Impact of agricultural tractors advancement on productivity of selected machine units

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Summary. An analysis of the impact of technical sophistication of tractors on the performance of selected machine units was performed. It was found out that depending on the degree of technical sophistication of tractor with relation to the cooperating units, there is an increase in capacity from about 31 to about 55%.

Key words: tractor, performance, machine units.

INTRODUCTION

An important feature of a machine unit is its performance [1,2]. The performance of a machine unit has an impact on the duration and cost of application of agrotechnical activity. Krok and Piotrowski (1985) distinguish the practical performance (Ap), calculated taking into account the overall time utilization of shift (K08). This rate in the structure of the time control change takes into account time losses for reasons independent on the machine (such as meteorological and organizational) [5]. But many writers of materials about selection of agricultural machines such as [4,7] use the operational performance (W07) obtained from the product of theoretical yield (technical) and operating time utilization factor (K07) [4,3,2,7].

Knowledge of operational performance is essential also for the economic evaluations of selection of machines and tractors for the farm. In the literature there are works on optimizing the operation of machine units, which help to increase their productivity [9,10]. However, there is lack of publications on determining the operational performance depending on the degree of technical sophistication of tractors. Determining the impact of technological advancement of tractors on the operating efficiency with the use of the operating time utilization factor (K07) presented in the literature [6] is impossible, because its value does not include changes in the time structure of operating shift that are dependent on the degree of technical sophistication of tractors.

There is therefore a need to define correction factors that take into account the degree of technical sophistication of tractors for presented in the literature values of the coefficient of utilization of operating time. The presented need has set the goal of studies that were pursued in the research project of Ministry of Science and Higher Education no. 115 089 639. The purpose of study, whose results are presented below, was to assess the impact technical sophistication of tractors on the practical area performance (operational) of the selected machine units (stubble cultivator, seed drill, generator, sprayer and fertilizer spreader).

Yields were determined for the units cooperating with tractors with power of 60, 86 and 110 kW.

METHODS

In order to assess the impact of technological advancement in the performance of tractor units it was proposed to introduce to the formula for a correction factor for practical area performance (operational) ΔApij for the particular type of agricultural practices. Correction factor taking into account the relation for the practical area productivity (operational) is as follows:

$$W_{07_{ij}} = 0,36 \cdot b_i \cdot v_i \cdot K_{07_i} \cdot \eta_{v_i} \cdot \eta_{bi} \cdot \Delta A_{p_{ij}}, \quad (1)$$

where: W07ij – area practical efficiency (operational) of the i-th unit cooperating with a tractor with the equipment corresponding to the j-th scenario [h · ha-1], b – operating unit width [m], vi – machine operating speed [m · s -1], K07i - the utilization rate of shift overall time [-] ηvi - the working speed use ratio [-] ηbi – operating width utilization factor [-] ΔApij - correction factor taking into account the change in the practical performance of the unit depending on the cooperation with the

Table 1. Scenarios of tractor technical sophistication variants

	Scenario_1	Scenario_2	Scenario_3	Scenario_4
Engine	Controlled mechanically	Controlled mechanically	Controlled mechanically	Electronically controlled
Gearbox	Manual gearbox (synchronized)	Manual gearbox (synchronized)	Some gears shifted under load	Controlled electro-hydraulically with optionally programmed activities performed automatically (e.g. at turns)
Reverse	no	Controlled mechanically	Electro-hydraulic control	Electro-hydraulic control
Front drive	Controlled mechanically	Controlled mechanically	Electro-hydraulic control	Electro-hydraulic control – possible automatic control
Hydraulic lift	Controlled mechanically	Controlled mechanically	Electro-hydraulic control (via EHR)	Controlled electro-hydraulically with optionally programmed activities performed automatically (e.g. at turns)
External hydraulic system	Controlled mechanically	Controlled mechanically	Electro-hydraulic control	Controlled electro-hydraulically with optionally programmed activities performed automatically (e.g. at turns)
WOM drive	Controlled mechanically	Controlled mechanically	Electro-hydraulic control	Controlled electro-hydraulically – automatically
Differential lock	Controlled mechanically	Controlled mechanically	Electro-hydraulic control	Controlled electro-hydraulically – automatically
HVAC	no,	Tractor is equipped	Tractor is equipped	Tractor is equipped

Source: own study

tractor with the equipment corresponding to the j-th scenario [-].

ΔApij coefficient value was calculated on the basis of expert knowledge using expert and mathematical methods (Delphic) and the scenario method. For this purpose, based on the analysis of available in Poland tractor manufacturers offer four scenarios of technical equipment of tractors were developed, reflecting different degrees of technical sophistication (Table 1). These scenarios represent the most common variants of technical sophistication of tractors. Scenarios 1 and 2 correspond to tractors with low-technical sophistication, scenario_3-average tractors and scenario_4 - highly sophisticated tractors.

Research organization in accordance with the expert and mathematical methods (Methods Delphic) included the following activities [7]:

– finding the required number of experts
– obtaining the consent of an expert to participate in research and conducting a preliminary interview
– providing the expert with research questionnaire
– acquisition of a study questionnaire from the expert
– preliminary analysis of the research questionnaire to determine the correctness of its filling in (no blank rows, to the compliance of sum of points allocated to parameters, etc.)
– entering the data obtained from the questionnaire to a calculation program
– control of the experts' compliance concerning their assessments
– preparation of the next stage of testing procedures in the event of insufficient experts' compliance

The basic action in the test procedure provided in the mathematical expert method was the development of special research questionnaires through which the experts united their opinions on the issues analyzed.

The task of an expert in the various scenarios was to enter the percentage value reflecting a change in productivity of the tractor during agronomic work listed in the questionnaire (tillage work, sowing grain, mineral fertilizing, chemical protection, agricultural transport) in the variants of more favorable conditions (e.g. large field, the field without rocks , flat ground, the soil is not waterlogged) and in less favorable conditions (e.g. small fields, hilly terrain, rocky fields, marshy soil). The reference point for expert was operating performance in case of use of older generation tractor (equipment and work comfort corresponding to models produced in the 80's). It is worth noting that the K07 coefficients given by [6] were determined in the 80's.

After developing a research questionnaire the group of experts was approached. The group of experts consisted of qualified persons with practical experience in direct contact with machinery (tractors operating or managing the machinery) and evaluating the work of agricultural tractors from economic and agro-technical point of view.

The procedure of forming a group of experts assumed the choice of people, who could boast good economic results and the farm's production resulting from their knowledge. Other features that were taken into account that were less relevant to the knowledge derived but significant in the test procedure were: kindness and willingness to participate in the survey. Experts' competence assessment was made based on the evaluation given by the persons leading the research and expert's self-esteem.

On a scale of 0 to 10 the following expert features were evaluated:

– Practical experience in farm management
– Practical experience in the operation of agricultural tractors
– Knowledge of modern solutions in the construction of tractors and their impact on the effects of the tractor.

The method of deliberate selection of experts was applied. Candidates for the experts were indicated by experts from the industry of agricultural technology (such as journalists, agricultural magazines specializing in agricultural technology, local dealers for agricultural tractors and machinery, ODR workers). After the initial conversation and positive verification of the suitability of a person's expertise with regard to the aforementioned criteria, he or she was included in the list of experts.

The study involved 74 experts attended representing the holding of between 11 to 1,000 acres located in different Polish regions.

Compliance of experts' evaluation was assessed using the coefficient of variation calculated by the following formula [10,11]:

$$Vj = \frac{g_j}{\bar{m}} \cdot 100\ [\%], \tag{2}$$

where: gj - standard deviation, mj - arithmetic mean given by the experts

$$\bar{m}_j = \left(\sum_{i=1}^{Ne} m_{ij} \right) / N_e, \tag{3}$$

where: Mij-stature ratio normalized of j-th factor designated by the i-th expert

The standard deviation was calculated from the formula:

$$g_j = \sqrt{\frac{\sum_{i=1}^{Ne} \left(m_j - m_{ij} \right)^2}{Ne}} \text{ for } N_e > 30. \tag{4}$$

According to the literature [10,11] it was considered that if Vj ≤ 0.25, the compliance of individual assessments appointed by experts is sufficient. If Vj 0.3, compliance were considered to be low.

In case of discrepancies in the assessments of experts the second phase of the study provided for in the Delphic method was conducted. Group of experts was selected, whose assessment differed significantly from the average grade in the first stage. Then, questionnaires were sent to them, which showed the average evaluations of all experts. These experts were to comment on the mean ratings and express their acceptance or rejection. If accepted, the assessment given by the expert was replaced by averages, in this way bringing the expert closer to the mean. The experts to whom questionnaires were sent with an average rating of all experts agreed with the opinions of other experts.

Obtained on the basis of expert knowledge productivity changes were processed later in the test procedure as the value of the correction factors ΔApij for individual agricultural practices with the fact that it was expressed as decimals.

K07 coefficients, necessary for the calculation of operational performance for each treatments were taken from the literature [6]. Based on the literature operating speed and the values of the coefficients of used width and speed were assumed. Working widths were assumed on

Table 2. Characteristics of machine units included in the analysis of performance

Item	**Stubble machine**	**Cultivation-seed machine**	**sprayer**	**Fertilizer distributor**
Tractors power 80 HP				
producer	Unia Group	Unia Group	Unia Group	Unia Group
type	CUT L 2,8X510	ECO 350 I	LUX 1015	MX 1200h
Operating width [m]	2,8	3	15	30
Tractors power 117 KM				
producer	Unia Group	Unia Group	Unia Group	Unia Group
type	ARES T XL 3,0	ECO 550	EUROPA II 4024	RCW 10 000
Operating width [m]	3	3	24	30
Tractors power 150 KM				
producer	Unia Group	Unia Group	Unia Group	Unia Group
type	ARES T XL 4,0	IDEA 2200/3	EUROPA II 4028	RCW 10 000
Operating width [m]	4	3	28	30

the basis of the technical data presented by the manufacturer. For tractors of the same group the same set of machines was selected (Table 2).

For fertilization treatments and chemical protection it was assumed that the machines are constantly working on the field and working and liquid fertilizers are delivered means of transport. By adopting this assumption spreaders and sprayers efficiency was calculated based on formula No. 1

For tractors with a power of 110 kW only scenarios 3 and 4 were analyzed, because the market in Poland does not provide tractors with equipment corresponding to scenarios 1 and 2.

RESULTS

Results obtained on the basis of the Delphic method are presented in Table 3.

The calculated efficiency of machine units cooperating with tractors with technical advancement corresponding to the analyzed scenarios are summarized in Tables 5-7.

The performed analyzes showed an increase in performance depending on the degree of technical sophistication of the tractor. For example, if of cultivation of stubble made with 110 kW power unit demand, it is an increase from 2.57 to 3.98 ha · h-1. In the case of mineral fertilizers spreader cooperating with a tractor of 110 kW capacity, it is an increase from 18.47 to 26.78 h·ha-1 in the case of unfavorable working conditions and the level of 28.26 ha · h-1 for favorable working conditions.

CONCLUSIONS

The performed analyses have shown that technical advancement results in increases in the efficiency

Table 3. Changes in performance of machine units depending on the tractor tech advancement scenario

Changes in performance of machine units **[%]**		
	Activity performed in less favorable conditions (e.g., small fields, hilly terrain, rocky fields, marshy soil)	Activity performed in favorable conditions (e.g. large field, the field without rocks , flat ground, the soil is not waterlogged)
	SCENARIO_1	
Cultivation works (plowing, harrowing, etc.)	33,60	42,87
Sowing cereals	31,68	40,82
Fertilization, chemical protection	36,25	40,36
Transportation of agricultural products	36,44	40,25
	SCENARIO_2	
Cultivation works (plowing, harrowing, etc.)	41,37	44,29
Sowing cereals	38,55	43,10
Fertilization, chemical protection	39,45	41,90
Transportation of agricultural products	36,88	39,90
	SCENARIO_3	
Cultivation works (plowing, harrowing, etc.)	46,72	51,64
sowing cereals	46,42	50,90
Fertilization, chemical protection	45,08	50,50
Transportation of agricultural products	46,64	50,16
	SCENARIO_4	
Cultivation works (plowing, harrowing, etc.)	48,54	55,51
Sowing cereals	46,46	52,05
Fertilization, chemical protection	45,41	53,46
Transportation of agricultural products	45,03	50,51

Source: own study

Table 5. operational performance of cooperating units of tractors with power of 60 kW [h · ha-1]

Item	**Stubble machine**	**Cultivation-seed machine**	**sprayer**	**Fertilizer distributor**
Machine efficiency without correction factor	1,80	1,87	6,41	18,47
Scenario_1				
Unfavorable work conditions	2,39	2,46	8,72	25,12
Favorable work conditions	2,57	2,63	8,98	25,86
Scenario_2				
Unfavorable work conditions	2,53	2,58	8,91	25,67
Favorable work conditions	2,59	2,67	9,04	26,04
Scenario_3				
Unfavorable work conditions	2,62	2,73	9,30	26,78
Favorable work conditions	2,71	2,80	9,62	27,70
Scenario_4				
Unfavorable work conditions	2,66	2,73	9,30	26,78
Favorable work conditions	2,78	2,84	9,81	28,26

Source: own calculations

Table 6. Operating Efficiency of units cooperating with tractors with a power of 86 kW [h · ha-1]

Item	**Stubble machine**	**Cultivation-seed machine**	**sprayer**	**Fertilizer distributor**
Machine efficiency without correction factor	1,92	1,87	10,26	18,47
Scenario_1				
Unfavorable work conditions	2,56	2,46	13,95	25,12
Favorable work conditions	2,75	2,63	14,36	25,86
Scenario_2				
Unfavorable work conditions	2,71	2,58	14,26	25,67
Favorable work conditions	2,77	2,67	14,47	26,04
Scenario_3				
Unfavorable work conditions	2,81	2,73	14,88	26,96
Favorable work conditions	2,90	2,82	15,39	27,70
Scenario_4				
Unfavorable work conditions	2,85	2,73	14,88	26,78
Favorable work conditions	2,98	2,84	15,70	28,26

Source: own calculations

Table 7. Operating Efficiency of units cooperating with tractors with a power of 110 kW [h · ha-1]

Item	Stubble machine	Cultivation-seed machine	sprayer	Fertilizer distributor
Machine efficiency without correction factor	2,57	1,87	11,97	18,47
Scenario_3				
Unfavorable work conditions	3,74	2,73	17,36	26,96
Favorable work conditions	3,87	2,82	17,96	27,70
Scenario_4				
Unfavorable work conditions	3,80	2,73	17,36	26,78
Favorable work conditions	3,98	2,84	18,31	28,26

Source: own calculations

of machine units. Depending on the degree of tractor advancement, the performance increase is 31.68% to 55.51%. The highest values of productivity growth have occurred for the cultivation work, and lower for transportation work. In the case of performing the work under conditions favorable in comparison to the work carried out under less favorable conditions the difference is about 6%. Differentiation of labor units performance, depending on the degree of technological advancement should be taken into account in analyses of cost-effectiveness of purchased tractors. Due to the fact that values of the K07coefficient reported in the literature are outdated at the present time, the authors postulate to include the proposed correction factor in the efficiency calculation.

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WPŁYW ZAAWANSOWANIA TECHNICZNEGO CIĄGNIKÓW NA WYDAJNOŚĆ WYBRANYCH PODZESPOŁÓW MASZYN

Streszczenie. Analizowano wpływ zaawansowania technicznego ciągników na charakterystykę wybranych podzespołów maszyn. Stwierdzono, że w zależności od stopnia zaawansowania technicznego ciągnika w stosunku do jednostek współpracujących, następuje wzrost ich mocy od około 31 do około 55 procent.

Słowa kluczowe: ciągnik, wydajność, podzespoły maszyn.