OPTIMIZATION OF FUEL CONSUMPTION DURING THE HARVEST OF WHEAT

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Summary. Hourly and per ton fuel consumption of the combine harvester *Claas Lexion 540C* is determined for idle running conditions and for conditions of cutting winter wheat *'Bussard'*. At zero combine harvester speed and at engine speed of rotation equal to 2200 min^{-1} and when the gears of cutter bar, threshing device and straw chopper are turned off, fuel consumption reaches 14.5±1.1 l·h^{-1}. If the engine rotation speed is reduced to 1200 rpm the fuel consumption is only 4.0 l·h^{-1}. It is observed that if combine is running on field stubble the increasing of speed by 1 km·h^{-1} causes the rise of fuel consumption by 1.3 l·h^{-1}. Fuel consumption reaches 29.6 l·h^{-1} for conditions of running at 7 km·h^{-1} speed on field stubble with full tank of grain, if the running speed is reduced to 4 km·h^{-1} it is of 23.8 l·h^{-1} value. For winter wheat *'Bussard'* harvesting and for wheat inflow to the combine of 10 kg·s^{-1} hourly, fuel consumption reaches 43.6 l·h^{-1}. Fuel consumption per one ton is about 2.1 l.

Key words: combine harvester, fuel consumption, running speed.

INTRODUCTION

Agricultural production requires great energy consumption. To grow winter wheat 3735.4 MJ·ha^{-1} of energy is used [Canakci *et al*., 2005]. Yield harvesting cost equals to 22.9% [Canakci *et al*., 2005] or 32% of all the energy expenditure [Vitlox & Michot, 2000]. Fuel makes the greatest part of energy consumption. To harvest one ton of wheat grain during the harvest time requires approximately 11 kWh of energy [Turan *et al*., 2006].

Fuel consumption is closely related with environmental pollution [Vitlox & Michot, 2000]. Thus mineral fuel consumption and carbon dioxide (CO_2) emission should be minimized in technological processes of agricultural production [Nielsen & Luoma, 2000]. It has been calculated that annual reduction of mineral fuel to 2000 kg would minimize the harmful emissions of CO_2 into the atmosphere by 5.5 tons [Busato *et al*., 2007].

Fuel consumption during harvesting is conditioned by many factors: soil type, structure and moisture content, weather conditions, the field shape and size, species of harvested crops and their yield, combine design, its preparation for work and the operator's qualifications [Nielsen & Luoma, 2000; Safa & Tabatabaeerfar, 2008]. When the weather is good for the crop harvesting, the combine

harvester uses 17–20 l of diesel fuel per hectare of harvested crops. When the weather is bad, the fuel consumption increases up to 25 l [Vitlox & Michot, 2000; Safa & Tabatabaeerfar, 2008]. Fuel consumption during crop harvesting is also dependent on due transportation works [Busato *et al*., 2007; Botta *et al*., 2007].

It has been determined that greater crop yields require more fuel but fuel consumption for harvested ton of grain is lower [Kehayov *et al*., 2004]. Demmel (2008) stated that fuel consumption during wheat harvesting equals to 20 $l \cdot ha^{-1}$, but he did not give the grain flow supplied into combine harvester.

Fuel consumption during crop harvesting depends on field size and shape [Busato *et al*., 2007]. In big, regular shape fields a combine harvester uses less fuel, because it makes fewer turnarounds at the end of the field [Demmel, 2008]. When the field area is smaller than 2 ha, the fuel consumption is equal to 27 $l \cdot ha^{-1}$, and when the crop is harvested in the field of >10 ha area, it increases up to 20 $l \cdot ha^{-1}$ [Safa & Tabatabaeerfar, 2008].

Fuel consumption during crop harvesting is related with combine harvester wear and tear. It was stated that after ten years of operation the combine uses approximately 1.2 times more fuel than the new one [Зубахин & Камша, 2006]. But when the filters in all systems of combine harvester are changed in due time, the fuel consumption could be reduced by 5% [Demmel, 2008]. Fuel consumption also depends on the air pressure in tires [Demmel, 2008]. In soils with great moisture content the pneumatic pressure in tires should be reduced two times.

Fuel consumption could also be minimized by supplying less straw into the combine harvester. There are several methods to reduce the mass of straw supplied into the combine harvester: stems sprayed by growth regulators get lower and the straw mass drops from 10% to 15% [Čaikauskas, 1995]; when a desiccant is applied to the crop before harvesting, the straw mass supplied into the combine harvester is drier and has no weeds [Strakšas & Jurpalis, 2001]; when the stubble of 0.2 m height is left, the combine harvester fuel consumption drops by 14% [Voßhenrich *et al*., 2008]; when the stripped ears are threshed, the fuel consumption is reduced by more than 22% [Strakšas, 2006].

When the stubble height is increased from 0.1 m to 0.4 m, the combine harvester fuel consumption decreases 1.5 times. But stubble height has a smaller impact on fuel consumption than the moisture content of harvested crops [Voßhenrich *et al*., 2008]. Many authors when depicting the test results of combine harvester operation give the average fuel consumption per ha of harvested crops or for a ton of threshed grains, but they do not relate it with crop species, the change of the crop flow supplied into a combine harvester, and the technological indices of the threshing apparatus.

The research goal is to determine the relationship of fuel consumption in the combine harvester *Claas Lexion 540C* with the inflow of winter wheat *"Bussard"* supplied into its threshing apparatus as well as with its technological parameters.

METHOD OF INVESTIGATION

The operation of combine harvester *Claas Lexion 540C* was tested in field experiments. The width of combine harvester cutter bar is 6.07 m, the threshing drum diameter is 0.6 m, its width 1.7 m, the concave wrapping angle is 142°, its area is 1.26 m^2, the area of grain cleaner sieves is 5.8 m^2, the area of six straw walker sections is 7.48 m^2, the capacity of the grain tank is 8100 l, the engine power of *Caterpillar* is 203/276 kW/AG. There is an acceptance drum of 0.45 m diameter in front of the combine harvester threshing drum and the concave of 0.6 m^2 is underneath.

Biometrical indices. To determine biometrical indices of winter wheat species *'Bussard'* tests were performed in five plots, the area of which is 0.25 m^2 in the harvested crop field. After the cutting crops were weighed (reading accuracy is 0.01 g), and the stem length till ears was measured, their average height was determined. Grains threshed from ears were weighed and their moisture content measured, as well as the mass of 1000 grains and biological yield of grains with 14% moisture content.

Fuel consumption. It was measured by AG device AIC-888 *Instructor* made by Swiss company Automotive Information and Control Systems. The device calibration passes Euro-Norm 95/54/CE. The device throughput is from 4 l·h^{-1} to 200 l·h^{-1} of fuel, and measurement error is ±1%. The device threaded pipe branch is connected with a fuel tank of combine harvester through the hose assembly. The second pipe branch is connected with motor fuel pump and the third pipe branch is connected with the fuel return line. The device is connected with the monitor via the cable and installed in the combine harvester cabin.

When combine harvester *Class Lexion 540C* was harvesting the crop in the field strip of 100 m length, the computer data were recorded, i.e., the stubble height, combine harvester operation speed, technological parameters of the threshing device, and the change of the fuel consumption. The fuel consumption was calculated at l·ha^{-1} and l·t^{-1}, accordingly. The research data were estimated after the calculation of the average confidence interval of 95% certainty value.

RESULTS AND DISCUSSION

Meteorological conditions. The second decade of July (2008) was rainy (73 mm of precipitation), thus the harvesting of winter wheat started later than usual. The third decade was warm and dry with only 4 mm of rainfall. Harvesting conditions of winter wheat were very good. In August there were 20 rainy days with 127 mm of rainfall. Crop harvesting tests could be performed only after the external surface moisture of the plants dried after the rain.

Crop biometrical indices. Fuel consumption of combine harvester *Class Lexion 540C* during the harvesting of winter wheat *'Bussard'* was tested in 2008. Crops were of medium thickness. Stem height was 0.79 m, the crops were leaning in some places. The wheat grains were big, the mass of 1000 grains was 55.2±3.5 g, and average biological yield was 8.81 t·ha^{-1}.

Fuel consumption during idle running of engine. It was determined when the combine harvester: did not work; during idle running of engine; and when the drives of the cutter bar, threshing device and straw chopper were in operation.

The motor rotation frequency of the combine harvester *Class Lexion 540C* was changed by setting the fuel delivery control handle into three fixed positions. Then the motor rotated at the speed of 1200 min^{-1}; 1450 min^{-1} and 2200 min^{-1}.

When the combine harvester is in field the drives of cutting bar and threshing device are not always switched off and the rotation speed is not reduced to 1200 min^{-1}. The hourly fuel consumption of the engine during idle running was 14.5±1.1 l (Fig.1) when the motor rotation speed was 2200 min^{-1}. When the motor rotation speed was reduced from 2200 min^{-1} to 1200 min^{-1}, the fuel consumption reduced 10.5±1.14 l, and when the motor operated with switched on drives of cutting bar, threshing device and straw chopper the fuel consumptions equalled to 12.1±1.1 l. To rotate the cutter bar drive (*n*=2200 min^{-1}) 0.7 l·h^{-1} of fuel is needed, to rotate the threshing device drive – 4.3 l·h^{-1}, and to rotate the straw chopper drive – 5.5 l·h^{-1} of fuel is needed. When the motor rotated at the frequency of 1200 min^{-1}, less fuel, 5.5 l·h^{-1} , was required to rotate the drives.
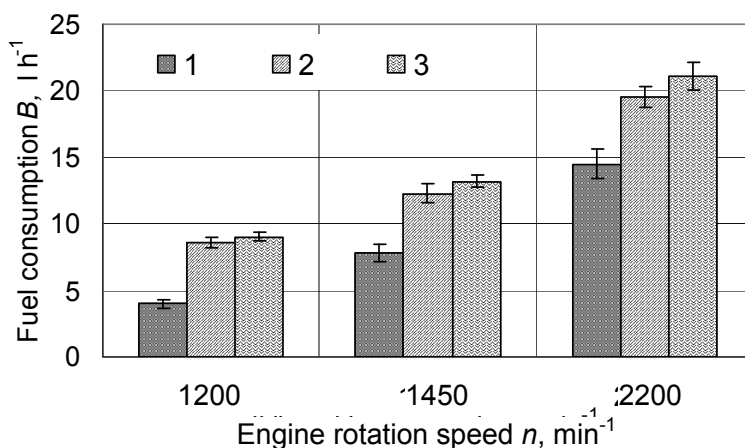
Fig. 1. The influence of engine rotation speed n of combine harvester *Claas Lexion 540C* on fuel consumption B: drum rotation speed n_1=800 min^{-1}, straw chopper rotation speed n_2=3300 min^{-1}; fan rotation speed n_3=800 min^{-1}, gap between drum and concave a=8 mm, gaps between upper sieve plates b=12 mm, gaps between bottom sieve plates b_1=8 mm; 1 – engine operated at idle running; 2 – the drives of cutter bar and threshing device is switched on; 3 – the drives of cutter bar and threshing device and straw chopper are switched on

Fuel consumption when combine harvester operates at idle running. Combine harvester operates at idle running when it drives to the field or to the end of the field with full grain tank. When the combine harvester was passing the field the drives of the cutting bar and threshing device were switched on and it often ran at a greater speed. When the combine harvester ran through the wet (22.6%) stubble with empty grain tank and switched off technological drives at the speed of 7 km·h^{-1}, the motor used 23.9±0.53 l·h^{-1} of fuel, and with the tank full of grains (5.7 t of grains) – 29.6 l·h^{-1}. When driving with empty grain hopper but switched on drives of cutting bar, threshing device and straw chopper, the hourly fuel consumption was 29.7±0.7 l. When the speed of the empty combine harvester was reduced to 4 km·h^{-1} the fuel consumption decreased to 4.3±0.97 l·h^{-1}. It had been recommended to switch off the drives of the cutter bar, threshing device and straw chopper and choose rational driving speed when the combine harvester was passing the field with an empty grain tank.

Fuel consumption while harvesting winter wheat *'Bussard'*. The previous research showed that grain damage and grain losses due to operation of straw walkers and cleaner depended on the crop inflow supplied to the combine harvester [Špokas *et al*., 2007]. It was related with combine harvester operation conditions and its throughput. Grain damage is the least and the permissible grain amount in the straw and chaff remained when the rational grain inflow was supplied into the combine harvester. During wheat harvesting the wheat inflow from 8 kg·s^{-1} to 12 kg·s^{-1} can be supplied into the combine harvester *Class Lexion 540C*. Qualitative indices of technological process and fuel consumption evaluate combine harvesters' work.

The hourly fuel consumption of combine harvester was tested while harvesting winter wheat *'Bussard'* (Fig. 2). The combine harvester operation speed and accordingly the wheat inflow supplied into the combine harvester were changed.
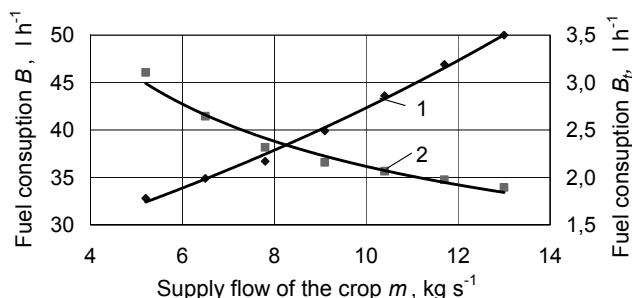
Fig. 2. The influence of combine harvester *Claas Lexion 540C* supply inflow of the crop (*m*) on the hourly fuel consumption (*B*) and fuel consumption per ton of winter wheat *'Bussard'* (B_t): n=2200 min^{-1}, n_1= 850 min^{-1}, n_2=3300 min^{-1}, n_3=1300 min^{-1}, *a*=8 mm, *b*=12mm, b_1=4 mm, A_g=8.8 t·ha^{-1}, U_1=17%; $1 - B = 24.24e^{0.055m}$, (R^2= 0.99); $2 - B_t = 0.021m^2 - 0.52m + 5.28$, ($R^2$= 0.98)

It was determined that when the inflow of the supplied wheat was increased from 5.2 kg·s^{-1} to 13.0 kg·s^{-1}, the hourly fuel consumption increased to 17.2 l·h^{-1} but fuel consumption per ton of winter wheat decreased by 1.2 l·t^{-1}. When the rational grain flow was supplied (10 kg·s^{-1}), the hourly fuel consumption was 43.6±0.69 l·h^{-1}, and fuel consumption per ton of winter wheat was 2.06±0.03 l·t^{-1}.

CONCLUSIONS

1. During idle running the hourly fuel consumption of combine harvester *Class Lexion 540C* engine (*n*=2200 min^{-1}) was 14.5±1.1 l, the fuel consumption to drive the gear of the cutter bar was 0.7 l·h^{-1}, that of the threshing device – 4.3 l·h^{-1}, and that of the straw chopper – 1.6 l·h^{-1}. When combine harvester was not operating and the motor rotation speed was minimized to 1200 min^{-1} and when all the technological drives were switched off the fuel consumption was reduced to 4.0±0.34 l·h^{-1}.

2. When the combine harvester with empty grain tank and switched off technological drives was running through the stubble at the speed of 7 km·h^{-1}, the engine used 23.9±0.53 l·h^{-1} of fuel, and when the drives of cutter bar, threshing device and straw chopper were switched on the fuel consumption was 29.7 ± 0.7 l·h^{-1}.

3. Fuel consumption during the harvesting of winter wheat *'Bussard'* was 43.6±0.69 l·h^{-1} (the supplied inflow of wheat was 10 kg·s^{-1}). When the combine harvester run at the rational speed of 4 km h^{-1}, and the wheat supply inflow into the combine harvester was 10 kg s^{-1}, the fuel consumption per ton of winter wheat was approximately 2.1 l.

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OPTYMALIZACJA ZUŻYCIA PALIWA PRZY ZBIORACH PSZENICY

Streszczenie. Zużycie paliwa na godzinę i na tonę w kombajnie żniwnym *Claas Lexion 540C* zostało obliczone w warunkach postoju i podczas koszenia pszenicy zimowej *'Bussard'*. Przy szybkości zerowej oraz prędkości obrotowej silnika równej 2200 min^{-1} , przy wyłączonych biegach kosiarki, młocarki i snopowiązałki, zużycie paliwa sięga 14.5±1.1 l·h^{-1}. Jeśli prędkość obrotowa silnika jest zredukowana do 1200 obr/min, zużycie paliwa wynosi tylko 4.0 l·h^{-1}. Zaobserwowano, że jeśli kombajn jedzie po rżysku, wzrost szybkości o 1 km·h^{-1} powoduje wzrost zużycia paliwa o 1.3 l·h^{-1}. Zużycie paliwa osiąga 29.6 l·h^{-1} przy szybkości 7 km·h^{-1} po rżysku z pełnym zbiornikiem ziarna; jeśli szybkość jazdy zredukowana jest do 4 km·h^{-1}, jego wartość wynosi 23.8 l·h^{-1}. Przy zbiorze pszenicy *'Bussard'* i przy podawaniu do kombajnu 10 kg·s^{-1} na godzinę, zużycie paliwa osiąga 43.6 l·h^{-1}. Zużycie paliwa na jedną tonę wynosi około 2.1 l.

Słowa kluczowe: kombajn żniwny, zużycie paliwa, prędkość jazdy