Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. IX, 2020
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

METHOD FOR DETERMINING THE FUEL COST OF AGRICULTURAL MACHINES THROUGH GPS SIGNAL

Zhulieta ARNAUDOVA, Georgi KOMITOV

Agricultural University of Plovdiv, 12 Mendeleev Blvd., Plovdiv, Bulgaria

Corresponding author email: gkomitov@abv.bg

Abstract

In operating a machine-tractor park on a modern farm, the most significant expense is that of fuel. Modern agriculture, as a way of doing business, is unthinkable without the use of modern machinery. In many cases even funny. In the technical specification of power machines, only the specific fuel consumption is specified. This is because the manufacturer of these machines is unable to know the specific operating characteristics of the machines he produces. In practice, there are different options for determining fuel consumption, but for the most part, these options are incorrect, unacceptable or inapplicable. The article deals with the variant of the application of GPS signal from a satellite to determining the speed of the machine and the time for crawling the specific field. In this way, its known formulas determine its slipping. After determining the machine's slipping, the fuel consumption can be determined accurately enough with the introduction of a corrective slipping factor.

Key words: *fuel, fuel economy, GPS, slipping, tractors.*

INTRODUCTION

A major element in the operating costs of vehicles is fuel. Its importance is increasing with the depletion of oil reserves worldwide and the continuing trend of rising fuel prices. At this stage, the methods for analyzing the fuel economy of wheeled vehicles are developed (Lilov et al., 2015; Totev et al., 2010; Ivanov et al., 2012).

According to Regulation 167/2013 of the European Parliament, the definition of "tractor" means any engine or wheeled or tracked agricultural or forestry vehicle equipped with at least two axles and a maximum design speed of at least 6 km/h, the principal function of which is related to its towing power and which is specially designed to tow, push, transport and propel certain removable equipment designed to carry out agricultural or forestry work, or to tow trailers or towed implements used in rural land and forestry; it may be adapted to carry loads when working in agriculture or forestry and/or may be equipped with one or more passenger seats (Regulation (EU) No 167/2013).

The ability to predict fuel consumption for tractors is very useful for budgeting and management. Using these equations, farmers can estimate and compare fuel consumption for different operating and loading conditions (Grisso et al., 2014; Grisso et al., 2004).

On the other hand, reducing the fuel consumption of transport vehicles reveals one of the possibilities of reducing air pollution from them. Fuel consumption is influenced by a number of design and operational factors.

The main operational factors that affect fuel consumption are (Evtimov et al., 2015):

- the type and condition of the road;
- the mass of the transport machine;
- speed of movement;
- ambient temperature;
- the speed of acceleration;
- vehicle operating time.

The use of an identifiable model for calculating tractor fuel consumption during soil cultivation for different types of soil cultivation significantly increases fuel efficiency and economy.

This leads to lower operating costs and increases agricultural productivity and ultimately leads to increased profitability in crop production (Nkakini et al., 2019).

This article introduces an innovative methodology for experimentally determining the fuel consumption of agricultural tractors. The methodology takes advantage of industry 4.0 and satellite navigation and information systems.

Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

MATERIALS AND METHODS

Each element of the methodology has links to the other elements. The multigraph of the relationship between the various elements of the methodology is shown in Figure 1.

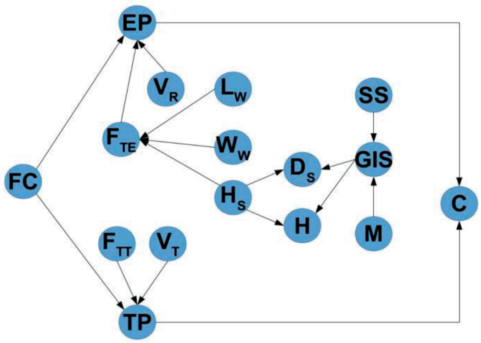

Figure 1. Multigraph of interconnections between the elements of the methodology for determining the fuel consumption of a tractor

According to Figure 1, the fuel economy (FC) of a tractor is determined by its fuel consumption over a certain operating time. It can be determined by some dependence (Equation 1) (Dimitrov, 1997; Dimitrov et al., 1980; Lilov et al., 2015):

$G_e = (g_T.P_T)/\rho$, l/h .... (1)

where:

- g_T - the specific draft fuel consumption, g/kWh;
- ρ = 0.832 - density of the diesel fuel at temperature 20°C, kg/l;
- P_T - useful tractor traction power, kW.

The specific fuel consumption for each engine is a known value and is taken from the tractor's prospectus materials or documentation. This is because the operating conditions of the tractor are variable and depend on many factors (Evtimov et al., 2015). The most important element of the formula is the useful tractive power of the tractor is determined by Equation 2.1. (Dimitrov, 1997; Dimitrov et al., 1980):

$P_T = F_T.v$ .... (2.1)

where:

- F_T - the tractor's pulling power, N;
- v_T - tractor speed, km/h.

For machines reporting hourly performance, the following formula can be used to determine the tractor's pulling power. With a known tractor hourly capacity, the traction power is determined according to Equation 2.2 (Dimitrov et al., 1980):

$P_T = (R.W)/(0.36\ \eta_{TT}.\tau)$, kW .... (2.2)

where:

- R - the specific pulling resistance per unit width of the machine, N/m. The coefficient is different for different machines. For a plow with a working width of 0.5-3 m, the resistance is 10.0-2.4.10^4 N/m.
- W - hourly tractor performance in ha/h. It is reported directly from the readings of the tractor dashboard;
- η_{TT} - traction efficiency for operating mode. It can be read from the tractor's traction characteristic or selected. The value varies from: 4K4 with same wheels - 0.68; 4K4 with different wheels - 0.65 and 4K2 - 0.64;
- τ - ratio of working time;

With some hourly productivity, the determination of the tractive force is not necessary. However, a calculation can be made to compare the values of theoretical traction power. The speed of the tractor can be used in the calculations, which is determined by the tractor's hourly productivity (Equation 2.3) (Dimitrov et al., 1980):

$v_T = W/(0.36\ B)$, km/h .... (2.3)

where:

- B - the machine working width, m. It is measured directly.

There are two approaches to determining the tractor's pulling power. One is theoretical and the other is experimental. It is necessary to make a comparison between the two types of approaches in order to compare the difference between them and to select a correction factor for fuel consumption.

The theoretical traction determination (FTT) is based on the known dependencies and speed characteristics of the engine. The approach is a little more general and probably leads to some differences with the actual fuel consumption of the machine. It is necessary to take into account the speed of rotation of the crankshaft during operation.

According to the methodology, the theoretical tractor traction force (FTT) is determined by the tractor traction balance Equation 3 (Dimitrov, 1997; Dimitrov et al., 1980; Lilov et al., 2015):

$F_{TT} = (M_E.i_T.\eta_T)/r_K – f.G$, N .... (3)
where:

- M_E is the moment of the tractor engine, Nm;
- i_T - the transmission number. The total transmission number of the i_T transmission is a known value for each machine and is usually chosen depending on the nature of the agricultural work carried out, mainly in the operating range of the gears;
- r_K - radius of the tractor wheel;
- η_T - mechanical transmission efficiency. The mechanical transmission efficiency is also known and shows how much of the engine energy is lost to cover the transmission resistances. It varies from 0.88 to 0.9;
- f - traction resistance coefficient of the tractor. It is selected tabularly depending on the soil properties. For example, for stubble the drag coefficient is 0.12 for a wheeled tractor (Ivanov et al., 2006);
- G - traction coupling weight.

Tractor towing weight is obtained as the product of tractor mass and ground acceleration (Equation 4) (Lilov et al., 2015; Staneva et al., 2016):
$G = m.g$, N .... (4)
where:

- m - the mass of the tractor, kg;
- g - acceleration due to gravity: $g = 9.81$ m/s^2.

The wheel radius is a size that is significantly difficult to determine because of the specific nature of the wheel contact with the road and the size of the contact spot. With sufficient accuracy for the gears, the wheel radius can be determined from Equation 5 (Dimitrov et al., 1980; Lilov et al., 2015):
$r_K = 1.035\ (0.5\ D\text{-}\xi B)$, m .... (5)
where:

- B is the outer diameter of the tire, m;
- H - tire profile height, m.

Data on the outer diameter of the tire and the height of the tire profile are known values for each tire. They can also be measured directly.
Of interest is the tire deformation factor. It is determined experimentally or taken from a priori information (Ivanov et al., 2006). Convenient for calculation is a value of 0.14-0.2.

Wheel radius values are determined based on the tractor's 8-12 km/h operating speed.
Determining the tractor speed is more accurate using the Formula in 2.3, but it can also determine the dependence (Equation 6) by taking into account the crankshaft speed of the engine (Lilov et al., 2015; Dimitrov, 2011):
$v_T = (\omega/i_T).r_K$, km/h .... (6)
where:
ω - the angular velocity of the crankshaft of the engine.
The angular velocity of the crankshaft of the engine is divided according to Equation 7:
$\Omega = (\pi.n)/30$, rad/s .... (7)
where n is the crankshaft rotation frequency recorded by the engine speed control, min^{-1}.
In a number of cases, however, the speed determined by Formula 6 is not real at work. This is because it does not account for the machine slipping into the soil. In this case, the engine consumes more fuel to do the job. In order to determine the travel speed of the tractor while running, it is necessary to take the slip value from the slip curve $\delta = f\ (F^T)$ for the determined tractive power.
After determining the slip, the speed of the tractor must be adjusted in Equation 2.1 according to Equation 8 (Dimitrov, 1997):
$V = v_T.(1\text{-}\delta)$ .... (8)
Of course, considerable knowledge of the tractor's theory and calculation, as well as a rich mathematical apparatus, is required to obtain the fuel consumption of the method thus outlined. In addition, a new load capacity calculation is required for any change in operating conditions. This leads to the creation of a huge database of calculations and complicates the process of determining fuel consumption, because after each determination of towing capacity it is necessary to calculate the hourly consumption and all the hourly fuel costs need to be added to the receipt of the total fuel consumption over a given period.
In order to determine the traction power experimentally (EP), it is necessary to capture different indicators from different sources. The determined traction power in this approach is more realistically determined. The traction power itself is determined by Equation 2.1. As has already been explained, the machine's traction power and the speed of the machine during processing are included. In the

experimental determination of traction power is taken from modern global sources of information.

The GNSS Global Navigation Satellite System can be used to determine the speed of the tractor. It is a combination of all existing navigation systems - GPS, GLONASS, WAAS, EGNOS, MSAS. WAAS, EGNOS and MSAS are in addition to the system as they are satellites that are geostationary orbit and provide corrections with much lower accuracy. The simultaneous use of GPS and GLONASS signals significantly increases the number of satellites observed, which in practice increases the ability to obtain more accurate results in real time and in adverse conditions (forest and mountain terrain, heavily urbanized areas, etc.). When the number of satellites observed is large, there is always sufficient data to resolve ambiguities in location. Currently, GPS and GLONASS contain 32 and 24 satellites respectively, with the tendency to increase in number (https://www.geonet.bg/home.html).

The actual speed of the machine is reported directly from the user interface (Figure 2) of the navigation system for the specific operation (https://agriculture.trimble.com/products/).

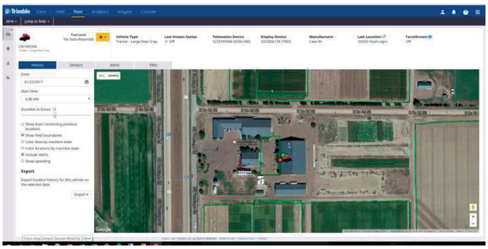

Figure 2. User interface of navigation system

The system connects to GLONASS and determines the position and speed of the tractor through a device mounted on it.

The system is compatible with tractor models equipped with such special devices or more up-to-date tractors (Figure 3).

Figure 3. General type of navigation system

In principle, any tractor can be equipped with a navigation system, but there are also cases where this is impossible for structural reasons or is economically disadvantageous. Then a mobile device of the type (Figure 4) is appropriate.

Figure 4. Mobile navigation system in general

The (F_{TE}) is less different in determining the tractor traction force. The traction resistance of a particular machine is determined, for example, the determination of the traction resistance of a plow of Equation 9 (Ivanov, 1962; Demirev et al., 2012):

$F_{TE} = f_M\, GM + H_S.a.b.n + \varepsilon.a.b.v^2$ …………..... (9)

where:

- f_M - the drag coefficient of the plow. It can be expressed as the coefficient of soil friction on the metal;
- G_M - weight of the working machine. It can be determined by Equation 4 using the values for the working machine;
- H_S - soil layer hardness, N/m^2;
- A - depth of treatment, m. The processing depth is set at the setting of the agricultural machine for operation and does not change until the machine tractor unit is disconnected;
- n - number of working bodies of the machine;
- ε - the coefficient of speed resistance, N.s^2/m^4. It depends on the form of the plow work surface and the soil properties (Ivanov, 1962). For the current plow the recommended value is $\varepsilon = 4000$ N.s^2/m^4.

The hardness of the soil layer is actually the coefficient of specific soil resistance to deformation. Prior to Industry 4.0, it was experimentally determined by a number of soil samples. This is history and can be determined with sufficient accuracy by dependence

(Equation 10) (Shishkov et al., 1973; Nguen et al., 1990):

$H_S = e^S$ .... (10)

where:

- S is the computational value of the exponent.

The exponent is calculated by dependence (Equation 11) (Shishkov et al., 1973; Nguen et al., 1990):

$S = -9.32+0.194W_a+15.92\rho W_a-2.717\rho^2$ … (11)

where:

- Wa is the absolute soil moisture, %;
- ρ - soil density, kg/dm^3.

As already stated, soil density (DS) and soil moisture (H) is a complex process associated with constant field trawling and soil sampling.

This development proposes an innovative approach to determine soil moisture and density by obtaining satellite data (SS).

To determine the moisture value, it is convenient to use the Santinel-2 L1C, Santinel-2 L2A satellites to obtain the moisture index for the specific operating field and the set work time, as shown in the example in Figure 5 (https: //eos.com/sentinel-2/).

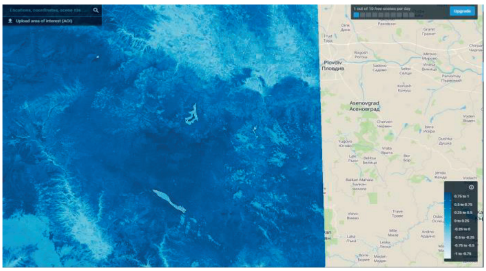

Figure 5. Moisture signal for satellite "Santinel-2 L1C"

After receiving a specific value of the moisture index, it is necessary to enter that value into the Global Information System (GIS).

An appropriate such system is ArcGIS (Figure 6) (Dallev et al., 2014).

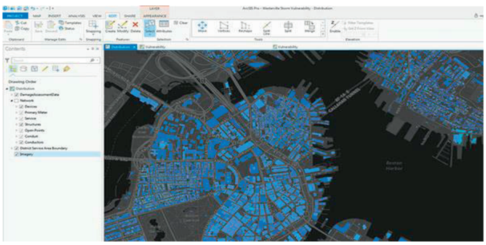

Figure 6. ArcGIS product overview

In the information system, the value of the humidity index after conversion with the help of a correction factor extracts the absolute moisture value Wa for the soil of the working field through the card that is selected.

Depending on which card is selected in the system, the type of soil and its density ρ are plotted. Soil maps are pre-programmed into the program and can be retrieved at any time with the desired information.

Direct measurement (M) is used to determine the correction factor for determining the absolute soil moisture. The direct measurement is performed with the help of a special hydrometer mounted on the agricultural machine, which measures the humidity at certain points in the field. In addition to the humidity, the apparatus allows to obtain other information on the content of certain substances in the soil. They can serve as a basis for creating a special map for the composition of the cultivated soil and the need to add substances to it. The measured humidity value can be used directly to determine (Formula 11) when the weather is cloudy and the satellite signal is inadequate. Based on the values of these points and using a GIS algorithm, a correction coefficient is constructed. The correction factor is different for different soil types. It connects modern satellite technology with conventional humidity detection technologies.

The last element of the methodology is the comparison (C) of the two models. At this stage, the values of the traction power determined by the two approaches are compared. This is necessary to evaluate the adequacy of the model. The obtained values of traction power determine the hourly fuel consumption and the pressure approach. The values are compared to the actual fuel consumed by the tractor as measured by the fuel flowmeter fitted to the combustion system.

To confirm the results, the fuel consumption, using a flowmeter, of an experimental tractor with a working plow attached was measured. Fuel consumption was determined using both approaches. Fuel consumption was determined using both approaches. The results show that the innovative fuel consumption method using satellite systems is closer to the actual fuel consumption of the machine. The method is suitable for use by farmers without the need for a fuel consumption monitoring system.

CONCLUSIONS

An innovative methodology has been developed to determine the fuel consumption of tractors by determining its towing capacity.
The developed methodology uses satellite systems to determine tractor speed and soil moisture.
The methodology developed has been tested and shows the adequacy of the model.

REFERENCES

Grisso, R., M. F. Kocher, M., Vaughan, D. (2004). Predicting tractor fuel consumption. *Applied Engineering in Agriculture, Vol.* 20, Issue 5, 553-561.

Grisso, R., Perumpral, J., Roberson, G., Pitman, R. (2014). Predicting Tractor Diesel Fuel Consumption. *CALS Communications and Marketing, Virginia Polytechnic Institute and State University*, USA, 1-11.

Dallev, M., Arnaudova, Zh., Ivanov, I. (2014). Application of gis in optimizing the aggregate composition of the soil. *Conference "Agriculture for life, life for agriculture", Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering,* Vol. III, Bucharest, 121-126.

Demirev, Zh., Bratoev, K. (2012). Zemedelski mashini I. *RU "Angel Kanchev"*, Ruse.

Dimitrov, S. (2011). Rakovodstvo za kursova rabota po teoria na avtomobila. *Technical University - Sofia*, Sofia.

Dimitrov, Y., Georgiev, P., Morchev, E., Stanimirov, S. (1980). Rakovodstvo po proektirane, konstruirane i izchisljavane na avtomobila, traktora i kara. *Technika*, Sofia.

Dimitrov, Y. (1997). Traktori. Proektirane i konstruirane na traktora. *Technical University - Sofia*, Sofia.

Evtimov, I., Ivanov, R. (2015). Vliyanie na nyakoi eksploatacionni factori varhu razhoda na gorivo na avtomobilite. *Scientific Journal of University of Ruse*, vol. 54, book 4, Ruse, 121-130.

- https://www.geonet.bg/home.html
- https://agriculture.trimble.com/products/
- https://eos.com/sentinel-2/

Ivanov, I., Lihoedenko, K., Reznichenko, M., Chernov, G. (1962). Selyskohozyaystvennie mashini. *Mashgiz*, Moscow.

Ivanov, R., Totev, T., Staneva, G., Kadikyarov, G. (2012). Edna vazmozhnost za izsledvane gorivnata ikonomichnost na avtomobili v eksploatatsionni uslovia. *Trans&MOTAUTO'12*, Varna, 255-258.

Ivanov, R., Rusev, R., Ilchev, P. (2006). A laboratory investigation of tyre sliding grip coefficient. *Research Journal "TRANSPORT"*, Vol 21, No 3, Lithuania, 172-181.

Lilov, I., Dimitrov, D., Lalev, L. (2015). Analysis of the fuel economy at steady speeds of motion of wheeled armored transporter. *Technics. Technologies. Education. Safety proceedings* vol. 1 "Transport technics and technologies. Management, security and ecology". Scientific technical union of mechanical engineering, year XXIII, Issue 4(167), Veliko Tarnovo, 56-58.

Nguen, AnT., Daskalov, Dzh. (1990). Izsledvane vzaimozavisimostite mezhdu tvardostta, platnostta i absolutnat vlazhnost na pochvata. *Selskostopanska tehnika,* Sofia.

Nkakini, S., Ekemube, R., Igoni, A. (2019). Development of predictive model for fuel consumption during ploughing operation in agricultural soil. *European Journal of Engineering and Technology,* Vol. 7, № 1, Progressive Academic Publishing, UK, 16-30.

Shishkov, S., Daskalov, Dzh. (1973). Nyakoi rezultati ot izsledvaneto na rabotni organi i rezhimi za pochvoobtabotvashtite frezi. *Selskostopanska tehnika*, vol. 1, Sofia, 17.

Staneva, G., Kadikyarov, G., Evtimov, I., Totev, T. (2016). Izsledvane koeficienta na sceplenie na pnevmatichna guma s eksperimentalno pokritie za trekove v promishlenosta. *BULTRANS-2016*, Proceedings, Sofia, 114-117.

Regulation (EU) № 167/2013 of the European Parliament and of the Council of 5 February 2013 on the approval and market surveillance of agricultural and forestry vehicles.

Totev, T., Petrov, Tz. (2010). Method of experimental investigation on learning car's fuel eficciency. *MTM intenational virtual journal*, Year 4, "MOTAUTO '10", Sofia, 44-47.