draft ($N\ mm^{-1}$ or $N/tool$)
- D = Tillage depth (cm)
- S = Travel speed ($km\ h^{-1}$)
- $\beta_{0, 1, 2, 3, 4, 5}$ = Regression coefficient (-)

The above equation can be used to predict the unit draft for various agricultural implements operating on sandy loam soil within the ranges of speeds and depths used in this study. Table 4 shows the regression coefficients for the implements tested on a sandy loam soil.

DISCUSSION

The data acquisition system performed well during the field operation and the results obtained showed that the accuracies of the transducers were acceptable. The system proved to be an effective means of measuring and recording the draft of four primary tillage implements on

sandy loam soils at various speeds and depths. The average values of draft showed a significant increase in draft with increases in tillage depth and speed for all tillage implements. However, the depth had the most effect on the specific draft. The Regression equation was used to predict the unit draft for the chisel plow 1. The results showed that unit draft can be predicted reasonably ($R^2 = 0.998$). The predicted values showed a good fit with experimental results as shown in Fig. 11.

CONCLUSION

An instrumentation system was developed and installed on a Massey Ferguson (MF) 3090 tractor to measure and evaluate tractor and implement performance parameters. The instrumentation system consisted of: (a) a drawbar dynamometer, to measure drawbar pull (b) two wheel torque transducers, to measure wheel forces (c) a three-point linkage-implement force and depth transducer, to measure three-point linkage forces, (d) other transducers, to monitor ground speed, fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant and engine fuel), Power Take Off (PTO) torque, right and left position of front wheel steering and angular position and indication of the lifting position of the three-point linkage and (d) a data logger, to monitor and record data from various parameters.

Other developments included: (a) designing an electric circuit to determine the angle of the first transducer on front and rear wheels, (b) changing the design of the fifth wheel to become smaller and wider, (c) increasing the number of pulses from 20-360 pulses/turn in order to increase the accuracy of reading of the actual tractor speed and (d) developing a microprocessor unit with an interactive screen for monitoring the performance of the tractor and the mounted implement using Visual C++ programming tools.

The system performed well during the field operation and the results obtained showed that the accuracies of the transducers were acceptable. The wheel torque and weight transducers measured the torque and forces acting on the tractor wheels with high accuracy. The other transducers measured the vertical and the horizontal forces on mounted implements of categories II (40-100 hp) and III (80-225 hp) with high accuracy. The system was capable of measuring and recording data for primary tillage implements on sandy loam soils at various speeds and depths. The data was displayed and analyzed simultaneously. A general regression equation to predict the draft of the implements was developed.

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