Review Paper

Review of Fuel consumption, draft force and ground speed measurements of the agricultural tractor during tillage operations.

Abstract

Estimating the amount of fuel consumption of an agricultural tractor during various tillage operations will help the selection of the best conservation practices for farm equipment. Draft requirements often dictate the size of the power unit required on a particular farm and, therefore, will also be required for energy management decisions. They will also be considered a prominent factor during the selection of a tractor's machinery and power source. In addition, ground speed measurement is not only necessary for many agricultural machinery applications but also to monitor and map crop yield and properly change the application rate of agricultural inputs. There are several methods and techniques to measure a tractor's fuel consumption, draft force, and ground speed. All these methods have many advantages and disadvantages depending on the tractor, the implement used, and the operating conditions. This article reviews some of these methods, providing scope for further research to focus on the potential development and improvement of the measurement methods, and this could positively affect the accuracy of the data and final results of the research.

Keywords: Diesel engine; Fuel meter; Monitoring system; Sensor; Tillage implement

1. Introduction

Tillage is a very important practice in agriculture (Mamkagh, 2009a; Hunaiti and Mamkagh, 2003; Mamkagh, 2018; Mamkagh, 2019) and one of the major energy consumers in agricultural production; its efficiency is measured by the power consumption (Bentaher et al., 2013), and considered as the most fuel-consuming practices in agriculture (Mamkagh, 2002a and b). Plowing as a part of tillage also accounts for more traction energy than any other field operation and often determines the size of the suitable tractor. It consumes up to 59% of all diesel required for the complete technology (Egidijus Sarauskis et al., 2016).

There are many methods to decrease the tractor's fuel consumption during tillage operations. One of them is the wheel slippage reduction to the minimum, whereas great slippage deteriorates the structure of soil and increases fuel consumption. Therefore the issue of reducing the tractor wheel slippage during tillage have been investigated and reported by many researchers (Mamkagh, 2009 b and c), (Udompetaikul et al., 2011), (Adewoyin A. and Ajav E., 2013), (Janulevicius A. and Damanauskas V., 2015), (Pitla S. et al, 2016). Estimating the amount of fuel consumption of an agricultural tractor during various tillage operations will help the selection of the best conservation practices for farm equipment (Abbaspour-Gilandeh et al., 2006 and 2009).

Implement energy requirements vary greatly with soil type, soil moisture, soil density, previous treatment, ground cover, and operation speed and depth (Michel et al., 1985). Draft requirements will often dictate the size of the power unit required on a particular farm. Since the power unit represents a major capital investment, a better understanding of draft requirements can aid machinery management decisions. Energy management of agricultural machinery will also be increasingly important in the future. Draft requirements will also be required for energy management decisions (Thomson and Shinners, 1989). The implement draft force is used to determine the fuel consumed for soil tillage because the decrease in draft could lead to a decrease in tractor's fuel consumption.

Measurement of ground speed is necessary for many agricultural machinery applications. The ground speed is needed to monitor and map crop yield and properly change the application rate of agricultural inputs such as pesticides and fertilizers in precision agriculture (Shannon et al., 2001; Vishwanathan et al., 2005; Mullenix et al., 2010; Keskin et al., 2017).

2. Measurement of the tractor fuel consumption

Diesel engines have two fuel-lines: a delivery line from the tank to the cylinders, and a return line, to convey back in the tank the fuel not injected as a consequence of the accelerator position and pump settings (Bietresato M. and Mazzetto F., 2018). Measurement of fuel consumption on a diesel engine requires compensation for fuel returned to tank from the injectors and injection pump. The return flow is often hot and foamy, making accurate measurement difficult (McLaughlin et al., 1993).

To find the effect of some operating factors on the farm tractor during the tillage practice Mamkagh (2002a, 2002b, 2007 and 2008) measured the fuel consumption using the traditional, manual method wherein the fuel tank is filled to full capacity and the amount of fuel consumed is then calculated.

Green et al. (1985) developed an instrumentation package to monitor tractor performance on a John Deere 4440 tractor where performance variables measured included front and rear wheel rotational speed, ground speed by Doppler radar, engine speed, differential speed, drawbar pull, axle torque and fuel consumption. They measured the fuel consumption with a fluidyne instrumentation model 1214-D flow measurement system. Primary components of the system were a four-piston positive displacement flow transducer with two phase (quadrature output) photo optical transmitter, a thermocouple probe installed in-line before the flow transducer for sensing fuel temperature, and a flow indicator/totalizer which displayed digital values of average fuel flow (lb/h), fuel temperature (°F), and totalized values of fuel metered (lb).

Also Bedri and Al-Hashem (2006) developed an instrumentation package for monitoring tractor performance. The package included a data acquisition system and transducers for monitoring forward speed, rear wheel speed, fuel consumption and drawbar pull. They measured the fuel flow with an RS 256-225 turbine flow transducer of a range of 3-90 L/hr. The transducer has a neutrally buoyant rotor that spins with the fuel at rotational velocity proportional to the fuel flow. The rotor movement is sensed when a hall effect switch inside the housing is activated by three small magnets in the turbine. The transducer was connected between the main fuel tank and the injection pump for measuring the fuel flowing from the tank.

Heat exchanger placed in front of the tractor radiator and used to cool the return fuel from the injection pump and the injectors which then returned to an intermediate vented fuel tank as shown in Fig. (1). Finely, they concluded that their results reflected a high precision for the transducers and the data acquisition system.

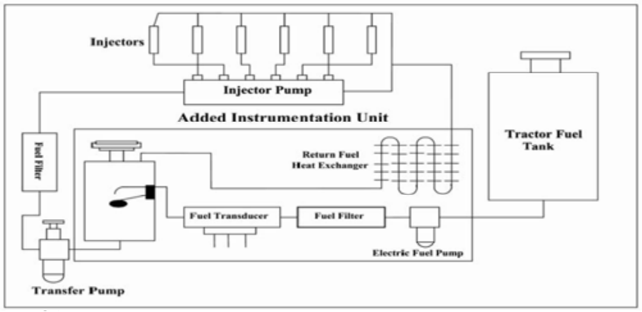

Fig. 1. Design of fuel measurement system; Bedri and Al-Hashem (2006).

To study the effect of plow depth on tractor's fuel consumption during moldboard plowing Fathollahzadeh et al. (2010) installed two turbine type fuel flow meter sensors on a diesel engine of the John Deer tractor. An electronic board received and saved digital pulses from these sensors.

Kheiralla et al. (2004) used oval flow meter sensor to measure fuel consumption of the tractor which was located between injection pump and fuel filter.

A tractor monitor circuit was developed by Pang et al. (1985) to measure the tractor fuel consumption indirectly. This device used the exhaust gases temperature and fifth wheel signals to provide an output proportional to instantaneous fuel consumption in terms of liters per hectare. The standard error of that monitor system was 0.07 L/ha.

When Ranjbarian et al. (2015) studied the performance of tractor and tillage implements in clay soil the fuel consumption was measured by using a secondary tank of 8L capacity with a level marked tube and bulb with volume of 138.6 cm^3 (Figure 2). 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 was easy to calculate the fuel consumption.

Fig. 2. The fuel meter; Ranjbarian et al. (2015).

Moitzi et al. (2014) installed a high-performance flow meter (PLU 116H, AVL 2005, List, Graz, Austria) with a proportional–integral (PI) controller in the fuel system of the tractor (Fig.3). They measured volumetric fuel consumption continuously with a measurement precision uncertainty of 0.3% with a negligible pressure drop between inlet and outlet, also air bubble releaser and heat exchanger between fuel inlet and fuel outlet of the measurement system were installed. The digital rectangular signal was logged with a scan rate of 1 Hz.

Then they calculated consumption flow rate (L.h^{-1}) according the below equation:

$$Q = \frac{f \cdot 3.6}{K_D}$$

where, Q is flow rate, L h^{-1}; f is frequency, Hz.

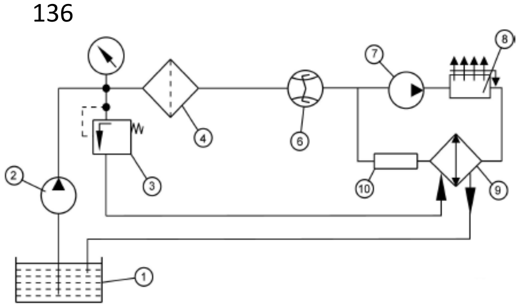

Fig. 3 Fuel consumption monitoring system; Moitzi et al. (2014).
1. Fuel tank. 2. Pre-pump. 3. Pressure control with manometer. 4. Pre-filter.
6. Flow meter PLU 116H. 7. Fuel pump. 8. Fuel injection pump. 9. Fuel/fuel heat Exchanger. 10. Glass sight gauge for fuel recirculation control.

When a robotic tractors was used in weed and pest control Gonzalez-de-Soto et al. (2015) a fuel measurement system consists of two flow sensors as shown in Fig.4 measured the fuel flow during the experiment. The instantaneous fuel consumption was the difference between the data from flow meter 1 and the data from flow meter 2. Because a substantial amount of noise was observed during the measurement process due to high temperature of the fuel returned they had to add a cooling device in the return line before the flow meter.

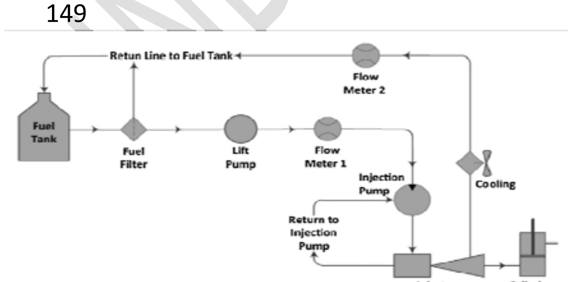

Fig. 4 Scheme of the fuel flow measurement system; Gonzalez-de-Soto et al., (2015).

A high precision computerized instrumentation package was developed by Singh and Singh (2011) and mounted on a 50 kW tractor to monitor and measure the three-point linkage forces, ground speed, tillage depth, fuel consumption, forward speed, wheel slip, engine speed, hydraulic pressure and fluid temperatures. They measured the fuel flow rate with turbine flow transducer which located between the main fuel tank and the injection pump. This transducer had a neutrally buoyant rotor that spins at rotational velocity proportional to the fuel flow. The fuel flow transducer calibration was achieved by collecting the output pulses for a known volume (100 ml) of diesel fuel.

3. Draft measurement

Minimum power consumption and improved operating efficiency can be obtained by ideal matching of the tractor and implement. This can be achieved by measuring the draft force required by tillage implements which is a prominent factor during selection of machinery and power source of the tractor. (Chethan et al., 2018).

Bedri and Al-Hashem (2006) measurement the draft with a 10 tone Novatech 50-204 bidirectional load cell. During their experiment link points between the drawbar and load were modified to assure that the load cell is maintained horizontally. Also, a Novatech amplifier 58-307 was connected between the load cell and the data logger. They concluded that the study results reflected a high precision for the transducers and the data acquisition system.

While Green et al. (1985) measured draft with a proving ring load cell mounted on the front end of the existing drawbar. The load cell consisted of a full wheatstone bridge assembly with 35 ohm gage located in the proving ring to maximize effects of axial forces and minimize effects of bending moments.

To measure the draft of mounted implements Tewari et al. (2012) developed a three point hitch system. It consisted of four parts including the arms with extension for left and right, sensing components, inverted T frame and a head bar as shown in fig 5 a. The force sensing elements consisted of three load cells, which were inserted between the frame and the hook brackets. The front end of the frame attached to the tractor and the rear end attached to the implement as sown in fig. 5b.

Fig. 5 a) Developed Three point linkage dynamometer, b) Field testing of the developed three point hitch dynamometer with an implement (Tewari et al., 2012).

When Roeber et al., (2017) developed a high precision computerized instrumentation package to monitor and measure various performance parameters of a tractor and implement system the draft measurement was achieved with 20 kN and 25 kN Novatech 50-204 bidirectional pin type load cell used as a connector to attach top link and lower link of tractor to implements. They found no significant differences between drawbar and load car measurements confirming that the system developed as part of their research project can be used for field use.

4. Ground speed

There are a number of techniques for the determination of the ground speed; however, each of these methods has some disadvantages (Keskin M. and Say S. M., 2006).

To measure the tractor ground speed (Tompkins et al., 1988) used a pneumatic free-floating fifth wheel arrangement on the left side of the tractor as indicated schematically in Fig. 6. A hydraulic cylinder was used to raise and lower the wheel. Taken from the original design (Tompkins and Wilhelm, 1982) a gear and a magnetic sensor were used to count the wheel rotation.

Using another method, they designed and constructed a front-wheel speed sensor as shown in Fig. 7, where a gear was mounted on the hub of the front left wheel of the tractor. A Disc Instruments Inc. Model EC82 incremental optical shaft encoder was mounted on the assembly axle. Thus, the encoder produced 150 pulses per revolution of the front tractor tire.

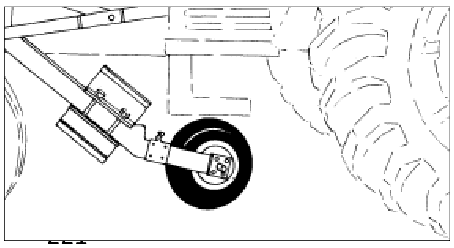

Fig. 6 Schematic of fifth wheel ground speed sensor; part of the original figure from Tompkins et al., 1988

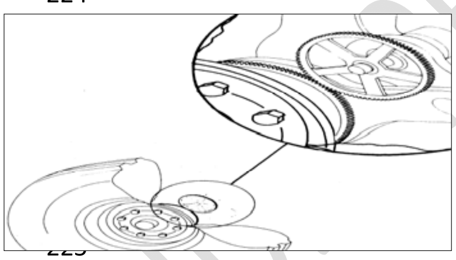

Fig. 7 Schematic of ground speed sensor mounted on left front tractor wheel; Tompkins et al., 1988.

For the same purpose, they mounted a single-beam radar on the right side of the tractor engine compartment. Operating on the Doppler frequency shift principle, this sensor transmitted and received radio frequency at 24.125 GHz. The measured frequency difference between transmitted signals and those reflected from the ground surface was proportional to the ground speed of the vehicle. Output from the radar unit was routed directly to the counter board in the microcomputer.

From the results, they noted that both the front- and fifth-wheel sensors consistently indicated ground speeds less than actual on all soil surfaces due to slip between the tire and the tractive surface.

Keskin and Say (2006) investigated the effectiveness of two low-cost GPS receivers for measuring ground speed under varying speed conditions of a two-wheel drive agricultural tractor on four different dates. They used a rotary shaft encoder on an auxiliary wheel mounted on an agricultural tractor as a reference case and they concluded that the GPS receivers provide reliable data during constant speed operating conditions.

Conclusions

An agricultural tractor's fuel consumption can be measured using the traditional, manual method wherein the fuel tank is filled to full capacity and the amount of fuel consumed is then calculated. However, nowadays, it is often measured using novel systems such as a fluidyne instrumentation flow. The instrumentation package includes a data acquisition system and transducers, a turbine flow transducer, a developed tractor monitor circuit that uses the exhaust gas temperature, a secondary tank, a high performance flow meter with a proportional integral controller, fuel flow sensors, and a high-precision computerized instrumentation package.

Draft force can be measured by using many devices like; a 10 tone Novatech bidirectional load cell between the drawbar and load, a proving ring load cell mounted on the front end of the drawbar, developed a three point hitch system and a high precision computerized instrumentation package.

To determine the tractor ground speed, a number of techniques were found, such as fifth-wheel arrangement, front-wheel speed sensor, and single-beam radar on the right side of the tractor engine compartment.

All measurement systems mentioned above have many advantages and disadvantages depending on the tractor and implement used and operating conditions.

References

Abbaspour-Gilandeh Y., Alimardani R., Khalilian A., Keyhani A. and Sadati H., 2006. Energy requirement of site-specific and conventional tillage as affected by tractor speed and soil parameters. International Journal of Agriculture and Biology 8(4), 499-503.

Abbaspour-Gilandeh Y., Rahimi-Ajdadi F., Asli-Ardeh E and Sharabiani V., 2009. Application of artificial neural network for predicting fuel consumption of tractor, International Agricultural Engineering Conference, Bangkok, Thailand, 7 – 10.

Adewoyin A. and Ajav E., 2013. Fuel consumption of some tractor models for ploughing operations in the sandy-loam soil of Nigeria at various speeds and ploughing depths. International Agricultural Engineering Journal 15(3), 67-74.

Bedri A-R A. and Al-Hashem H A. S. 2006. High precision instrumentation package for monitoring the tractor performance. Scientific Journal of King Faisal University (Basic and Applied Sciences). 7: 95-106.

Bentaher H., Ibrahmi A., Hamza E., Hbaieb M., Kantchev G., Maalej A., Arnold W., 2013. Finite element simulation of moldboard–soil interaction. Soil and Tillage Research 134, 11–16.

Bietresato M. and Mazzetto F., 2018. Ideation, realization and experimentation of prototype device for measuring farm tractor fuel consumption during dyno tests. Conference: Engineering for Rural Development, Jelgava, 23.-25.05.2018.

Chethan C. R., Tewari V. K., Nare B. and Kumar S. P., 2018. Transducers for Measurement of Draft and Torque of Tractor-implement System—A Review. Agricultural mechanization in Asia, Africa and Latin America 49(4), 81-87.

Egidijus Sarauskis, KristinaVaitauskiene, Kestutis Romaneckas, Algirdas Jasinskas, Vidmantas Butkus, Zita Kriauciunien, 2016. Fuel consumption and CO_2 emission analysis in different strip tillage scenarios. Energy 118, 1-12.

Fathollahzadeh H., Mobli H., Rajabipour A., Minaee S., Jafari A.,Tabatabaie S., 2010. Average and instantaneous fuel consumption of Iranian conventional tractor with moldboard plow in tillage. ARPN Journal of Engineering and Applied Sciences 5(20), 30-35.

Gonzalez-de-Soto M., Emmi L., Garcia I. and Gonzalez-de-Santos P., 2015. Reducing fuel consumption in weed and pest control using robotic tractors. Computers and Electronics in Agriculture 114, 96–113.

Green M. K., Stout B.A. and Searcy S. W., 1985. Instrumentation package for monitoring tractor performance. Transactions of the ASAE 28(2), 346 355.

Hunaiti D. and Mamkagh A., 2003. Economics of plowing productivity (application study for barely crop). Minufiya Journal of agricultural research 28(4), 1093-1099.

Janulevicius A. and Damanauskas V., 2015. How to select air pressures in the tires of MFWD (mechanical front-wheel drive) tractor to minimize fuel consumption for the case of reasonable wheel slip. Energy 90 (1), 691-700.

Keskin M. and Say S. M., 2006. Feasibility of low-cost GPS receivers for ground speed measurement. Computers and Electronics in Agriculture 54(1), 36-43.

Keskin M., Sekerli Y. E. and Kahraman S., 2017. Performance of two low-cost GPS receivers for ground speed measurement under varying speed conditions. Precision Agriculture 18(2), 264-277.

Kheiralla A.F., Yahya A., Zohadie M. and Ishak W. 2004. Modeling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia. Soil and Tillage Research. 78: 21-34.

Mamkagh, A. M., 2002a. Factors affecting tractor fuel consumption during tillage operation. Arab Universities Journal of Agricultural Sciences 10(2), 441–452.

Mamkagh, A. M. 2002b. Effect of speed, tillage angle and tilt angle on fuel consumption using disk plow. Iraqi Journal of Agricultural Sciences 3(4), 100-104.

Mamkagh, A., 2007. The effect of landside length on tractor fuel consumption and depth stability of moldboard plow. Bull. Fac. Agric., Cairo Univ., 58, 233-238.

Mamkagh, A.M. 2008. The effect of the weights loading on the front of farm tractor on depth stability using disk plow. Bulletin of Faculty of Agriculture, Cairo University 59, 1-5.

Mamkagh, A. M., 2009a. Effect of tillage time and plastic mulch on growth and yield of okra (Abelmoschus esculentus) grown under rain-fed conditions. International Journal of Agriculture and Biology 11(4): 453-457.

Mamkagh A. M., 2009b. Some Factors Affecting the Wheel Slip of a 2WD Farm Tractor. Jordan Journal of Agricultural Sciences, 5(4), 519-525.

Mamkagh A. M. 2009c. Effect of plowing speed, disk angle and tilt angle on farm tractor wheel slip and on plowing depth using disk plow. Jordan J. Agric. Sci., 5(3): 352-360.

Mamkagh A. M. 2018. Effect of tillage speed, depth, ballast weight and tire inflation pressure on the fuel consumption of the agricultural tractor: A review. Journal of Engineering Research and Reports, 9(1), 1-7.

Mamkagh A. M. 2019. Effect of Soil Moisture, Tillage Speed, Depth, Ballast Weight and, Used Implement on Wheel Slippage of the Tractor: A Review. Asian Journal of Advances in Agricultural Research, 9(1), 1-7.

McLaughlin N. B., Heslop L. C., Buckley D. J., Amour J. R., Compton B. A., Jones A. M. and Van Bodegom P., 1993. A general purpose tractor instrumentation and data logging system. American Society of Agricultural Engineers 36(2), 265-273.

Michel Jr., J.A., Fornstrom, K.J., Borelli, J., 1985. Energy requirements of two tillage systems for irrigated sugarbeets, dry beans and corn. American Society of Agricultural Engineers 28(6), 1731-1735.

Moitzi G., Wagentristl H., Refenner K., Weingartmann H., Piringer G., Boxberger J. and Gronauer A., 2014. Effects of working depth and wheel slip on fuel consumption of selected tillage implements. Agricultural Engineering International: CIGR Journal 16(1), 182-190.

Mullenix, D., Fulton, J. and Winstead, A., 2010. Using GPS as a source for ground speed radar inputs. Precision agriculture series timely information. Alabama Cooperative Extension System Publication, USA. September 2010, p. 2.

Pang S., Zoerb G., Wang G., 1985. Tractor monitor based on indirect fuel measurement.Transactions of the ASAE. 28 (4): 994-998.

Pitla S., Luck J., Werner J., Lin N. and Shearer S., 2016. In-field fuel use and load states of agricultural field machinery. Biological Systems Engineering at Digital Commons, University of Nebraska - Lincoln.

Ranjbarian S., Askari M. and Jannatkhah J., 2015. Performance of tractor and tillage implements in clay soil. Journal of the Saudi Society of Agricultural Sciences, 16(2), 154-162.

Shannon K., Brumett J., Ellis C. and Hoette G., 2001. Can a $300 GPS receiver be used for yield mapping. American Society of Agricultural Engineers. Paper number 011154, 2001 ASAE Annual Meeting. (doi: 10.13031/2013.7358)

Singh C. D. and Singh R. C., 2011. Computerized instrumentation system for monitoring the tractor performance in the field.Journal of Terramechanics 48, 333–338.

Thomson N. P. and Shinners K. J., 1989. A Portable instrumentation system for measuring draft and Speed. American Society of Agricultural Engineers 5(2), 133-136.

Tompkins F. D., Hart W. E., Freeland R. S., Wilkerson J. B. and Wilhelm L. R., 1988. Comparison of Tractor Ground Speed Measurement Techniques. Transactions of the ASAE. 31 (2), 0369-0374. (doi: 10.13031/2013.30716)

Tompkins F. D. and Wilhelm L. R., 1982. Microcomputer based, tractor data acquisition system. TRANSACTIONS of the ASAE 25(6),1540-1543.

Vishwanathan, R., Weckler, P. R., Solie, J. B. and Stone, M. L., 2005. Evaluation of ground speed sensing devices under varying ground surface conditions. Paper No: 051087, ASABE, St. Joseph, MI, USA.

Udompetaikul V. , Upadhyaya S. and Vannucci B., 2011. The effect of tire inflation pressure on fuel consumption of an agricultural tractor operating on paved roads. Trans. ASABE 54 (1), 25–30.