A novel three-point hitch dynamometer to measure the draft requirement of mounted implements

M. Askari, M.H. Komarizade, A.M. Nikbakht, N. Nobakht, R.F. Teimourlou

Department of Agricultural Machinery Engineering, Faculty of Agriculture, Urmia University, Urmia, Iran

Abstract

Askari M., Komarizade M.H., Nikbakht A.M., Nobakht N., Teimourlou R.F., 2011. **A novel three-point hitch dynamometer to measure the draft requirement of mounted implements**. Res. Agr. Eng., *57*: 128–136.

An adjustable three-point hitch dynamometer with a draft capacity of 50 kN was developed to measure forces on the tractor and mounted implements. The design concept of the dynamometer was based on two linkage frames mounted between tractor links and the implement. The force sensing elements were comprised of a loadcell that was installed between the frames. The system provides variable width and height of the dynamometer links to satisfy a wide range of implement dimensions. All mounted tillage implements at categories II and III such as plows, cultivators and harrows were able to be tested by this dynamometer excluding mounted implements powered by power take-off (PTO). The dynamometer was calibrated and several field tests were conducted to measure the force required to pull a moldboard plow in a clay loam soil. The calibration showed a high degree of linearity between the draft requirements and the dynamometer outputs. Field tests showed that it was able to function effectively as intended without any mechanical problems.

Keywords: dynamometer; adjustable; linkage frames; loadcell; draft

Energy management on farms will be of paramount importance in future years. This will be brought about by the increased cost of all forms of energy and the need to do field operation and produce crops with optimization of inputs (Chaplin et al. 1987). Tillage energy represents a considerable portion of the energy utilized in crop production. The availability of draft requirement data for tillage implements is an important factor in selecting suitable tillage implement for a particular farming situation (Alimardani et al. 2008). On the other hand, the forces exerted by the implement on the tractor play an important role in the tractor performance, such as the traction, steering control, etc. Therefore, prediction of implement draft requirement is important for tractor selection and implement adaptability (Al-Janobi, Al-Suhaibani 1998).

In general, measuring the draft requirements of tillage tools is accomplished by the dynamometers which in turn could be grouped into two major categories; drawbar dynamometers and three-point hitch dynamometers. Drawbar dynamometers are designed to measure the forces exerted by pull type implements on the tractor drawbar (Chen et al. 2007). These dynamometers have been extensively studied by many researchers (Godwin 1975; Zoerb 1983; Godwin et al. 1993; Kirisci et al. 1993; Chen 2007).

Mounted implements necessitate the use of three-point hitch dynamometers to determine the forces between the tractors and implements (Aljalil et al. 2001). The mechanical design of three-point hitch dynamometers could be divided into two categories; either the force sensors were installed on the tractor arms or on a frame or frames which are mounted between the tractor and implement as described by Palmer (1992). The preliminary attempts to measure the forces between tractor and mounted implement were made by measuring the forces in links themselves. This required simultaneous recording of at least three forces which involved very complicated instrumentation. This method was used by many researchers (Reece 1961; Morling 1963; Scholtz 1964; Luth et al. 1978; Upadhyaya et al. 1985). Alternatively, the sensors can also be attached on the frame or frames between the implement and the tractor linkage. This approach was also used by many researchers (Scholtz 1966; Johnson, Voorhees 1979; Smith, Barker 1982; Reid et al. 1983; Chaplin et al. 1987; Aljalil et al. 2001; Kheiralla et al. 2003; Alimardani et al. 2008). It had the advantage of allowing easy segregation of the forces exerted by the implement on the tractor into horizontal, vertical and side forces and their moments. However, this system moves the implement backward and adds additional weight to the tractor-implement system.

A large number of the frame type three-point hitch dynamometers are rigid and built to standard dimensions to fit either or both category II and III hitches. Quick couplers are used to overcome the difficulty of attaching the implement to the dynamometer. These dynamometers are able to measure only horizontal (draft requirement) and vertical forces with high accuracy and usually don't measure side force. Severe side force can affect tractor steering ability. However, the side force is generally negligible during field operation (Godwin 1975; Leonard 1980), even though it may be significant during transportation on the road. The transportation of mounted equipment on the road and on rough field tracks can impose large shock loads to the dynamometer which have been proved to reduce the fatigue life of the implements (Palmer 1984).

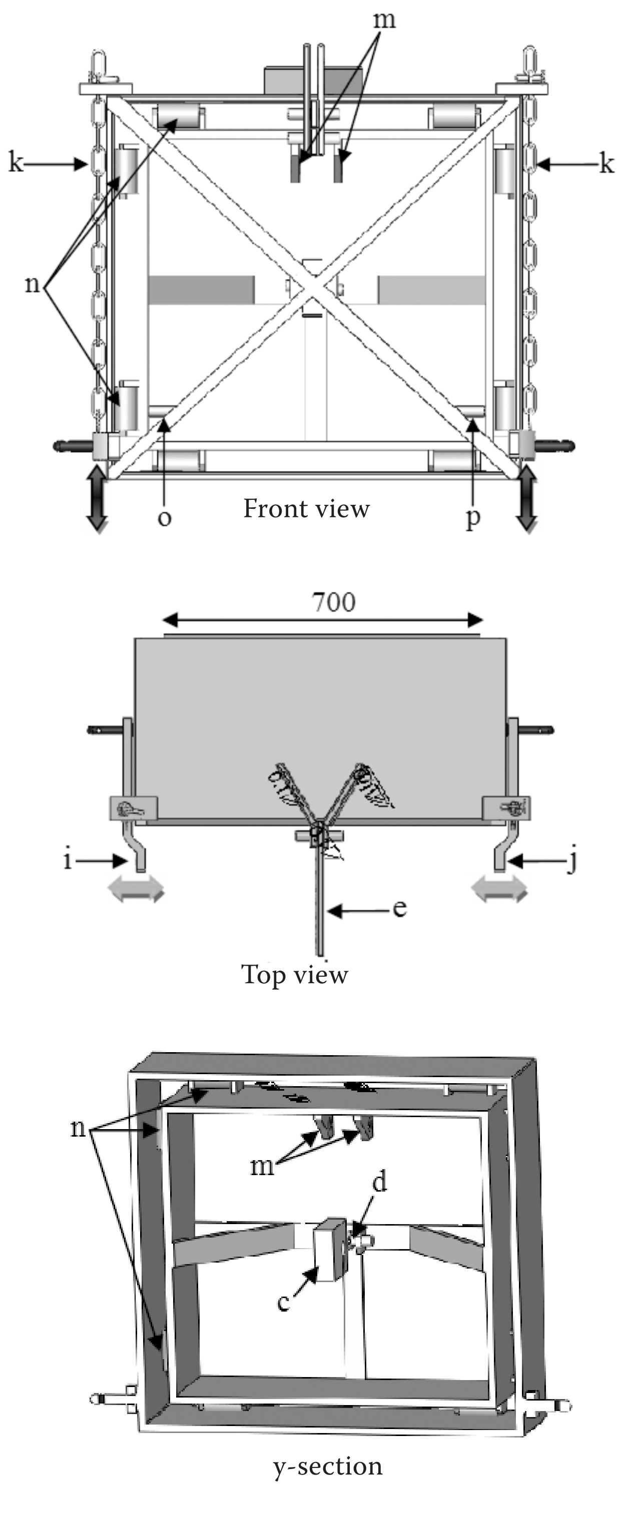
The objective of this work is to design, construct and calibration of a novel adjustable frame type three-point hitch dynamometer that can fit most of implements with category II and III. This system is able to directly measure the draft requirement of mounted tillage implements by using a single loadcell.

MATERIAL AND METHODS

Dynamometer design

The design of the three-point hitch dynamometer is shown in Fig. 1. Dynamometer was modeled in Solid Works 2009 modeling package. It was consisted of two frames, one of them placed inside of the other and the frames could move easily in travel direction by using installed rollers on the internal frame but this motion was hindered by a loadcell installed between the frames. On both frames of dynamometer the three-point linkages were installed so that the dynamometer could be placed between the tractor and the implement. Three links consisting of i, j and e as shown in Fig. 1, were attached to the implement where link e was fixed while the other two (i and j) could be easily moved vertically and horizontally by changing the length of chain system. The minimum and maximum distance between links i and j was 750 and 1,200 mm, respectively. Such arrangement provides variable width and height of the dynamometer links to satisfy a wide range of implement dimensions with category II and III (Fig. 1). It also facilitates attaching the dynamometer to the implement without the need for quick couplers. It was decided to allow the rearward displacement of the implement to be as much as 120 mm according to ASAE standard S278.6 (ASAE Standards 1998) which has proposed the size of implements 127 mm for categories II and III and 103 mm for category I.

Three arms of tractor were connected to o, p and m links. When the tractor was pulling the mounted implements, the frames moved inversely in travel direction and the installed loadcell between two frames could measure the implement draft requirement. The dynamometer was considered to be used with a FWA Massey Ferguson tractor (MF-399) (ITM, Tabriz, Iran) with a net engine power of 82 kW and rated drawbar power of 75% to 81% of its net engine power in accordance to ASAE D497.3 (ASAE Standards 1997). When this tractor was operated in its lowest gear combinations, a maximum pull of 60 kN would be developed. Maximum draft force that was measured by dynamometer was 50 kN. This was equal to capacity of installed loadcell on the dynamometer. The maximum force and torque on the dynamometer was investigated in two positions; field operation and transport position. In the field operation, the maximum force and torque on the dynamometer was calculated by



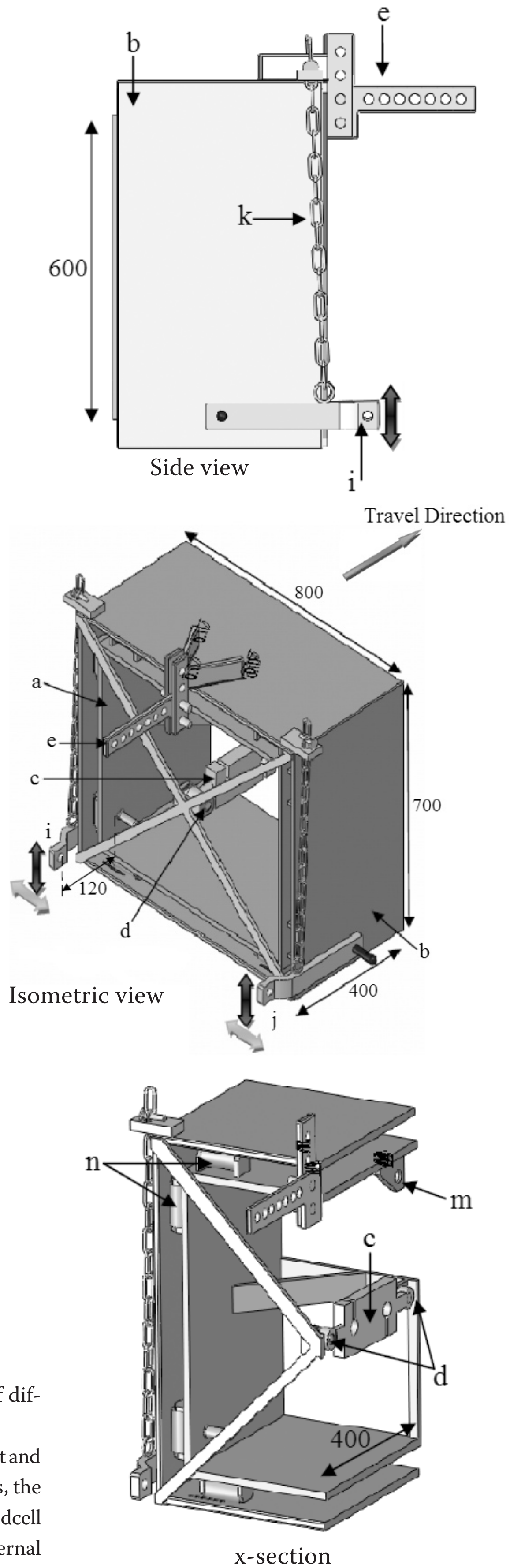


Fig. 1. Three-point hitch dynamometer showing disposition of different components
(i), (j) and (e) linkages on external frame (b) could connect to implement and (o), (p) and (m) linkages on internal frame (a) were for tractor arms, the external and internal frames were connected by loadcell (c), (d) is loadcell linkages, (k) is chain system and (n) is installed rollers on the internal frame (dimensions in mm)

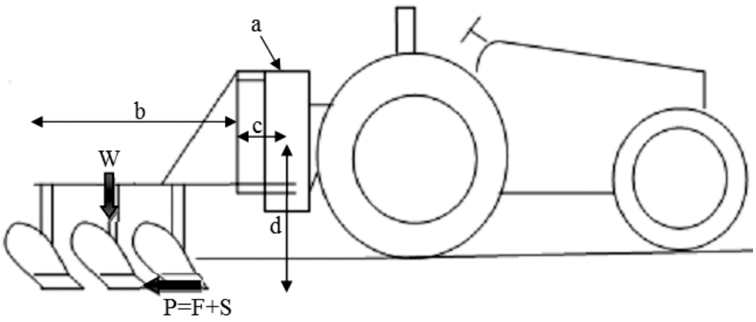


Fig. 2. The acting forces on the implement and supposed dimensions of dynamometer-mounted implement system in field operation (W) implement weight, (P) draft requirement, (F) soil resistance, (S) friction force; (*a*) dynamometer, (*b*) implement prolongation, (*c*) distance between implement junction into dynamometer links and center of dynamometer frames, (*d*) distance between P and center of dynamometer frames

considering the maximum draft requirement and maximum implement weight that were 50kN and 15 kN, respectively. The draft requirement consists of two parts; soil resistance and friction force. The maximum amounts of implement prolongation, vertical distance between draft requirement and center of dynamometer frames and horizontal distance between implement junction into dynamometer links and center of frames was investigated, too. These amounts were 200, 70 and 30 cm, respectively (Fig. 2). According to Fig. 2 and substituting P = 50 kN, d = 0.7 m, W = 15 kN, b = 2 m and c = 0.3 m, the resulting P × d and W × (b/2 + c) equal 35 kNm and 19.5 kNm, respectively.

It shows that the transportation of mounted equipment imposed large loads to the dynamometer. These loads are greater than those to be calculated when the implement is in work. Consequently, dynamometer strength was investigated in Solid Works simulation software in transport position. Material of dynamometer for stress and strain analysis was defined as steel AISI 1020. The results

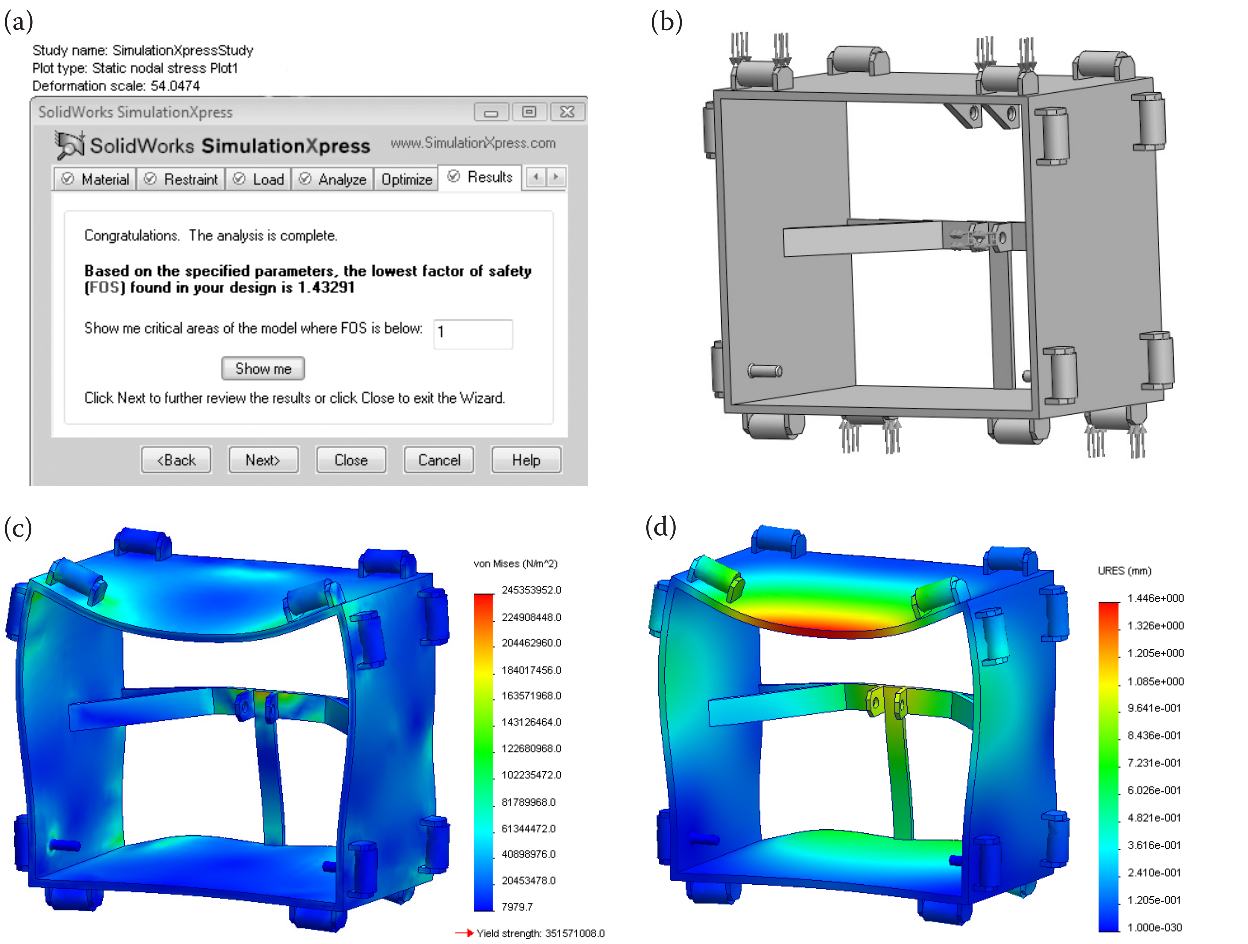


Fig. 3. Model analysis in internal frame: (a) factor of safety and deformation scale (b) exerted forces (c) stress (d) strain

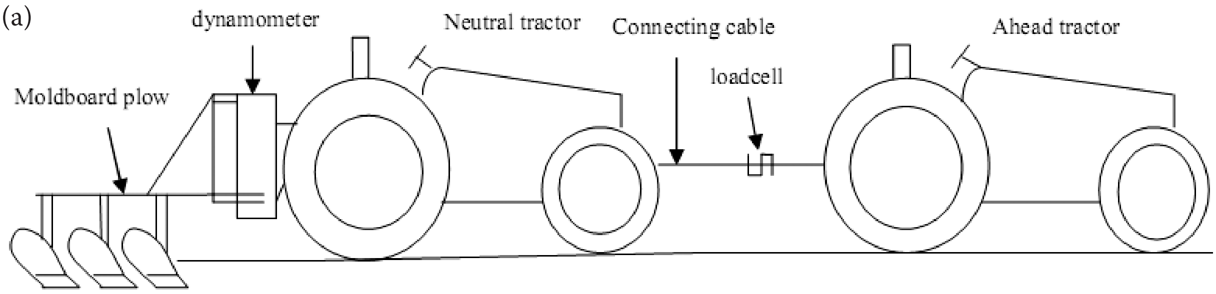


Fig. 4. Field calibration of the dynamometer: (a) frontal tractor pulled the neutral tractor-dynamometer-moldboard plow system (b) frontal tractor pulled the neutral tractor and dynamometer

of model analysis in internal frame was shown, for example, in Fig. 3 which proved that the supposed sizes of dynamometer frames, links, etc., were suitable and reliable. The analysis of stress model in internal frame showed that the factor of safety (FOS) of this frame was 1.43. At the second step, the designed dynamometer was fabricated to be used for measuring the draft requirement of the mounted implements. Ultimately, the weight of dynamometer including frames, loadcell, links, and interfacing members (rollers) becomes 200 kg.

Calibration

Before the calibration of the dynamometer, it was necessary to adjust and calibrate the data acquisition system consisting of loadcell, amplifier multiplexer and data logger. BS-7220 data logger in this work could recognize several different loadcells and was calibrated automatically by entering the loadcell properties. The calibration of the other parts was measured by applying known forces and recording the electrical gain response. The coefficient of determination (R^2), for linearity equation was obtained to be 1.0. The three-point hitch dynamometer was mounted between a tractor and a moldboard plow for field calibration. Two FWA Massey Ferguson tractors (MF-399) were applied in the field calibration. These tractors are popular and widely used in the country. A calibrated loadcell with a capacity of 50 kN was also used. The field calibration was divided into two stages. First, the neutral tractor-dynamometer-moldboard plow system was pulled by another (frontal) tractor through a connecting cable and 50 kN loadcell (Fig. 4a). Different loads were obtained by driving the foregoing tractor with the variable forward speed. The data of loadcell installed between the tractors were recorded to get the horizontal force which was representing the pull force. In the next stage, frontal tractor pulled the neutral tractor and dynamometer (Fig. 4b). In this stage, the data of loadcell were recorded. The difference between the two data series of 50 kN loadcell was draft requirement of moldboard

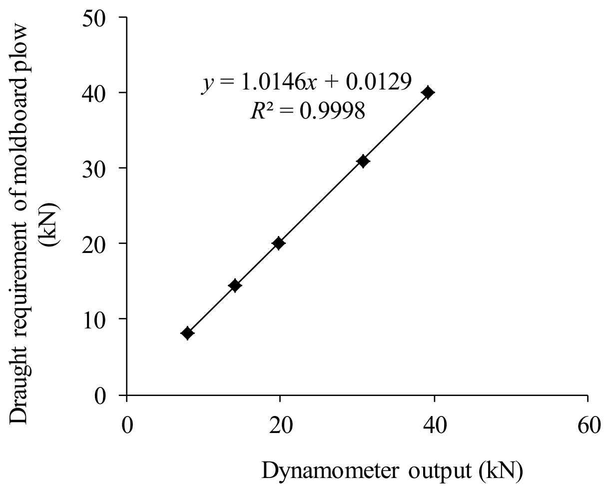


Fig. 5. Field calibration curve of the dynamometer

Fig. 6. Field test of the dynamometer

plow that should be equal to the data recorded by the dynamometer. The recorded data of dynamometer were plotted against draft requirement to form the calibration curve shown in Fig. 5. The calibration curve showed a high degree of linearity between dynamometer output and the draft requirement. The coefficient of determination (R^2), for linearity equation was resulted to be 0.999.

Data acquisition system

The used instruments were a commercial loadcell connected to an amplifier multiplexer, a data logger and a notebook computer. The loadcell had a force capacity of approximately 50 kN which provided adequate sensitivity and sufficient strength for the high power range. The signals from the loadcell were multiplexed and amplified by the PCLD-789 amplifier multiplexer board (Advantech Co., Ltd., Taipei, Taiwan). The power to the amplifier multiplexer was supplied by the computer. The amplified signals were digitized in the data logger BS-7220 (Bongshin Co., Ltd., Incheon, Korea), which were then transferred to the notebook computer and stored temporarily in the computer memory as it is received at the end of each measuring interval. The data logger and notebook computer would be carried on the tractor and powered from the tractor electric system by a 12 V direct current to 240 V alternate current inverter with a nominal 600 W load capacity.

Field tests

The dynamometer and data acquisition system for the test and evaluation were transferred to the field. This field area was earlier established for barley. A moldboard plow (3–40 cm) and a FWA Massey Ferguson tractor (MF-399) were used (Fig. 6). The tested dynamometer was placed between the plow frame and tractor while data logger and notebook computer were located on a metal tray next to the operator. Tests were performed at the depth of 20 cm and average speed of 3.1 km/h, in a route of 30 m. Before experiments, the dynamometer was horizontally adjusted relative to ground surface (parallel to ground surface). The data acquisition was accomplished at the distance interval of 10–25 m of the 30 m field plot. The data logger was adjusted to record the dynamometer signals with frequency of 1.2 Hz (72 data in min).

The affecting properties and parameters of soil on draft force and required energy include: soil moisture content, bulk density, cone index and soil structure (Upadhyaya et al. 1984). These parameters as the major influencing parameters on the draft force were analyzed in a clay loam soil (43% clay, 29% sand and 28% silt). Penetration tests were conducted at 15 points from 0 to 20 cm deep using a manually operated penetrometer (Rimik CP20-UK,

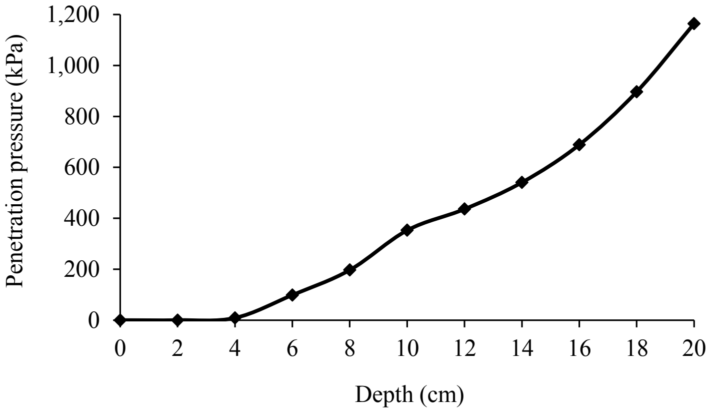


Fig. 7. Results of penetrometry tests of field soil

Table 1. Obtained data from soil analysis at 5 points and 2 depths consisting of 0–10 and 10–20 cm

Depth (cm)	Mass water content (dry base)	Porosity	Void ratio	Particle density (g/cm^3)	Degree of saturation
A10	9	0.538	1.16	2.5	0.205
A20	8.1	0.547	1.21	2.4	0.176
B10	8.9	0.536	1.15	2.5	0.205
B20	8.5	0.460	0.85	2.4	0.263
C10	7.2	0.504	1.02	2.5	0.189
C20	7.4	0.495	0.98	2.6	0.199
D10	7.5	0.515	1.06	2.4	0.189
D20	8.2	0.485	0.94	2.5	0.230
E10	9.7	0.524	1.1	2.5	0.233
E20	8.1	0.567	1.31	2.6	0.164

A, B, C, D, E – five points of sampling and numbers in front of them are explanatory of sample depth

Rimik, Queensland, Australia). Detailed results of these tests are depicted in Fig 7.

Soil moisture and other physical properties were measured at 5 points (A, B, C, D and E) and two ranges of soil depth (0–10 and 10–20 cm). Soil samples were weighed, oven dried at 105°C for 24 h and weighed again. Results are detailed in Table 1.

RESULTS AND DISCUSSION

Results of measuring the draft requirement of moldboard plow in field tests is illustrated in Fig 8. It is of importance that the changes in draft resistance are caused due to soil failure. To assess and confirm the measured forces by the dynamometer, ASABE standards D497.5 (ASABE Standards 2006) expressed as Eq. (1) was used. Parameters related to soil and tool were determined and applied.

$$D = F_i\,[A + B\,(S) + C\,(S)^2]\;W \times T \qquad (1)$$

where:

- D – horizontal draft force
- F_i – parameter related to soil (soil texture was clay loam and $F_1 = 1.0$)
- A, B, C – specific amounts for tool (for moldboard plow A = 652, B = 0 and C = 5.1)
- S – forward speed of tractor
- W – width
- T – working depth of tillage tool

Magnitude of D was calculated to be 16.8 kN for forward speed of 3.1 km/h, depth of 20 cm, and a work width of 120 cm. With regard to the 40% deviation proposed by ASAE standard, calculated magnitude of D is a number within ranges of 10 to 23.5 kN. The average horizontal force measured in field test was 14.7 kN (average of 21 numbers drawn out from the recorded data file of Fig. 8) which is close to the calculated draft force. The error of magnitude D between measurement and calculation were ±12%. Using more repetitions error can be significantly reduced.

Field tests showed that the dynamometer can measure the draft requirement with high accuracy and data acquisition system can record the data instantaneously. Different sets of force sensing elements can be attached and arranged between the installed rollers on the internal frame and external frame to detect the exerted forces on the rollers so that both lateral and vertical forces can be measured. It will allow measurement of horizontal, lateral and vertical forces simultaneously, and therefore, the implement force on the tractor could be completely defined.

CONCLUSION

Implements attached to the three-point hitch of tractor are categorized as mounted implements. The knowledge of the forces between mounted implement and tractor is considered by designer which justifies the needs of a three-point hitch dynamometer. The adjustable three-point hitch dynamometer described in this paper provides the measurement of draft force imposed on agricultural tractors by mounted implements that can fit most of imple-

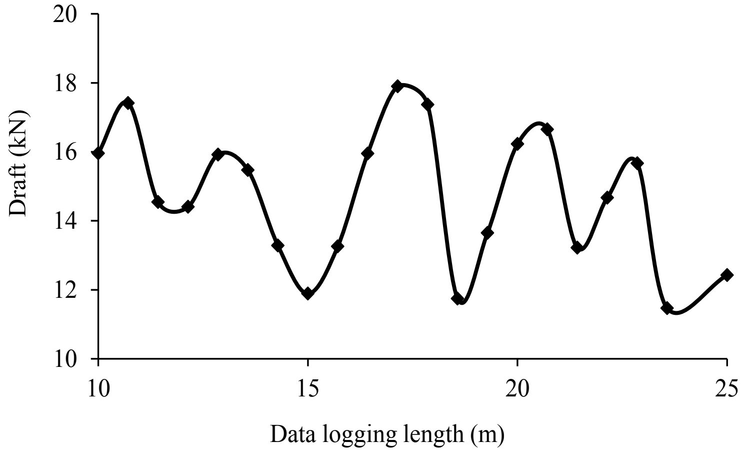


Fig. 8. Draft force of the moldboard plow obtained in field test

ments with category II and III. The novel arrangement of the dynamometer links makes it suitable for a wide range of implements, and facilitates attaching the implement to the device. The dynamometer introduced in this research is a novel and premier design which used a single loadcell to measure the draft force of mounted implements. The design was considered successful and the dynamometer can be utilized for field measurements on tillage implements for draft requirement up to 50 kN. The stiffness of the dynamometer to applied forces was very high and resulted in small deflections at the implement at maximum design load. The calibration showed a high degree of linearity between the draft requirements and the dynamometer outputs. Dynamometer performed well under a field condition where the draft requirement of a moldboard plow was measured. The mass of the dynamometer was 200 kg. This mass and the rearward displacement of the implement by 120 mm, which of course allowed by ASAE S278.6 (ASAE Standards 1998) for implements of categories II and III may alter the dynamic characteristics of the tractor/implement system and may limit the usefulness of this dynamometer in the study of shock loads and other dynamic effects.

References

Aljalil H.F., Khadir A., Mukahal W., 2001. Design and performance of an adjustable three point hitch dynamometer. Soil &Tillage Research, *62*: 153–156.

Alimardani R., Fazel Z., Akram A., Mahmoudi A., Varnamkhasti M.G., 2008. Design and development of a three-point hitch dynamometer. Journal of Agricultural Technology, *4*: 37–52.

Al-Janobi A.A., Al-Suhaibani S.A., 1998. Draft of primary tillage implements in sandy loam soil. Transactions of the ASAE, *14*: 343–348.

ASAE Standards, 1998. ASAE S278.6, Attachment of implements to agricultural wheel tractors equipped with quick attaching coupler. Available at www.asabe.org

ASAE Standards, 1997. ASAE D497.3, Agricultural machinery management data. Available at www.asabe.org

ASABE Standards, 2006. ASAE D497.5, Agricultural machinery management data. Available at www.asabe.org

Chaplin J., Lueders M., Zhao Y., 1987. Three-point hitch dynamometer design and calibration. Applied Engineering in Agriculture, *3*: 10–13.

Chen Y., McLaughlin N.B., Tessier S., 2007. Double extended octagonal ring (DEOR) drawbar dynamometer. Soil &Tillage Research, *93*: 462–471.

Godwin R.J., 1975. An extended octagonal ring transducer for use in tillage studies. Journal of Agricultural Engineering Research, *20*: 347–352.

Godwin R.J., Reynolds A.J., O'Dogherty M.J., Al-Ghazal A.A., 1993. A triaxial dynamometer for force and management measurement on tillage implements. Journal of Agricultural Engineering Research, *55*: 189–205.

Johnson C.E., Voorhees W.B., 1979. A force dynamometer for three-point (tractor) hitches. Transactions of the ASAE, *22*: 226–228.

Kheiralla A.F., Yahya A., Zohadie M., Ishak W., 2003. Design and development of a three-point auto hitch dynamometer for an agricultural tractor. ASEAN Journal on Science and Technology for Development, *20*: 271–288.

Kirisci V., Blackmore B.S., Godwin R.J., Blake J., 1993. Design and calibration of three different three-point linkage dynamometers. ASAE/CSAE Paper No. 93-1009. St. Joseph, ASAE.

Leonard J.J., 1980. An extended-octagon rigid drawbar dynamometer. Agricultural Engineering Australia, *9*: 3–8.

Luth H.T., Floyd V.G., Heise R.P., 1978. Evaluation energy requirements of machines in the field. ASAE Paper 78-1538. St. Joseph, ASAE.

Morling R.W., 1963. Soil force analysis as applied to tillage equipment. ASAE Paper 63-149. St. Joseph, ASAE.

Palmer J., 1984. Evaluation of peak loads and load cycles of implements in soil. ASAE Paper 84-1550. St. Joseph, ASAE.

Palmer A.L., 1992. Development of a three-point-linkage dynamometer for tillage research. Journal of Agricultural Engineering Research, *52*: 157–167.

Reece A.R., 1961. A three-point-linkage dynamometer. Journal of Agricultural Engineering Research, *6*: 45–50.

Reid J.T., Carter L.M., Clark R.L., 1983. Draft measurements with a three-point dynamometer. ASAE Paper 83-1036. St. Joseph, ASAE.

Scholtz D.C., 1964. A three-point linkage dynamometer for mounted implements. Journal of Agricultural Engineering Research, *9*: 252–258.

Scholtz D.C., 1966. A three-point linkage dynamometer for restrained linkages. Journal of Agricultural Engineering Research, *11*: 33–37.

Smith L.A., Barker G.L., 1982. Equipment to monitor field energy requirements. Transactions of the ASAE, *25*: 1556–1559.

Upadhyaya S.K., Williams T.H., Kemble L.J., Collins N.E., 1984. Energy requirement for chiseling in coastal plain soils. Transactions of the ASAE, *27*: 1643–1649.

Upadhyaya S.K., Kemble L.J., Collins N.E., Camargo F.A., 1985. Accuracy of mounted implement draft prediction using strain gauge mounted directly on three-point hitch linkage system. Transactions of the ASAE, *28*: 40–46.

Zoerb G.C., Musonda N.G., Kushwaha R.L., 1983. A combined drawbar pin and force transducer. Canadian Agricultural Engineering, *25*: 157–162.

Received for publication February 21, 2011
Accepted after corrections May 30, 2011

Corresponding author:

A.M. Nikbakht, Urmia University, Faculty of Agriculture, Department of Agricultural Machinery Engineering, Nazloo Road, Urmia, Iran
phone: + 98 912 638 9682, fax: + 98 441 2779558, e-mail: a.nikbakht@urmia.ac.ir