ARTICLE IN PRESS
Journal of the Saudi Society of Agricultural Sciences (2015) xxx, xxx–xxx

King Saud University
Journal of the Saudi Society of Agricultural Sciences
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FULL LENGTH ARTICLE

Performance of tractor and tillage implements in clay soil

Saeed Ranjbarian [a], **Mohammad Askari** [b,*], **Javad Jannatkhah** [b]

[a] *Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agriculture, Urmia University, Urmia, Iran*
[b] *Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, P.O. Box 165, Ardabil, Iran*

Received 1 December 2014; revised 26 May 2015; accepted 26 May 2015

KEYWORDS
Implement draft;
Fuel consumption;
Traction efficiency;
Wheel slippage;
Overall energy efficiency

Abstract A mobile instrumentation system was developed and mounted on an MF 285 tractor to measure the performance parameters of the tractor and attached implements. The system measures implement draft, fuel consumption, real forward velocity, tillage depth and engine speed. Other parameters such as wheel slippage, drawbar power and traction efficiency would be calculated by ASABE standard. Overall energy efficiency for the tractor-implement system was calculated, too. Three implements included of moldboard plow, disk plow and chisel plow at four forward velocities (1.5, 2.3, 3 and 4 km/h) in 23 cm depth and 1500 rpm engine speed was examined. Analysis of variance (ANOVA) of resulted data revealed that increase of forward velocity results in increase of implement draft, wheel slippage, drawbar power and overall energy efficiency but results in decrease of traction efficiency. Furthermore, fuel consumption decreased by increase of velocity from 1.5 km/h to 3 km/h but increased by increase of velocity from 3 km/h to 4 km/h. Moreover, it was observed that draft requirement for implements in tests ranged from 8.2 kN for the disk plow to 13 kN for the chisel plow and fuel consumption ranged from 10.72 L/ha for the chisel plow to 26.5 L/ha for the moldboard plow. The ranges in mentioned parameters indicate that energy saving can be readily done by selecting energy-efficient implements and by proper matching of the tractor size and operating parameters to the implements.

1. Introduction

Performance data from various tractors and implements are essential for farm machinery management and manufacturers alike. Proper selection of tractors and implements for a particular farm situation to minimize energy inputs for crop production can be determined from these performance parameters (Al-suhaibani, 1992). It becomes more critical as energy costs escalate because the field machines contribute a major portion of the total cost of crop production systems. Since the advent

* Corresponding author. Tel.: +98 935 991 5284; fax: +98 451 277 9558.
E-mail address: mohammadaskari@uma.ac.ir (M. Askari).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jssas.2015.05.003
1658-077X

Please cite this article in press as: Ranjbarian, S. et al., Performance of tractor and tillage implements in clay soil. Journal of the Saudi Society of Agricultural Sciences (2015), http://dx.doi.org/10.1016/j.jssas.2015.05.003

of the farm tractor, researchers have been developing equipment to measure tractor performance. A number of instrumentation systems based on data logger and computers have been developed to measure the performance of tractors and implements. These systems vary in complexity and sophistication from measuring one or two parameters and recording display readings by hand (Williford, 1981) to on-board microcomputer-based monitoring of several operating parameters (Wolf et al., 1980; Adsit and Clark, 1981; Wendte and Rozeboom, 1981; Tompkins and Wilhelm, 1982; Grevis-James et al., 1983; Clark and Adsit, 1985; Thomson and Shinners, 1989; McLaughlin et al., 1993; Al-Janobi et al., 1998; Sahu and raheman, 2008; Al-Hamed et al., 2010; Al-Suhaibani et al., 2010; Younis et al., 2010). A review on different instrumentation systems shows that the majority of these systems were designed for an exclusive tractor and not easily adoptable to others, they are not portable.

Measurement of implement draft and developing draft prediction equations has received most of the attention in tractor instrumentation systems (Zoerb et al., 1983; Musunda and Bigsby, 1985; Harrigan and Rotz, 1995; Grisso et al., 1996; Al-Suhaibani and Al-janobi, 1997 and Kheiralla et al., 2004). Many of the results of these researches have been summarized in ASABE Standard D497.6 (ASABE Standards, 2009). This standard uses a simplified draft prediction equation proposed by Harrigan and Rotz (1995):

$$D = \mathrm{Fi}[A + B \times S + C \times S^2]WT \quad (1)$$

where D is the implement draft; Fi is a dimensionless soil texture adjustment parameter with different values for fine, medium, and coarse textured soils; A, B, and C are machine-specific parameters; S is field velocity; W is implement width; and T is tillage depth. The quadratic coefficient for velocity, C, is zero for all tillage tools except subsoilers, manure injectors, and moldboard plows (ASABE Standards, 2009). The objective of the standard is to provide a draft prediction equation that is applicable to a wide range of soil conditions. The standard provides a good estimate of tillage implement draft but indicates that a range in draft of up to ±50% can be expected within the same broad textural soil class (Mclaughlin et al., 2008). There are many types of tillage systems such as different combinations of plows as primary and harrows as secondary implements. Draft and energy data for many of these implements are sparse or non-existent. Energy input data for a range of conventional primary tillage implements under local conditions are essential for selecting the most energy-efficient systems. On the other hand, past global researches indicated that the draft requirement of chisel plow was about half of the draft requirement of the moldboard plow in equal width and depth operation (Kepner et al., 1978). Recently, extensive activities for replacing moldboard plow by chisel plow in dry farming have been done in all over the world (Shafei, 1995).

One of the main indexes of energy consumption in tillage operation is overall energy efficiency of tractor. The overall energy efficiency transferred energy from tractor (for implement launch) per energy equivalent of fuel consumption in different operations (Serrano Joao et al., 2005). The overall energy efficiency indicated the general condition of tractor performance. This index is more important comparing draft efficiency and specific fuel consumption in survey of tractor performance (Crowell and Bowers, 1985). Crowell and Bowers (1985) reported that the normal range for overall energy efficiency (OEE) is 10–20%. A tractor-implement combination having an overall energy efficiency below 10% indicates poor load matching or/and low tractive efficiency, while a value above 20% indicates a good load match or/and high tractive efficiency. Many researchers believed the increasing of overall energy efficiency for tractor and implements and correct matching of tractor and agricultural machinery can be effective in decreasing fuel consumption (Samiei Far et al., 2015). With regard to the mentioned issues, the following objectives were considered for the present study:

(1) Development of a portable instrumentation system for tractors up to 90 kW (120 hp) covering the range of the common agricultural tractors in use in the Middle East.
(2) Measurement and record the performance of Massey Ferguson (MF285) tractor that is the most common tractor in Iran and other district countries.
(3) Determination of the draft requirements of primary tillage implements applied to a clay soil.
(4) Verifying the applicability of the ASABE standard equation for predicting the draft requirements of tillage implements in west Azerbaijan province, northwest of Iran.

2. Material and methods

2.1. General setup of the instrumentation system

The instrumentation system includes of a three point hitch dynamometer, a fuel meter, a fifth wheel, a depth meter, an engine rpm meter and a data acquisition system. The three-point hitch dynamometer was used to measure draft requirements of mounted implements of categories II and III. It consisted of two frames, on both frames the three-point linkages were installed so that the dynamometer could be placed between the tractor and the implement. Maximum draft force that was measured by this dynamometer was 3000 kg (30 kN). The details concerning the design and other aspects of the facility can be found in Askari et al. (2011).

Fuel consumption was measured by using a secondary tank of 8 l capacity with a level marked tube and bulb with volume 138.6 cm^3. The tank was installed and connected to the tractor fuel Tank through hoses and two valves. The tank was first filled with fuel during the actual run. The tractor was first let go on its fuel from the main tank. To measure the fuel consumption during a specific field operation, the secondary tank was utilized through the valves to fill the bulb. Then, turn the valves off and used stop watch when the fuel arrived to the first mark of the bulb. After the fuel arrived to the second mark, turn off the stop watch at the same time. The bulb had constant volume, so it is easy to calculate the fuel consumption. Fig. 1 shows the secondary tank and connecting hoses.

The real forward velocity was measured using a fifth wheel attached to a suitable position underneath the tractor as shown in Fig. 2. A magnetic pick-up mounted to the fifth wheel sensed the rotation of a toothed gear with 12-tooth (12 pulses/revolution) that was attached to the fifth wheel. The

Figure 1 Fuel meter to measure the fuel consumption.

Figure 2 The fifth wheel for measuring the real forward velocity.

signal comes from magnetic pickup goes directly to the digital pulse meter. This system was used to measure the distance traveled and with measuring the time traveled by a chronometer, the real forward velocity was obtained.

Tillage depth was measured by an ultrasonic sensor that was installed under implements frame. This sensor measured the distance between implements frame and ground surface, continuously. By using this tool, amount of tillage depth would be measured, accurately. Engine speed was measured by an RS optical proximity sensor mounted at the front of the tractor near to the crankshaft pulley. Fully description of data acquisition system is provided in the following paragraphs.

2.2. Data acquisition system

The used instruments were a commercial load cell installed on three-point hitch dynamometer that was connected to an amplifier multiplexer, a data logger and a laptop. The signals from the load cell were multiplexed and amplified by the PCLD-789 amplifier multiplexer board (Advantech Co, Taipei, Taiwan). The power to the amplifier multiplexer was supplied by the laptop. The amplified signals were digitized in the data logger BS-7220 (Bongshin Co, Incheon, Korea), which were then transferred to the laptop and stored temporarily in the laptop memory as it is received at the end of each measuring interval. The data logger and laptop would be mounted on a platform to the left of the tractor operator 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.

2.3. Field tests

The instrumentation system for the test and evaluation was transferred to the Urmia University Research Farm (44°49′1.3″E, longitude; 37°42′28.7″N, latitude; and 1020 m above sea level) in northwest Iran near the Turkey border. The topography was flat (< 1% slope), and the soil was poorly aerated. Average organic carbon content was 0.71 weight%, and average pH was 7.1. This field area was earlier established for bar ley. Three primary implements include of moldboard, disk and chisel plows and a 56 kW Massey Ferguson tractor (MF285, ITMCO, Tabriz, Iran) were used. The implements were representative of the standard primary mounted tillage implements most commonly used for seed bed preparation in Iran. A general description of each implement is provided in the following paragraphs, detailed specifications are given in Table 1, and photographs of the implements are shown in Figs. 3–5.

Moldboard plow: The moldboard plow had three furrows. Furrow width was set to 330 mm, and its maximum work depth was 305 mm.

Disk plow: The disk plow consisted of four disks of 630 mm dia. Tilt and disk angles for all disks were 20° and 42°,

Table 1 Specifications of tillage implements used in the study.

Implement type	Manufacturer	Implement width (cm)
Moldboard plow	Shokhmiran, Mashhad, Iran	100
Disk plow	John Deere Company, USA	100
Chisel plow	RAU Agrotechnic Farm Machinery, Roma, Italy	250

Figure 3 The moldboard plow with three furrows.

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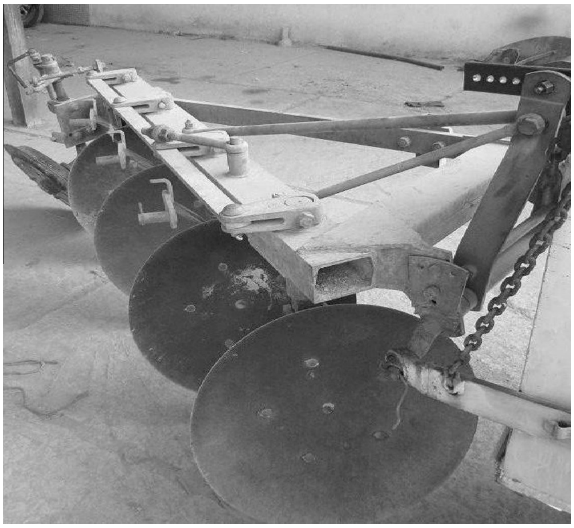

Figure 4 The disk plow with four disks.

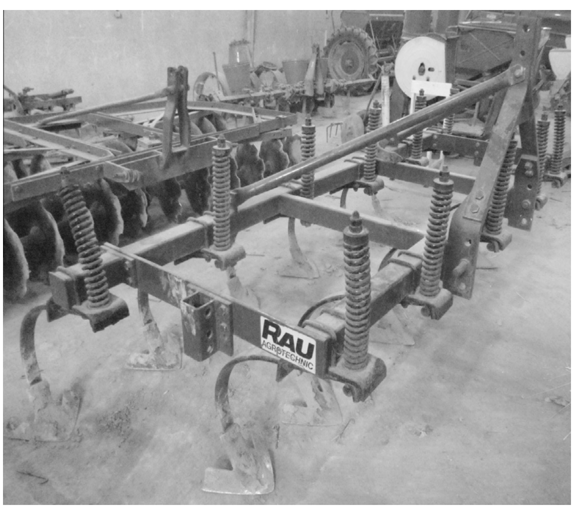

Figure 5 The chisel plow with eleven shanks.

respectively. The maximum operating depth of the disks was about 250 mm.

Chisel plow: The chisel plow had eleven shanks mounted on two toolbars. The soil engaging tools had 150 mm wide sweep blades spaced at 420 mm.

The dynamometer was placed between the plow and tractor while data logger and laptop were located on a metal tray next to the operator. Tests were performed at the depth of 23 cm, engine speed of 1500 rpm and four forward velocities of 1.5, 2.3, 3 and 4 km/h. For the three plows, four velocities and three repeat were used in combination for 36 treatments. The tillage treatments were arranged in a randomized complete block design (RCBD). Each plot had 3 m wide, 50 m long and a 3 m wide roadway was left between the blocks to allow sufficient turning area for equipment. The data logger was adjusted to record the dynamometer signals with a frequency of 5 Hz (300 data in min). Before experiments, the dynamometer was horizontally adjusted relative to ground surface (parallel to ground surface). After the experiments and transferring the data into the laptop, means were calculated from the individual measurements logged during the interval required to travel 50 m.

The affecting properties and parameters of soil on draft force and required energy include the following: soil moisture content, bulk density, cone index and soil structure (Upadhyaya et al., 1984, 1987). These parameters as the major influencing parameters on the draft force were analyzed in a clay soil (32% sand, 25.5% silt, and 42.5% clay). Soil moisture and other physical properties were measured at 10 points and 2 ranges of soil depth (0–125 and 125–250 mm). Soil samples were weighed, oven dried at 105 °C for 24 h and weighed again. Results are detailed in Table 2.

A RIMIK digital penetrometer (CP20, Queensland, Australia) with tip cone angle of 30° a standard bar was utilized to measure cone index. According to ASAE Standards S313.2 the penetration into the soil was performed with 0.02 m/s constant velocity. Soil cone index was measured at 20 points over the 0–260 mm depth range immediately before tillage and detailed results of this test are depicted in Fig. 6.

In the field tests, three parameters include of draft requirement, real forward velocity and fuel consumption were measured directly. Three parameters include of drawbar power, traction efficiency and slippage were needed to be calculated by the use of ASABE standards D497.6 (ASABE Standards, 2009). To calculate the drawbar power, traction efficiency and wheel slippage, Eqs. (2)–(4) were used, respectively:

$$\mathrm{DP} = D \times V_a \tag{2}$$

where
DP – Drawbar Power (kW).
D – Draft (kN).
V_a – Real velocity of tractor in the farm (m/s).

$$\mathrm{TE} = (1 - S)\mathrm{NT}/\mathrm{GT} \tag{3}$$

Table 2 Obtained data from soil analysis at 10 points and 2 depths consisting of 0–125 and 125–250 mm.

Mass water content (db)	Porosity	Void ratio	Particle density (g/cm^3)	Degree of saturation
0.205	2.49	1.08	0.52	14.06

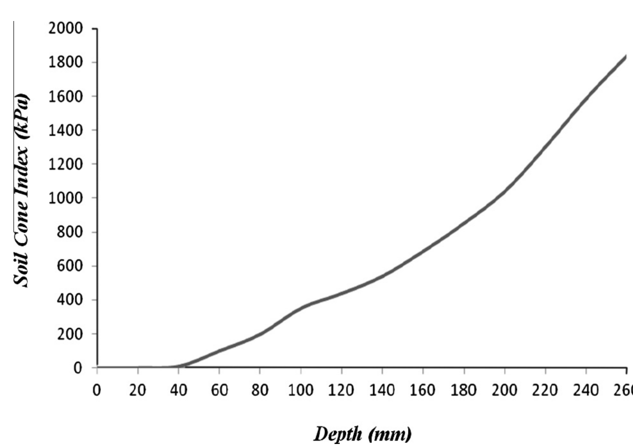

Figure 6 Results of pre-tillage soil cone index.

where
TE – Traction efficiency.
S – Slippage.
NT – Net traction, (as defined in ASAE S296).
GT – Gross traction, (as defined in ASAE S296).

$$\%S = 100(1 - (V_a/V_o)) \quad (4)$$

where
S – Slippage.
V_a – Real velocity of loaded tractor in the farm (km/h).
V_o – Velocity of no loaded tractor on the concrete surface (km/h).

One of the main parameters in this study was overall energy efficiency (OEE) of MF 285 that according to equation number 5 was calculated (Crowell and Bowers, 1985). Looking closely at its elements, it includes three variables of draft, real forward velocity and fuel consumption. While other important parameters or variables such as all wheels slip percentage indirectly influence OEE.

$$\mathrm{OEE} = \frac{V_a \times D}{10.2 \times F_c} \times 3.6 \quad (5)$$

Table 3 Draft requirement (kN) for primary tillage implements used in the study.

Implement	Dynamometer average	ASABE estimate	Velocity (km/h)
Moldboard plow (Range ASABE ± 40%)	8.95	10.6	1.5
	9.74	10.8	2.3
	10.2	11.12	3
	11.5	11.7	4
Chisel plow (Range ASABE ± 50%)	10.7	14.36	1.5
	11.45	14.98	2.3
	12.09	15.53	3
	13.03	16.31	4
Disk plow (No in ASABE)	8.24	–	1.5
	8.87	–	2.3
	10	–	3
	11.93	–	4

where
OEE – Overall energy efficiency (%).
V_a – Real forward velocity (km/h).
D – Draft (kN).
F_c – Fuel consumption (L/h) and, 10.2 is calorific value of diesel fuel (in terms of diesel fuel produced in Iran, kw/h).

3. Results and discussion

Results of measuring the draft requirement of implements in field tests are presented in Table 3 and for example, draft requirement and fuel consumption of moldboard plow in velocity of 3 km/h (third repeat) are illustrated in Fig. 7. The shown data were collected at the distance interval of 10–25 m of the 50 m field plot.

ASABE predicted values with respect to the measured values by new instrumentation (kN) are depicted in Fig. 8.

It is important to note that the changes in draft resistance (Fig. 7) are caused due to soil failure. Draft requirement for these implements ranged from 8.2 kN for the disk plow to 13 kN for the chisel plow. This large variation was due to the difference in implements specifications and operating width of the implements. ASABE Standard D497.6 defines implement draft except disk plow and this definition will be used for the remainder of this article. The ASABE coefficients are for a wide range of soil conditions and consequently cannot be expected to yield accurate estimates for a given situation; the ASABE Standard indicates an expected range of ±25–50% for the various tillage implements (McLaughlin et al., 2008). The ASABE data overestimated the draft requirement

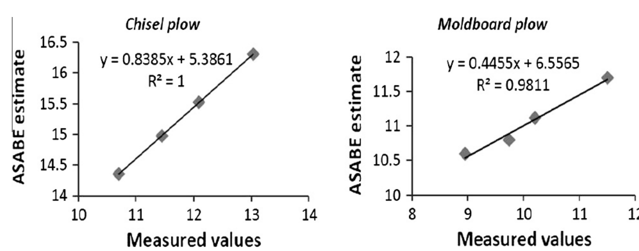

Figure 8 ASABE estimate with respect to the measured values (kN) in the tests.

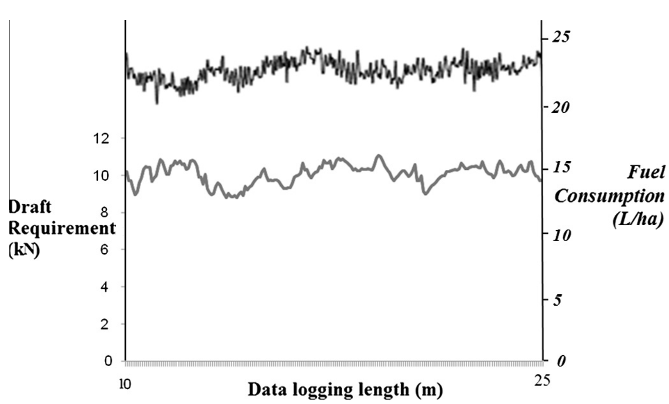

Figure 7 Draft requirement and fuel consumption of the moldboard plow in field test.

of moldboard plow at applied velocities by 18%, 11%, 11% and 2%, respectively, and overestimated the draft requirement of chisel plow by 34%, 31%, 28% and 25%, too. These results revealed that the measured drafts were within the expected range of draft given in the ASABE Standard. Moreover, it found that by the increase of forward velocity, difference between dynamometer data and ASABE estimate became smaller.

By considering the obtained draft forces from field tests (Table 3) and implements width, it shows that in the equal work width (1 m), mold board plow draft at different velocities was 2.09, 2.12, 2.07 and 2.2 times as much as the chisel plow draft requirement. This result shows that Consequence of past global researches about the relevance between draft requirement of moldboard and chisel plow was indefeasible and would be certified.

Other results of field tests were as follows:

3.1. Effect of forward velocity and implement type on the draft requirement

The effect of forward velocity and implement type on the draft requirement is presented in Table 4 and Fig. 9.

The results of Table 4 indicated that change of forward velocity and implement type and interaction effect of them are effective on the draft requirement ($p < 0.01$). Fig. 9 shows that when forward velocity was doubled, for example in moldboard plow when forward velocity increased from 1.5 to 3 km/h, the draft requirement increased from 9 to 10 kN and was not doubled. This increment occurred for all plow. Equation of draft prediction (ASABE Standards, 2009) indicated that by doubling the forward velocity, the draft requirement increased but was not doubled. Also many researchers confirmed this relationship between forward velocity and draft of primary implements (Upadhyaya et al., 1984; Crowell and Bowers, 1985; De Souza et al., 1994; Al-suhaibani et al., 2006; Sahu and Raheman, 2006).

Maximum draft requirement occurred in chisel plowing at forward velocity of 4 km/h and minimum occurred in disk

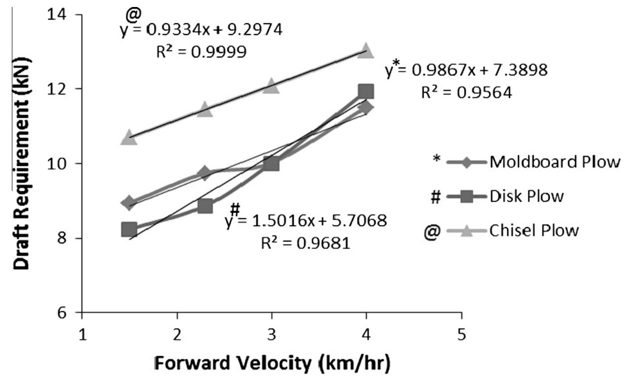

Figure 9 The relationship between forward velocity, implement type and draft requirement.

plowing at forward velocity of 1.5 km/h. It was revealed that the relationship between draft requirement and forward velocity in all implements was linear ($R^2 > 0.95$).

3.2. Effect of forward velocity and implement type on the fuel consumption

The effect of forward velocity and implement type on the fuel consumption is presented in Table 4 and Fig. 10.

The results of Table 4 indicated that change of forward velocity and implement type and interaction effect of them are effective on the fuel consumption ($p < 0.05$, $p < 0.01$ and $p < 0.01$, respectively). Fig. 10 shows that maximum fuel consumption occurred in moldboard plowing at forward velocity of 1.5 km/h (26.5 L/ha) and minimum occurred in chisel plowing by forward velocity of 3 km/h (10.72 L/ha). Because work width of chisel plow (250 cm) was more than moldboard (100 cm) and disk plow (100 cm), amount of chisel fuel consumption in hectare, was lower than moldboard and disk plow, significantly. Moreover, it was observed that the fuel consumption decreased as forward velocity increased between 1.5 and 3 km/h and then increased as forward velocity

Table 4 Analysis of variance (ANOVA) of tool type and wing type on the studied parameters.

Source of variation	Degree of freedom	Mean square					
		A	*B*	*C*	*D*	*E*	*F*
V	3	133,954.06**	269.16*	0.01**	148.74**	0.006**	40.88**
I	2	148,505.94**	1086.56**	0.011**	5.93**	0.006**	2.934**
V × *I*	6	4316.86**	37.72**	0.00*	0.14*	0.00*	0.443**
Error	24	631.08	2.99	0.00	0.04	0.00	0.003
Total	35						

V – Forward velocity.
I – Implement type.
V × *I* – Interaction between forward velocity and implement type.
A – Draft requirement.
B – Fuel consumption.
C – Slippage.
D – Drawbar power.
E – Traction efficiency.
F – Overall energy efficiency.
ns – Not significant.
* $P < 0.05$.
** $P < 0.01$.

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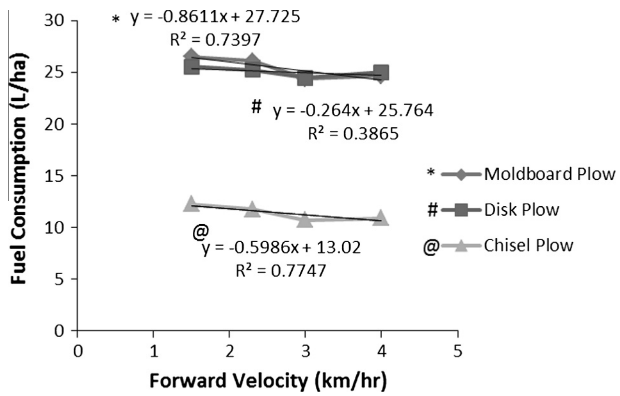

Figure 10 The relationship between forward velocity, implement type and fuel consumption.

increased between 3 and 4 km/h. Lowest fuel consumption occurred in velocity 3 km/h in all implements, consequently. It was found that the relationship between fuel consumption and forward velocity in moldboard and chisel plow was partly linear ($R^2 > 0.7$) but in disk plow was not linear. More increment of fuel consumption between velocities 3 and 4 km/h in disk plow relative to moldboard and chisel plow caused this nonlinearity.

3.3. Effect of forward velocity and implement type on the wheel slippage

The effect of forward velocity and implement type on the slippage is presented in Table 4 and Fig. 11.

The results of Table 4 indicated that change of forward velocity and implement type and interaction effect of them are effective on the slippage ($p < 0.01$, $p < 0.01$ and $p < 0.05$, respectively). Fig. 11 indicates that maximum slippage occurred in chisel plowing by forward velocity of 4 km/h and Minimum occurred in disk plowing by forward velocity of 1.5 km/h. It was found that the slippage increased as forward velocity increased. The main reason for high slippage was low weight of MF 285 tractor and no ballast. Additionally, driven tires were old and had no high lugs. These two factors caused high slippage in higher velocities. The relationship between slippage and forward velocity in all implements was linear ($R^2 > 0.9$).

3.4. Effect of forward velocity and implement type on the tractor drawbar power

The effect of forward velocity and implement type on the drawbar power is presented in Table 4 and Fig. 12.

The results of Table 4 indicated that change of forward velocity and implement type and interaction effect of them are effective on the tractor drawbar power ($p < 0.01$, $p < 0.01$ and $p < 0.05$, respectively). Fig. 12 indicates that maximum drawbar power occurred in chisel plowing by forward velocity of 4 km/h and Minimum occurred in disk plowing by forward velocity of 1.5 km/h. It was found that the drawbar power increased as forward velocity increased. The relationship between drawbar power and forward velocity in all implements was linear, quietly ($R^2 > 0.97$).

3.5. Effect of forward velocity and implement type on the traction efficiency

The effect of forward velocity and implement type on the traction efficiency is presented in Table 4 and Fig. 13.

The results of Table 4 indicated that change of forward velocity and implement type and interaction effect of them are effective on the traction efficiency ($p < 0.01$, $p < 0.01$ and $p < 0.05$, respectively). Fig. 13 indicates that maximum traction efficiency occurred in disk plowing by forward velocity of 1.5 km/h and Minimum occurred in chisel plowing by forward velocity of 4 km/h. It was found that the traction efficiency decreased slowly as forward velocity increased. Slippage is a main factor in traction efficiency and higher slippage in higher velocities caused lower traction efficiency. The relationship between traction efficiency and forward velocity in moldboard plowing was linear, quietly but in chisel and disk plowing was partly linear.

3.6. Effect of forward velocity and implement type on the overall energy efficiency

To calculate the overall energy efficiency (OEE), fuel consumption in terms of L/h was needed. By considering the fuel consumption in terms of L/ha plus width and forward velocity of implements, fuel consumption (L/h) was obtained and presented in Fig. 14.

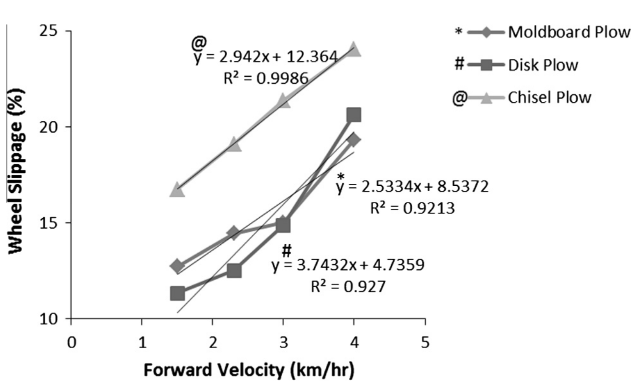

Figure 11 The relationship between forward velocity, implement type and slippage.

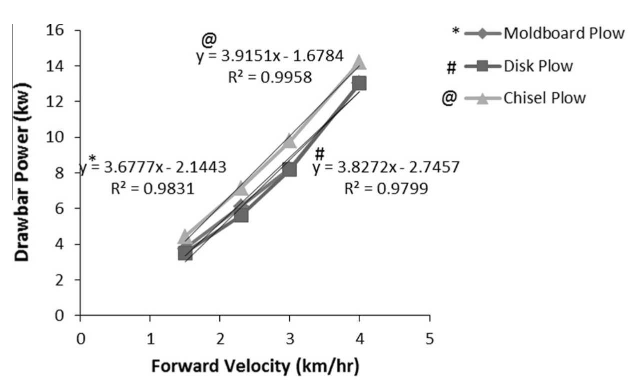

Figure 12 The relationship between forward velocity, implement type and drawbar power.

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Fig. 14 shows that by increasing the forward velocity, fuel consumption increased in all implements, intensively. Also, the relationship between fuel consumption and forward velocity in all implements was linear, quietly ($R^2 > 0.99$).

After the calculation of OEE for different velocities and implements, analysis of data was performed. The effect of forward velocity and implement type on the OEE is presented in Table 4 and Fig. 15.

The results of Table 4 indicated that forward velocity and implement type and interaction effect of them are effective on the OEE ($p < 0.01$). Fig. 15 indicates that maximum OEE occurred in chisel plowing at forward velocity of 4 km/h and Minimum OEE occurred in disk plowing at forward velocity of 1.5 km/h. It was found that the OEE increased as forward velocity increased. The relationship between OEE and forward velocity in all implements was linear ($R^2 > 0.95$). Moreover, the results indicated that the range of overall energy efficiency (OEE) was 10–20% and was normal (Crowell and Bowers, 1985). Crowell and Bowers (1985) reported that higher OEE indicates a good load match or/and high tractive efficiency. But in this study, higher OEE and lower traction efficiency were obtained in higher velocities (Figs. 13 and 15). Use of the light MF 285 tractor without ballast and without new driven tires with high lugs increased the slippage and fuel waste in higher velocities, intensively. Consequently, the traction efficiency decreased. Thus, the use of higher forward velocity, high lugged driven tires and ballast weight causes the higher drawbar power, higher traction efficiency, higher OEE and lower slippage and lower fuel consumption, to some extent.

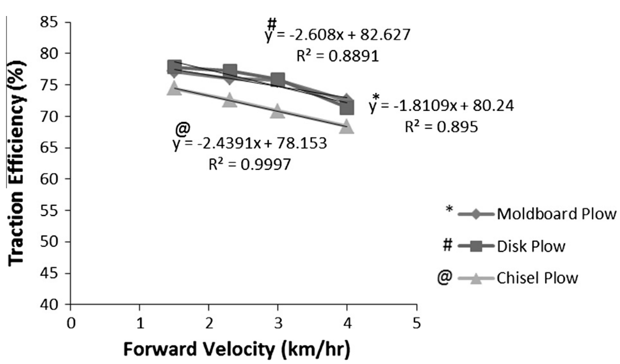

Figure 13 The relationship between forward velocity, implement type and traction efficiency.

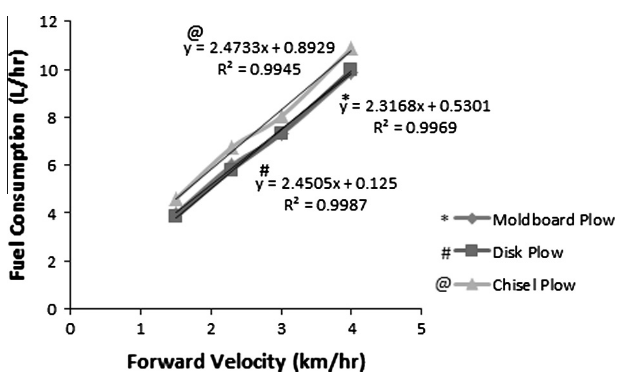

Figure 14 The fuel consumption in terms of liter per hour in the tests.

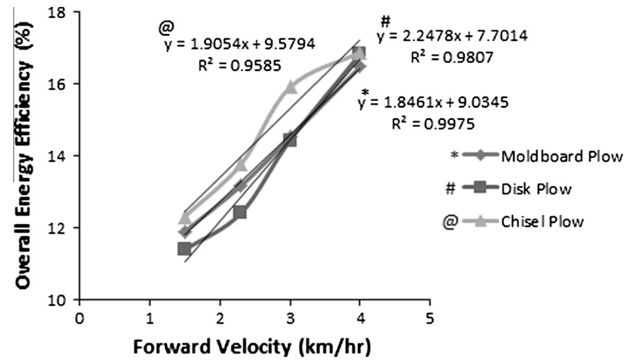

Figure 15 The relationship between forward velocity, implement type and overall energy efficiency.

4. Conclusion

The novel instrumentation system was developed to measure the draft requirements of implements, fuel consumption, real forward velocity, tillage depth and engine speed. Other performance parameters include of wheel slippage, drawbar power, traction efficiency and overall energy efficiency would be calculated. The system installed on Massey Ferguson 285 tractor and three primary implements of moldboard plow, disk plow and chisel plow and four levels of forward velocity (1.5, 2.3, 3 and 4 km/h) in constant tillage depth (23 cm) and constant engine speed (1500 rpm) were examined. Analysis of variance (ANOVA) of resulted data revealed significant consequences follows:

1. Forward velocity, implement type and interaction of them are effective on implements draft, fuel consumption, wheel slippage, drawbar power, traction efficiency and overall energy efficiency (different combinations of $p < 0.01$ and $p < 0.05$).
2. Increase of forward velocity results in an increase of draft requirement, wheel slippage, drawbar power and OEE but results in a decrease of traction efficiency and fuel consumption of tractor.
3. Draft requirement for the implements ranged from 8.2 kN for the disk plow at velocity of 1.5 km/h to 13 kN for the chisel plow at velocity of 4 km/h.
4. Amount of fuel consumption in terms of liter per hectare in forward velocity of 3 km/h was minimum in all implements.
5. The ASABE data overestimated the draft requirement of moldboard and chisel plow. Furthermore, ASABE has no data about disk plow.
6. By increase of velocity, difference between dynamometer data and ASABE estimate became smaller.
7. Mean fuel consumption at different forward velocities was 25.05 L/ha for the disk plow, 25.4 L/ha for the moldboard plow and 11.4 L/ha for the chisel plow.
8. The ranges in implement draft, fuel consumption and other mentioned parameters indicated that substantial energy savings can be readily obtained by selecting

energy-efficient tillage implements and by proper matching of the tractor size and operating parameters to the tillage implements.
9. Field tests showed that the system was able to function effectively as intended without any problems.
10. Obtained data could be used by district farmers for selecting the best combination of tillage implements, size of tractor and tractor implement match.
11. In general, for optimized performance of MF 285 tractor, the use of ballast weight, high lugged driven tires and forward velocity of 3 km/h to increase the drawbar power, traction efficiency and overall energy efficiency and decrease of fuel consumption at primary tillage are recommended.

Conflict of interest

The authors declared that there is no conflict of interest.

Acknowledgments

The authors express their appreciation to Professor Seyyed Mohammad Hasan Komarizade and the support staff of the Department of Mechanical Engineering of Agricultural Machinery at Urmia University for their contribution in field operations.

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Please cite this article in press as: Ranjbarian, S. et al., Performance of tractor and tillage implements in clay soil. Journal of the Saudi Society of Agricultural Sciences (2015), http://dx.doi.org/10.1016/j.jssas.2015.05.003