Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 2(150):5-13

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.150.026

# PERFORMANCE OF SELECTED CULTIVATION MACHINES IN RELATION TO FUEL CONSUMPTION

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ARTICLE INFO

*Article history:*
Received: May 2013
Received in the revised form: October 2013
Accepted: January 2014

*Keywords:*
cultivation machine,
performance,
fuel consumption

ABSTRACT

*Correct juxtaposition of a tractor with a machine affects time and being on time with a treatment as well as fuel consumption. The article presents analysis of the selection of various cultivation machines to a 14 kN class tractor in the aspect of obtaining maximum performance and minimum fuel consumption. The following cultivation machines were investigated: cultivation aggregates and chisel plows, disc harrows, field ploughs. During exploitation, research measurements of fuel consumption and actual speed of the units operation were taken. It was showed that incorrect selection of the working width of a machine for a tractor results in a decrease of the cultivation unit performance and in many cases in the increase of fuel consumption.*

## Introduction and objective of the paper

The range of offered farm machines and devices, both domestic as well as foreign is still increasing at the Polish market. Poland becomes one of the biggest users of farm equipment in the EU. Due to the newest technologies, machines are even better and as a result, more enduring, less energy consuming and more efficient. A considerable increase of sale of the said machines has taken place in the recent years. 2011 was record-breaking in the amount of sold tractors and agricultural machines. There were 17, 035 new farm tractors on our fields. Statistically, it is a digit by 34% higher than in comparison to 2010 (GUS, 2011). The increase of the number of purchased machines is the most frequently justified with the increased interest of farmers in the European Union subsidies. Tractors are equipped in even better engines, which meet even higher standards of combustion (Landis and Schiess, 2006). Machines aggregated to them, are characterized with even higher performance at low consumption of working elements. Farmers who have such tractors and machines look for savings in their exploitation (Lorencowicz, 2008; Muzalewski, 2008). Purchase of diesel oil is currently expensive, therefore, there is a tendency to obtain possibly the highest performance of machines, at the possibly the lowest fuel consumption (Talarczyk, 2012). The increasing range of machines, constant technology development and existing trends in agriculture, prove that analysis of the sets of a tractor-machine units is indispensable. High performance and optimization of costs of exploitation of machine aggregates may be obtained only by means of a correct selection of machines (Kuczewski and Majewski, 1999; Marks and Krzysztofik, 2000). Many factors affect the selection, inter alia: farm size, scale and type of plant production, form of mechanization of a farm, individual conditions of farming and economic power of a farm (Banasiak, 1999).

The objective of the paper was analysis of the selection of various cultivation machines for a farm tractor in order to obtain maximum performance at the minimum fuel consumption. The following measurements were requisite for performance of the objective: fuel consumption by a farm tractor, actual speed of work of tractor units and determination of operation of the researched tractor units.

## Subject and methodology of research

During the field research, machine aggregates composed of a tractor Zetor Proxima 75 of class 14 kN and the following cultivation machines were subjected to assessment:
- cultivation aggregates of a working width 3.2. and 3.6.m;
- chisel plows of a working width 1.8 and 2.2. m;
- disc harrows of a working width 2.4 and 2.7. m;
- 3 and 4 -furrow field ploughs.

Cultivation units and chisel plows as well as disc harrows were produced by BOMET company from Węgrów and ploughs by Akpil company from Pilzno and equipped with Vogel&Noot elements. A tractor was equipped with an engine of 53kW/72KM power at 2,200 rot$\cdot$min$^{-1}$ and the volume 4,156 cm$^3$. It was characterised with a modern structure which meets the standards of fuels emission TIER IIIA. It is a 4-cylinder engine equipped with a in-line pump and a turbo compressor along with an intercooler.

A module consisting in a measurement unit ZP2- 4-I by Rotameter company (fig. 1a), composed of a volumetric flow-meter, fuel filter and a clarifier as well as a digital recorder NOSAL-TECH (fig. 1b) were used for measurement of fuel consumption. A mentioned device measured actual fuel consumption determining the difference between the amount of diesel oil collected from a tank and excess of diesel oil, which was returned to the tank.

Actual speeds of tractor sets were determined for calculation of the performance of the investigated units. It was carried out by measurement of time of passing the measured 100 metres length from the first to the second control post (Banasiak, 2004).

Investigation were carried out in a farm in Waleńczów near Częstochowa on two fields of soil class 4a and 4 b, these were light soils. Measurements for particular groups of cultivation machines were carried out on the same fields, therefore, the soil compaction and moisture did not have to be determined. Weather conditions during investigations were varied depending on the performed cultivation treatments. Investigations with the use of cultivation units were carried out in Spring at the air temperature of 11ºC, then high moisture of soil occurred, which translated into the increased skid of tractor wheels. Subsequent investigations were carried out at the beginning of August when machines for stubble cultivation were investigated. During testing disc harrows temperature was 24ºC, and in case of testing chisel plows it was 26ºC. The mentioned tests were carried out on the third day after mowing grains by a combine harvester. Whereas, research of field ploughs was performed at the end of August when it was very dry, temperature was 24$^o$C and soils was overdried. Analysis of the selection of machines consisted in comparison of the quality of work of two similar sets which differed with a working width, working at the same field.

a) b)

*Figure 1. Measurement unit a – flow meter ZP@-4-I by Rotameter company, b – NOSAL-TECH mounted on a tractor*

## Results of the research

During research, assumptions presented in figure 2 were followed. Four rotational speeds of an engine from the minimum 1,500 rot.·min$^{-1}$ each 250 rot.·min$^{-1}$ to the signifying 2,200 rot.·min$^{-1}$were accepted for determination of fuel consumption. 100 m measurement lenghts were determined. Constant depth of operation between units was established in order to better compare their operation parameters. This depth for units and harrows was 0.1 m and for ploughs 0.15 m. Unit crossings with simultaneous soil cultivation were performed at the researched lengths. Time of operation of units and fuel consumption was determined during crossing.

Following measurements, hour fuel consumption and per 1 hectare of cultivated surface during a crossing of the investigated length, speed of the unit, cultivation time of 1 ha and efficiency of the investigated units in ha·h$^{-1}$ were calculated. The above parameters of the cultivation units operation were set in table 1. Depending on the theoretical working width of units, cultivated surfaces for one crossing were ranging from 180 m$^2$ for a chisel plow of a working width of 1.8 m to 360 m$^2$ for a cultivation unit of a working width 3.6 m. Whereas for a 3 – furrow plough the surface area of the cultivated measurement length was 120$^2$ and for a 4-furrow plough it was$^2$.

When comparing the speed of the investigated machines, one may state that the lowest working speed was for the cultivation unit and was within 1.63 to 2.31 m·s$^{-1}$; a similar speed was for a chisel plow within 1.67m·s$^{-1}$ to 2.78 m·s$^{-1}$. The highest working speed was at the cultivation of a disc harrow of 2.4 m and a rotational speed of an engine 2200 rot.·min$^{-1}$ and was 3.33 m·s$^{-1}$.

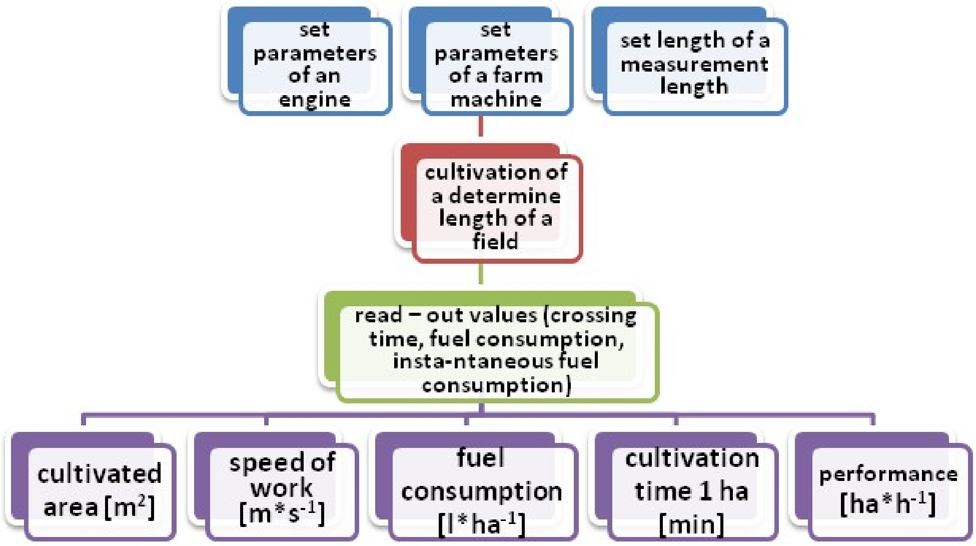


*Figure 2. Schematic representation of procedure during exploitation tests*

Comparing performance of the investigated cultivation machines, which performed cultivations at the same depth, one may observe that the lowest performance was for a chisel plow and was within 1.56 to 2.2 ha·h$^{-1}$ and the highest for a disc harrow from 2.11 do 3.14 ha·h$^{-1}$. Completely different performances were for plough work from 1.31 ha·h$^{-1}$ for a 3-furrow plough at the engine rotations 1,750 rot·min$^{-1}$ to 1.86 ha·h$^{-1}$ for a 4-furrow plough for rotations 2200 rot·min$^{-1}$. However, it was related to higher resistance, which occur at ploughing with a higher depth of operation i.e. 0.15 m.

Lower consumption of fuel in liters per a hectare was for a cultivation unit and a disc harrow and was within 4.2 to 6.3 l·ha$^{-1}$. Higher consumption occurred at the operation of chisel plows and plough and was within 7.5 to 10.0 l·ha$^{-1}$.

When comparing performance of the researched machines and fuel consumption in liters per hectare, one may state that a chisel plow with a lower width of 1.8 m characterizes with higher performance i.e. within 1.72 to 2.20 ha·h$^{-1}$ at a lower fuel consumption from 7.7 to 9.5 l·ha$^{-1}$ in comparison to an aggregate with a higher width (2.2 m), for which performance was within 1.56-1.84 ha·h$^{-1}$ and fuel consumption was within 7.7-10.0 l·ha$^{-1}$. It resulted from the fact that at the lower width of a chisel plow, a working speed of a unit was higher. Additionally, cultivation time of one hectare was shorter from 3 to 7 minutes. For the remaining cultivation machines - a cultivation unit and a disc harrow, a lower performance occurred in case of a machine with a lower width and a higher performance for higher width. Performance of field ploughs depended on the working width and was within 1.31 to 1.39 ha·h$^{-1}$ for a 3-furrow plough and within 1.65 to 1.86 ha·h$^{-1}$ for a 4-furrow. However, it was reported here that at the higher performance of a 4-furrow plough, lower consumption of fuel occurred 7.5-8.8 l·ha$^{-1}$ in comparison to a smaller plough where fuel consumption was within 9.2 do 10.0 $l \cdot ha^{-1}$. Ploughing time for a bigger plough was shorter and it was within 32 to 36 $min \cdot ha^{-1}$ and for a smaller within 43 do 46 $min \cdot ha^{-1}$.

Table 1
*Operation parameters of cultivation aggregates, disc harrows and field ploughs*

| | | Cultivation aggregate – depth 0.1 m | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Working width | (m) | 3.2. | | | | 3.6. | | | |
| Area of cultivation | ($m^2$) | 320 | | | | 360 | | | |
| Rotations of an engine | ($rot \cdot min^{-1}$) | 1,500 | 1,750 | 2,000 | 2,200 | 1,500 | 1,750 | 2,000 | 2,200 |
| Speed of the unit | ($m \cdot s^{-1}$) | 1.63 | 1.81 | 2.21 | 2.31 | 1.63 | 1.91 | 2.14 | 2.25 |
| Cultivation time 1 ha | (min) | 32 | 29 | 23 | 22 | 28 | 24 | 22 | 20 |
| Performance | ($ha \cdot h^{-1}$) | 1.87 | 2.08 | 2.55 | 2.67 | 2.11 | 2.47 | 2.77 | 2.92 |
| Fuel consumption | ($l \cdot ha^{-1}$) | 4.4 | 5.0 | 5.9 | 6.3 | 4.2 | 4.7 | 5.3 | 5.8 |
| | | Disc harrow – depth 0.1 m | | | | | | | |
| Working width | (m) | 2.4 | | | | 2.7 | | | |
| Area of cultivation | ($m^2$) | 240 | | | | 270 | | | |
| Engine rotations | ($rot \cdot min^{-1}$) | 1,500 | 1,750 | 2,000 | 2,200 | 1,500 | 1,750 | 2,000 | 2,200 |
| Speed of the unit | ($m \cdot s^{-1}$) | 2.44 | 2.78 | 3.13 | 3.33 | 2.50 | 2.78 | 3.13 | 3.23 |
| Cultivation time 1 ha | (min) | 28 | 25 | 22 | 21 | 25 | 22 | 20 | 19 |
| Performance | ($ha \cdot h^{-1}$) | 2.11 | 2.40 | 2.70 | 2.88 | 2.43 | 2.70 | 3.04 | 3.14 |
| Fuel consumption | ($l \cdot ha^{-1}$) | 4.6 | 5.0 | 5.4 | 6.3 | 4.4 | 4.8 | 4.8 | 5.6 |

| | | Chisel plow – depth 0.1 m | | | | | |
|---|---|---|---|---|---|---|---|
| Working width | (m) | 1.8 | | | 2.2 | | |
| Area of cultivation | ($m^2$) | 180 | | | 220 | | |
| Engine rotations | ($rot \cdot min^{-1}$) | 1,750 | 2,000 | 2,200 | 1,750 | 2,000 | 2,200 |
| Speed of the unit | ($m \cdot s^{-1}$) | 2.17 | 2.50 | 2.78 | 1.67 | 1.82 | 1.96 |
| Cultivation time 1 ha | (min) | 35 | 30 | 27 | 38 | 35 | 33 |
| Performance | ($ha \cdot h^{-1}$) | 1.72 | 1.98 | 2.20 | 1.56 | 1.70 | 1.84 |
| Fuel consumption | ($l \cdot ha^{-1}$) | 7.7 | 8.6 | 9.5 | 7.7 | 8.8 | 10.0 |
| | | Field plough – depth 0.15 m | | | | | |
| Number of machine frames | items | 3-furrow | | | 4-furrow | | |
| Area of cultivation | ($m^2$) | 120 | | | 160 | | |
| Engine rotations | ($rot \cdot min^{-1}$) | 1,750 | 2,000 | 2,200 | 1,750 | 2,000 | 2,200 |
| Speed of the unit | ($m \cdot s^{-1}$) | 3.03 | 3.13 | 3.23 | 2.86 | 3.13 | 3.23 |
| Cultivation time 1 ha | (min) | 46 | 44 | 43 | 36 | 33 | 32 |
| Performance | ($ha \cdot h^{-1}$) | 1.31 | 1.35 | 1.39 | 1.65 | 1.80 | 1.86 |
| Fuel consumption | ($l \cdot ha^{-1}$) | 9.2 | 10.0 | 10.0 | 7.5 | 7.5 | 8.8 |

The graph of fuel consumption presented in figure 1 confirms that the change of the working width of the cultivation unit from 3.2 to 3.6 m slightly affected hourly fuel consumption. For the same depth of the unit operation, fuel consumption was independently close to the working width. For example, only at the engine rotations amounting to 2000 $rot \cdot min^{-1}$ and the depth of work amounting to 0.1 m a smaller unit (3.2. m) consumed by

0.3 $l \cdot h^{-1}$ more fuel than the bigger one (3.6 m). The scope of the hourly fuel consumption was for an cultivation unit 3.2 m from 8.23 to 16.87 $l \cdot h^{-1}$ and for a unit 3.6 m from 8.86 to 16.94 $l \cdot h^{-1}$. Moreover, based on fuel consumption, it was found that in case of the use of a bigger cultivation unit, the power of the researched unit was optimally used.

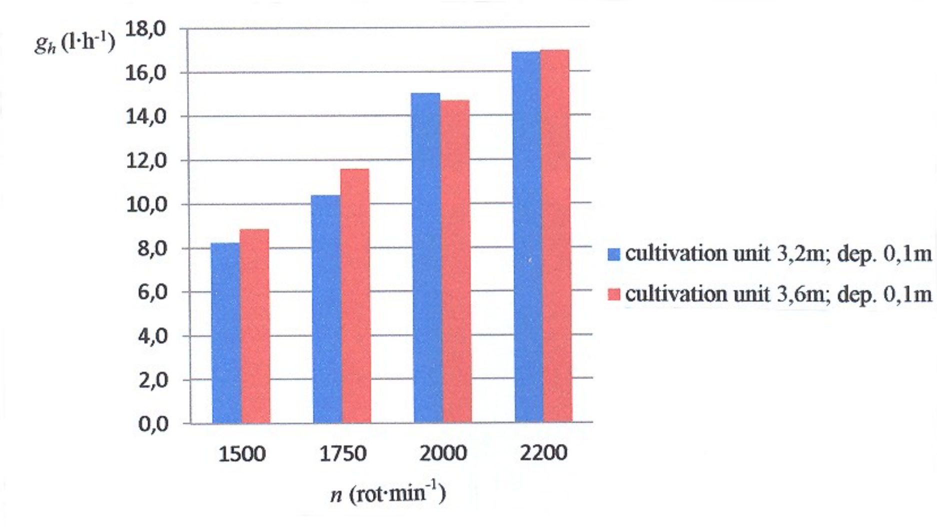


*Figure 3. Relation of an hour fuel consumption for the tested tractor to rotational speed of its engine for cultivation units. $g_h$ – hour fuel consumption, n – engine rotations*

Figure 4 presents the fuel consumption for disc harrows. It was reported that for the investigated four rotational speeds of an engine, the working width of a disc harrows (2.4 and 2.7 m) did not affect considerably the fuel consumption. The investigated units had similar values of fuel consumption for a set measurement length. For example for engine rotations 2000 $rot \cdot min^{-1}$ both harrows with width of 2.4 and 2.7 m has the same hourly fuel consumption 14.6 $l \cdot h^{-1}$.

Hourly fuel consumption for the selected chisel plows with the width of 1.8 and 2.2 m were presented in figure 5. The data presented on the graph show that the cultivation with a chisel plow 1.8 m had higher fuel consumption for all rotational speeds of an engine. For the highest gear (2,200 $rot \cdot min^{-1}$) a unit of 1.8 m had fuel consumption even by 2.5 $l \cdot h^{-1}$ higher.

Relation of fuel consumption for engine rotations for the selected field ploughs was presented in figure 6. Analysis of data allowed observation of a slight effect of the number of plough frames and thus a working width on fuel consumption. A tractor with a 3-furrow plough consumed the same amount of fuel within one hour as a tractor with a 4-furrow plough for a working speed 0.15 m. Only at higher rotations of an engine 2,200 $rot \cdot min^{-1}$ a 4-furrow plough working at the depth of 0.15 m consumed almost by 2.5 $l \cdot h^{-1}$ more fuel than a 3-furrow plough.

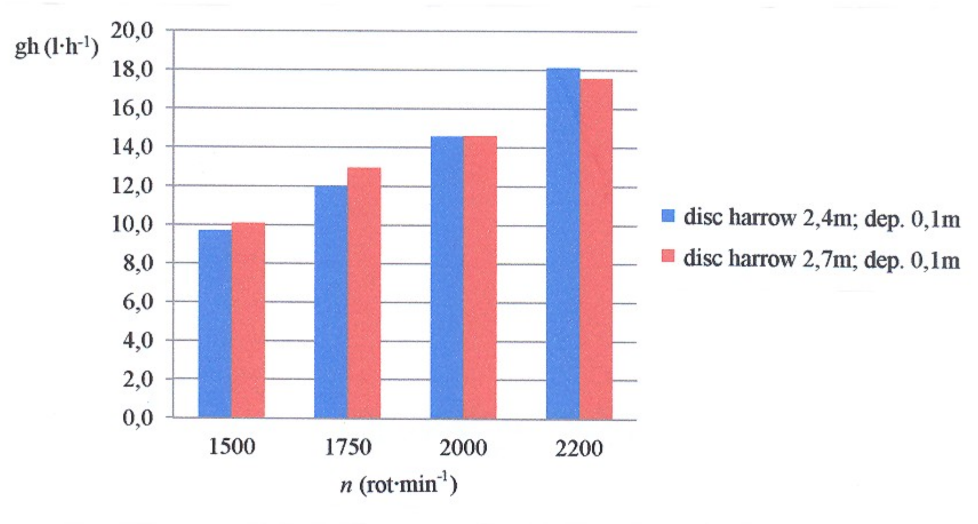


*Figure 4. Relation of an hour fuel consumption for a tractor to rotational speed of its engine for disc harrows. $g_h$ – hour fuel consumption, n – engine rotations*

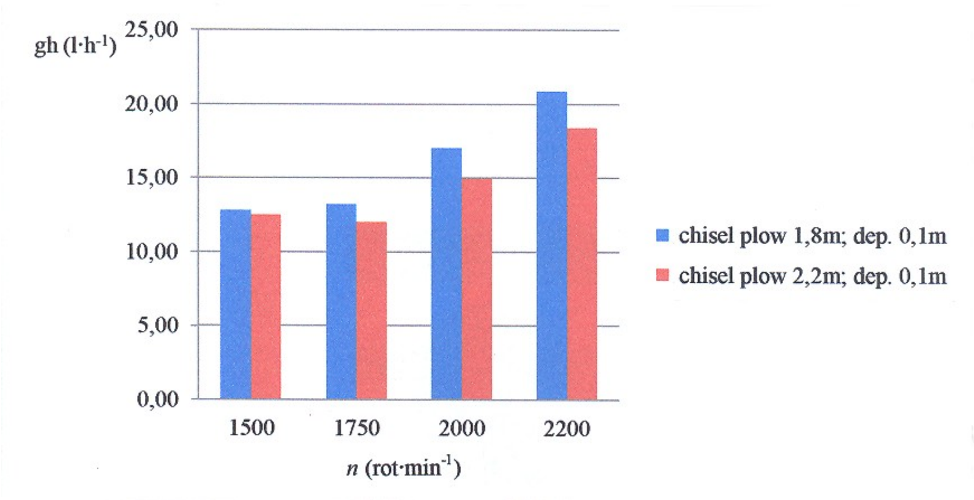


*Figure 5. Relation of an hour fuel consumption for a tractor to rotational speed of its engine for stubble aggregates. $g_h$ – hour fuel consumption, n – engine rotations*

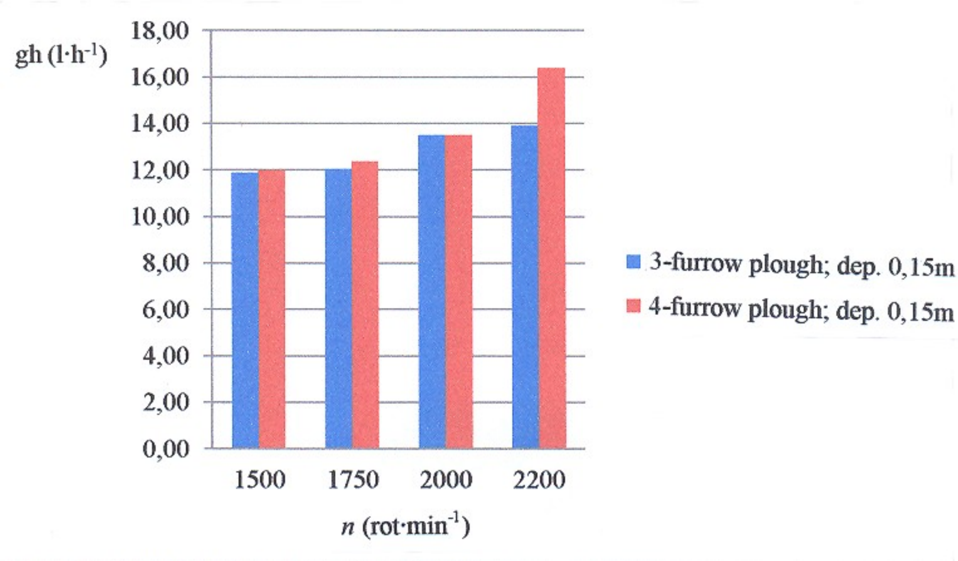


*Figure 6. Relation of hour fuel consumption for a tractor to rotational speed of its engine for field ploughs. $g_h$ – hour fuel consumption, n – engine rotations*

## Conclusions

Based on the research which was carried out, the following conclusions were expressed:

1. A unit, whose working width was 3.6 m was an optimum cultivation unit. This set obtained the highest performance; ca. 3 ha·h$^{-1}$ at the working speed 2.25 m s$^{-1}$ and engine rotations 2,200 rot·min$^{-1}$ at the simultaneous saving 0.5 litres of fuel per hectare in comparison to the speed 2.14 m s$^{-1}$ and engine rotations 2,000 rot·min$^{-1}$.
2. At the selection of disc harrows for the investigated tractor, it was reported that aggregating it with a wider disc harrow (2.7 m) affected obtaining the maximum performance 3.14 ha·h$^{-1}$ and by 11% of the lower fuel consumption in comparison to the plough with a lower working width.
3. A chisel plow with a working width 1.8 m should be selected for 14 kN class tractor, since it will affect obtaining the maximum performance amounting to 2.2 ha·h$^{-1}$ and simultaneously fuel consumption will lower by 5% in comparison to a bigger unit.
4. Combining a tractor with a 4-furrow field plough caused that the maximum performance of work was obtained and it amounted to1.86 ha·h$^{-1}$ and allowed obtaining fuel savings 1.2 l·ha$^{-1}$ for engine rotations 2,200 rot·min$^{-1}$ and at rotations 2000 rot·min$^{-1}$ savings were even 2.5 l·ha$^{-1}$ in comparison to a 3-furrow plough.
5. Disc harrows had the highest working speeds from among the investigated machines and the maximum working speed amounting to 3.33 m·s$^{-1}$ (12.0 km·h$^{-1}$) was obtained during cultivation with a harrow of 2.4 m width.

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## WYDAJNOŚĆ WYBRANYCH MASZYN UPRAWOWYCH A ZUŻYCIE PALIWA

**Streszczenie**. Prawidłowe zestawienie ciągnika z maszyną ma wpływ na czas i terminowość zabiegu oraz na zużycie paliwa. W artykule dokonano analizy doboru różnych maszyn uprawowych do ciągnika klasy 14 kN, w aspekcie uzyskania maksymalnej wydajności i minimalnego zużycia paliwa. Badaniom poddano następujące maszyny uprawowe: agregaty uprawowe i ścierniskowe, brony talerzowe, pługi zagonowe. W trakcie badań eksploatacyjnych dokonano pomiarów zużycia paliwa i rzeczywistej prędkości pracy agregatów. Wykazano, że nieodpowiedni dobór szerokości roboczej maszyny do ciągnika powoduje spadek wydajności agregatu uprawowego oraz w wielu przypadkach wzrost zużycia paliwa.

**Słowa kluczowe:** maszyna uprawowa, wydajność, zużycie paliwa