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DETERMINATION OF ENERGY CONSUMPTION AND CARBON DIOXIDE EMISSIONS RELATED TO FUEL CONSUMPTION FOR AGRICULTURAL MECHANIZATION APPLICATIONS

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Abstract: Energy efficiency is the goal of efforts to reduce the amount of energy required to provide products and services. In agricultural production, not only solar energy is used efficiently in the photosynthesis process, but also energy is used directly as fuel or electricity and indirectly due to energy consumption in the production processes of agricultural machinery, fertilizers or pesticides. The energy consumption per unit production area by the tractor and irrigation pump engines used during agricultural production processes is calculated regarding the diesel fuel and engine oil consumptions. During the operation of tractors and other engine–powered equipment, carbon (C) in the fuel is converted into carbon dioxide (CO_2) released in the engine exhaust. The fuel–based CO_2 emission calculation method is the preferred approach, as data on fuel consumed is generally more reliable. In this study, the methods used to determine energy consumption and CO_2 emissions related to fuel consumption in agricultural mechanization applications are discussed.
Keywords: agriculture, mechanization, fuel, consumption, energy, consumption, emissions

INTRODUCTION

Agriculture plays an important role in the economy of all countries in the world. In agricultural policies, it is aimed not only agricultural production in sufficient quantity and quality, but also the protection of the environment and the economic development of rural areas. Agricultural production is closely related to the economy, environment and energy consumption. Therefore, it interacts with all policies in these areas. The need for energy as an input in agricultural production can determine the profitability of production, which greatly influences the producer's investment in advanced agricultural systems.

Therefore, economically cost–effective energy measures are needed and at the same time commitments to reduce carbon emissions are made. Globally, energy use is projected to increase significantly in the coming years, with a widespread impact on the economy, including in the agricultural sector. This topic reveals the importance of research and development studies to develop more energy efficient technologies in agricultural production. Energy efficiency is the goal of efforts to reduce the amount of energy required to provide products and services. In agricultural production, not only solar energy is used efficiently in the photosynthesis process, but also energy is used directly as fuel or electricity and indirectly due to energy consumption in the production processes of agricultural machinery, fertilizers or pesticides.

While assessments of energy use in agriculture generally focus on direct energy use, it should be accepted that 50% and more of total energy use is related to nitrogen fertilizer production and other indirect energy uses (Woods et al. 2010; Pelletier et al., 2011). The energy use and energy saving potentials of different production systems in different environments are also drastically different.

MATERIALS AND METHODS

Fuel Consumption In Agricultural Production

About 1/3 of the total energy consumption in agriculture is spent on fuel. Production method and area are very important factors for fuel consumption. Fuel consumption varies between 500–15,900 liters/year. Diesel consumption for different products varies in the range of 60–120 liters/ha, depending on the processing intensity. The number of transactions is very important. (Handler and Nadlinger, 2012).

Amount of Fuel Consumed

Fuel consumption in agricultural production processes, consumed by tractor and irrigation pump engines in the use of tools and machinery;

- Diesel fuel consumption,
- Lubricant oil consumption and
- Total fuel (Diesel fuel + lubricant oil) consumption.

Diesel fuel and lubricant oil values consumed per unit production area (ha) by the tractor engine used during agricultural production processes are evaluated as the total fuel consumption.

$$m_t = m_D + m_l \ \text{[L/ha]} \qquad (1)$$

where:

m_t – total fuel consumption (L/ha),

m_D – Diesel fuel consumption (L/ha) and

m_l – lubricanting oil consumption (L/ha).

Fuel Consumption

Fuel consumption is determined for each application in the production process, based on the size of the equipment used and the power required to perform the operation. Diesel engines, gasoline engines or electric motors can provide power for agricultural applications. The type of engine used is specified as a machine variable. Fuel consumption (liter/hour, L/h) in gasoline and Diesel engines is determined as follows, depending on the power of the tractor or other engine used and the load value of the engine (ASAE, 2000):

$$m_D = (YTH) \times (NMG) \times (YKV) \times (TMY) \times (YKI) \ \text{[L/h]} \qquad (2)$$

where:

m_D – hourly fuel consumption of tractor engine (L/h),

YTH – Fuel consumption rate (L/kW–h),

NMG – Maximum usable or rated motor power (kW),

YKV – Fuel usage efficiency (decimal),

TMY – tractor or engine load (0–1) and

YKI – Fuel usage index (decimal).

Fuel usage efficiency (YKV) is a fuel usage reducing factor that takes into account the time consumed for turning and some minor adjustments where the engine is running at less than operating speed. As an average value for fuel use efficiency (YKV), the value determined by adding 1.0 to the area efficiency can be considered. Thus, when the area efficiency specified for an application decreases, the fuel usage efficiency decreases as well.

In the fuel use index (YKI), the time spent outside the actual operation is taken into account for transporting tools or machines to the agricultural production area and for some arrangements. It is normally taken into account as 1.10 in the fuel usage index (YKI). The motor load (TMY) for any given operation is determined by dividing the average power required to perform the operation by the maximum available power.

Fuel Consumption Rate

Fuel consumption rate (YTH) for diesel engines depends on engine load and throttle setting (ASABE, 2011):

$$YTH = GA\,(0.22 + 0.096 / TMY) \ \text{[L/kW–h]} \qquad (3)$$

where:

GA – partial throttle setting factor and is determined as follows:

$$GA = 1 - (T - 1)\,(0.45\ TMY - 0.877) \qquad (4)$$

where:

T – throttle setting and its value ranges from 0.0 to 1.0.

For simplicity, the throttle setting can be considered 50% greater than the engine load at 1.0 maximum. Therefore, for engine loads greater than 0.66, the throttle is assumed to be at maximum. For gasoline engines, this relationship is defined as follows:

$$YTH = GA\,(2{,}74\,(TMY) + 3{,}15 - 0{,}203\ \sqrt{(697\,(TMY))}) \ \text{[L/kW–h]} \qquad (5)$$

Lubricant Oil Consumption

The hourly lubricant oil consumption of the tractor engine used for agricultural production operations is determined based on the rated power of the tractor. For estimating the hourly lubricant oil consumption in Diesel tractor engines, the following linear equation based on engine rated power (P_e) and specified in ASABE Standard D497.7 Section 3.4 (2011) is used as the reference model.

$$m_l = 0.00059 \times P_e + 0.02169 \ \text{[L/h]} \qquad (6)$$

By Cancante et al., (2017), using MINITAB 17.0™ data processing software, linear regression (LRA) and analysis of variance (ANOVA) and the coefficients specified in equation (6) were determined as follows.

$$m_l = 0.000239 \times P_e + 0.00989 \ \text{[L/h]} \qquad (7)$$

where:

m_l – hourly lubricant oil consumption of the tractor engine (L/h) and

P_e – the rated power of the tractor (kW).

The Pearson correlation coefficient for the variables in equation (7) was r=0.90 ($p<0.05$). The standard errors of the constant term and linear coefficient in the developed model are 1.50 10–3 L/h and 9.0 10–6 L/h kW, respectively.

Fuel Energy Consumption

The total fuel energy consumption in the agricultural production processes is consumed by the tractor and irrigation pump motors in the use of tools and machinery;

- Energy consumption related to Diesel fuel consumption,
- Energy consumption related to lubricant oil consumption and
- Considered as the total energy consumption for Diesel fuel+ lubricant oil consumption.

The fuel energy consumption (EC_f, MJ/ha) of diesel fuel and lubricant oil consumed per unit production area (ha) by the tractor and irrigation pump engines used during agricultural production processes is determined as follows.

$$EC_f = EC_D + EC_l \ \text{[MJ/ha]} \qquad (8)$$

where:

EC_f – total fuel energy consumption (MJ/ha),

EC_D – Diesel fuel energy consumption (MJ/ha) and

EC_l – lubricant oil energy con sumption (MJ/ha).

Diesel fuel energy consumption (EC_D, MJ/ha) per unit production area (ha) by the tractor and irrigation pump engines used during production operations is determined as follows.

$$EC_D = m_D + LHV_D \ [MJ/ha] \quad (9)$$

where:
EC_D – Diesel fuel energy consumption (MJ/ha),
m_D – Diesel fuel consumption (L/ha) and
LHV_D – the lower heating value of Diesel fuel (MJ/L).

The lower calorific value of Diesel fuel consumed during production operations in the field with agricultural tools and machinery is taken into account as LHVD = 37.1 MJ/L (IPCC, 1996).

Lubricant oil energy (ECl, MJ/ha) per unit production area (ha) of lubricant oil consumption by tractor and irrigation pump engines used during production operations is determined as follows.

$$EC_l = m_l + LHV_l \ [MJ/ha] \quad (10)$$

where:
EC_l – lubricant oil energy consumption (MJ/ha),
m_l – lubricant oil consumption (L/ha) and
LHV_l – the lower heating value of lubricant oil (MJ/L).

The lower calorific value of lubricant oil consumed during production operations in the field with agricultural tools and machinery is taken into account as LHV_l = 38.2 MJ/L (IPCC, 1996).

Carbon Dioxide Emissions from Fuel Consumption

During the operation of tractors and other engine–powered equipment, carbon (C) in the fuel is converted into carbon dioxide (CO_2) released in the engine exhaust. The amount of CO_2 released is proportional to the amount of fuel consumed. The conversion factor used is 2.637 kg CO_2–equivalent per liter of Diesel fuel consumed. Fuel consumption is determined during the execution of each application. By summing up the amount of fuel consumed in all applications, the annual total amount of fuel used in the business is determined. This total value is then multiplied by the emission factor to determine the CO2 emissions from the combustion of the fuel.

In the process of agricultural production processes, carbon dioxide (CO_2) emissions are consumed during the use of tools and machinery;

- CO_2 emissions related to Diesel fuel consumption,
- CO_2 emissions related to lubricant oil consumption and
- The total CO_2 emissions related to the total fuel (Diesel fuel + lubricant oil) consumption.

Taking into account the lubricant oil consumption value of the tractor engine, CO_2 emissions related to lubricant oil consumption can also be calculated.

The fuel–based CO_2 emission calculation method recommended by the Intergovernmental Panel on Climate Change is taken into account in the calculations to determine the CO_2 emissions related to the use of fuel as a result of agricultural production (IPCC, 1996). The proposed approach for calculating CO_2 emissions based on fuel consumption is summarized in equations (12) and (13).

The total CO_2 emission ($kgCO_2/ha$) related to the unit production area (ha) fuel consumption by the tools and machines used during agricultural production processes is determined as follows.

$$CO_{2,t} = CO_{2,D} + CO_{2,l} \ [kgCO_2/ha] \quad (11)$$

where:
$CO_{2,t}$ – total CO_2 emissions related to fuel consumption ($kgCO_2/ha$),
$CO_{2,D}$ – CO_2 emissions related to Diesel fuel consumption ($kgCO_2/ha$) and
$CO_{2,l}$ – CO_2 emissions related to lubricant oil consumption ($kgCO_2/ha$).

The CO2 emission (CO2, D, kgCO2/ha) related to Diesel fuel consumption per unit production area (ha) by agricultural tools and machinery used during production processes is determined as follows.

$$CO_{2,D} = m_D \times LHV_D \times EF_D \ [kgCO_2/ha] \quad (12)$$

where:
$CO_{2,D}$ – emissions related to Diesel fuel consumption ($kgCO_2/ha$),
m_D – Diesel consumption (L/ha),
LHV_D – the lower calorific value of Diesel fuel (37.1 MJ/L) and
EF_D – CO_2 emission factor for Diesel fuel (0.07401 $kgCO_2/MJ$).

The CO_2 emission ($CO_{2,l}$, $kgCO_2/ha$) related to the lubricant oil consumption per unit production area (ha) by the agricultural tools and machinery used during production processes is determined as follows.

$$CO_{2,l} = m_l \times LHV_l \times EF_l \ [kgCO_2/ha] \quad (13)$$

where:
$CO_{2,l}$ – emissions related to lubricant oil consumption ($kgCO_2/ha$),
m_l – lubricant oil consumption (L/ha),
LHV_l – the lower calorific value of lubricant oil (38.2 MJ/L) and
EF_l – CO_2 emission factor for lubricant oil (0.07328 $kgCO_2/MJ$).

CONCLUSIONS

Diesel and gasoline engines are the most important power sources used in agricultural applications. Fuel consumption is determined for each application in the production process, based on the size of the equipment used and the power required to perform the operation. Fuel consumption in gasoline and Diesel engines is determined depending on the power of the tractor or other engine used and the load value of the engine. The hourly oil consumption of the tractor engine used for agricultural production operations is determined based on the rated power of the tractor.

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