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CONTRIBUTION REGARDING THE MANAGEMENT OF EFFICIENT USE OF CROP COMBINE HARVESTER

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Abstract: *The paper presents the methodology for calculating the harvesting combine hourly working capacity in cereal grains by using two distinct methods: analytical method, using mathematical models of computing, and graphical method, using nomograms developed based on mathematical models. The hourly capacity of the harvesting combine is expressed in units of the harvested area (ha/h) or in units of mass of harvested grain (in kg / h), based on the operating speed (in m/ s). The hourly capacity is determined for specific operating parameters and operation: working width of the machine (in m), the production of grain per hectare (kg/ha) in the specified crop and the coefficients of the effective use of working time.*
Keywords**:** *harvesting combine, hourly working capacity, mathematical models, calculation nomograms*

1. INTRODUCTION

Effective use of the harvesting combine in cereal grains is mainly characterized by the harvesting capacity of these machines per unit of time (productivity), while meeting predetermined quality performance limits (for grain loss level, grain damage requirements, percent MOG in grain or sample cleanliness/purity, as well as minimizing the fuel consumption during harvesting).
The working capacity of harvesting combines in cereal grains depends on the amount of harvested material entering the threshing unit per unit of time (second or time), i.e. the harvesting material flow (in kg/s or t/h). In the case of harvesting wheat, the nominal feed rate q is, typically, the flow rate in harvesting grain with a moisture content of 18%, while grain losses are below 1.5% [4,5,6].

2. METHODOLOGY FOR CALCULATING THE WORKING CAPACITY

The total material flow harvested by the cutter (header) and entering the harvesting combine threshing system is given by equqtion [4]:

$$q = q_b + q_p\,, \tag{1}$$

where:
q_b is the grain flow and q_p – straw material flow (straw, chaff).

Grain flow q_b depends on the harvesting width of the harvesting combine, working speed of the machine, the grain production per hectare of harvested crop, and is determined by the relation:

$$q_b = B.v_m.P_b.10^{-4} \text{ [kg/s]} \tag{2}$$

where:
v_m is the speed of the combine, in m/s; B- working width of the combine, in m;
P_b – grain yield per hectare, in kg/ha.
Taking into account the ratio λ of the mass of straw q_p and the total mass of harvested crop q $(q = q_b + q_p)$ given by the equation [1,2,4]:

$$\lambda = q_p/q = q_p.(q_b + q_p), \tag{3}$$

the material flow q_p can be expresed by the relation:

$$q_p = B.v_m.P_b.\ \lambda/(1-\lambda).\ 10^{-4} \text{ [kg/s]}, \tag{4}$$

which, in case of v_m being expressed in km/h, is given by the relation:

$$q_p = 0{,}1.\ B.v_m.P_b.\ \lambda/(1-\lambda) \text{ [kg/h]} \tag{5}$$

If we consider that the ratio λ of straw mass q_p and the total harvested crop mass $q = (q_b + q_p)$ has a conventional average value λ = 0,6, and the speed v_m is expressed in m/s, the total material flow q entering the threshing system is given by:

$q= 2,5. B.v_m.P_b. 10^{-4}$ [kg/s]. (6)

If the speed v_m is expressed in km/h, the material flow rate q is given by the formula:

$q= 2,5. B.v_m.P_b.$ [kg/h]. (7)

If the actual value of the straw content coefficient λ_e is different than the selected conventional average value (λ = 0,6), the actual flow of material supply to the threshing system $q_e=(q_{eb}+q_{ep})$ would change accordingly. In order to maintain the accepted machine working parameters, the material flow entering the combine is required to remain constant within a range during harvesting, so the following relationship must be met $q_p = \lambda.q = \lambda_e.q_e$. Therefore, the actual total material flow q_e becomes:

$q_e =\lambda.q/ \lambda_e = 0,6. q/ \lambda_e$ (8)

In real conditions, it appears that in the case of harvesting crop with long stems and high humidity, the actual flow rate q_e ranges within the limits q_e = (0,6 … 0,8).q.

Taking into account the equation (6), the total actual flow of the material entering the combine q_e is given by:

$q_e = 1,5. B.v_m.P_b. 10^{-4}/ \lambda_e$ [kg/s] (9)

where the machine working speed v_m is measured in m/s. If the machine working speed v_m is measured in km/h, then the formula for the effective flow rate becomes:

$q_e = 0,15. B.v_m.P_b/ \lambda_e$ [kg/h], (10)

During harvesting, the combine crop processing systems must be loaded and working in balance with the nominal incoming material flow q, a condition which involves the selection of harvesting width B and harvesting speed v_m , all in accordance with the crop yield per hectare P_b.

The harvesting width of the combine for various values of the conventional coefficient λ_e can be determined from the relation (10). If the actual value of the straw content coefficient λ =0,6 (conventional value), the header harvesting whith B is expressed by the formula:

$B =10^{-4}.q/2,5. v_m.P_b$ [m], (11)

where: q is the crop flow feeding rate in kg/s; v_m – the harvesting speed in m/s;

If the actual value of the straw content coefficient λ_e is different than the selected conventional average value of 0,6 ($\lambda_e \neq$ 0,6), culturilor de cereale păioase la care coeficientului conținutului de paie difera de valoarea de 0,6 ($\lambda_e \neq$ 0,6), the combine harvesting width B is determined from the equation (10), obtaining the relation:

$B =10^4.q_e. \lambda_e/1,5. v_m.P_b$ [m] (12)

in which the combine harvesting speed v_m is measured in m/s.

Since the crop characteristics vary widely and the optimal combine systems working speeds can only be used within established limits (technological limits), combines are matched with different size headers that carry a different working widths. Thus, if taller plants are being harvested, the header working width may reach B = 6 ... 7 m, and if short plants are being harvested B = 4 ... 5 m. For leveled farm land, a header working width of B = 8 ... 10 m may be used. There are headers that reach 15 m (45 ft) and succesfully being used on higher capacity combines.

The local production of grain seeds P_b (in kg/ha) that a combine can harvest varies between P_{bmax}... P_{bmin}, and reflects the development state of the harvested plant and its variety. Therefore the combine harvesting speed value v_m is chosen according to the specific production of grain per hectare P_b, while ensuring a smooth and normal functioning of combine working systems. From the equation (11), if the content of straw coefficient λ is set to λ=0,6 (conventional value), the combine speed should be adjusted between the minimum v_{min} and maximum v_{max} given by the relations:

$v_{min} = 10^4.q/2,5. B.P_{bmax}$ [m/s]; (13)

$v_{max} = 10^4.q/2,5. B.P_{bmin}$ [m/s]. (14)

In order to be able to continuously change the harvesting speed, today's harvesting combines are equipped with hydrostatic transmissions, hydraulic pumps and motors (infinite variable speed motors), allowing continuous and infinite ground speed adjustment (while maintaining a constant engine RPM and threshing speed), manually (operator input) or automatically (automatic ground speed control systems). This creates the possibility to optimize the combine harvesting systems working load.

In practice, the hourly working capacity of harvesting combines in grains is measured either in harvested area per unit of time (ha/h), or the mass of grain harvested per unit of time (t/h).

The theoretical value of the hourly working capacity of harvesting combines W_{th} , expressed in units of harvested area, is obtained taking into account continuously harvesting operation (without interruptions) and a combine harvesting speed equal to the theoretical speed v_t (ie no powered wheels slippage) and a combine cutting width equal to the maximum header designed cutting width B_c , and is defined by the relation [1,2]:

$W_{th} = 0,36.B_c.v_t$ [ha/h]. (15)

where the ground speed v_t is expressed in m/s. When the ground speed v_t is expressed in km/h, the hourly working capacity of harvesting combines W_{th} is defined by the relation [1, 2].

$$W_{th} = 0,1.B_c.v_t \text{ [ha/h]}. \quad (16)$$

The actual hourly working capacity (effective) W_{rh} of harvesting combines differs from the theoretical one W_{th} because of the following reasons: the effective working width of the header B_l varies from the design cutting width B_c , due to inaccurate driving of the combine or incomplete usage of the entire width of the cutting mechanism, such as in the case of tough working conditions; the actual harvesting combine working speed v_l is less than the calculated speed due to slippage of the drive wheels tires and reduced radius (due to the deformation of the tire); the actual harvesting time T_l is lower than the overall time it takes to harvest the crop T_s, as part of the time is spent during machine travel, or during technological operations (i.e., unloading grain), or maintenance of the combine and/or the combine attachments.

The actual hourly working capacity (effective) W_{rh} of harvesting combines is determined using the relations:

$$W_{rh} = 0,36.B_l.v_l \text{ [ha/h]} \quad (17$$

$$W_{rh} = 0,36.\ B_c.v_t.C_B.C_v.K_s \text{ [ha/h]}, \quad (18)$$

when the speed is expressed in m/s and with the relations:

$$W_{rh} = 0,1.B_l.v_l \text{ [ha/h]} \quad (19)$$

$$W_{rh} = 0,1.B_c.v_t.C_B.C_v.K_s \text{ [ha/h]}, \quad (20)$$

when the speed is expressed in km/h.

The following notations had been used in the above relations[5,6]:

- C_B – the coefficient of partially using the full design width of the header cutting mechanism, with values within the following limits: C_B=0,8 … 1,0;
- $C_v = (1-\delta)$ – the coefficient of partially using the theoretical combine harvesting speed, which takes into account the speed reduction due to powered wheels slippage δ;
- K_s - the coefficient of partially using the combine time for cutting crop, which in practical sense has a value within the range: K_s=0,58 … 0,73;

The calculation of hourly capacity of the combine harvesters can be done both analytically, based on the above relations, as well as graphically using nomograms [1, 2, 5], based on these analytical relations.

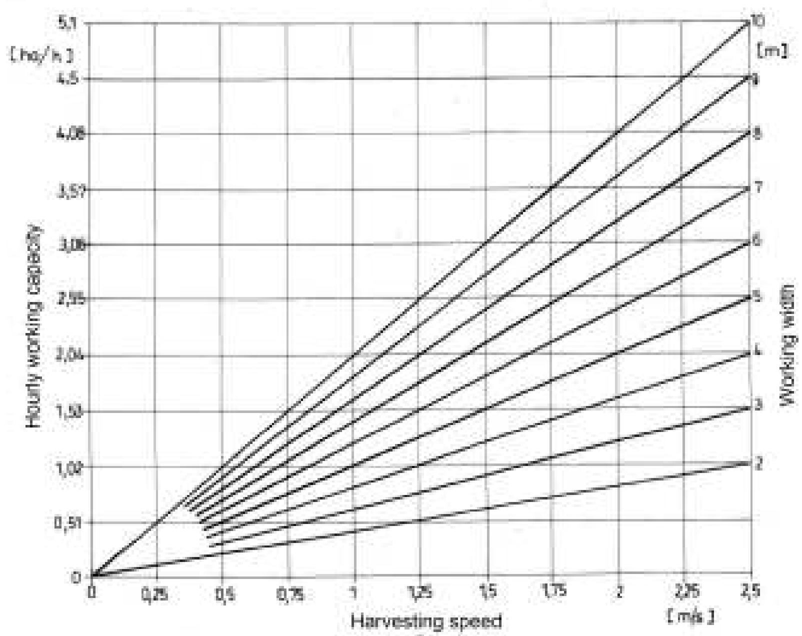

Figure 1. Variation of hourly actual working capacity W_{rh} (in ha/h) based on designed harvesting speed v_t (in m/s) for different working widths (header widths) B_c (in m)[4].

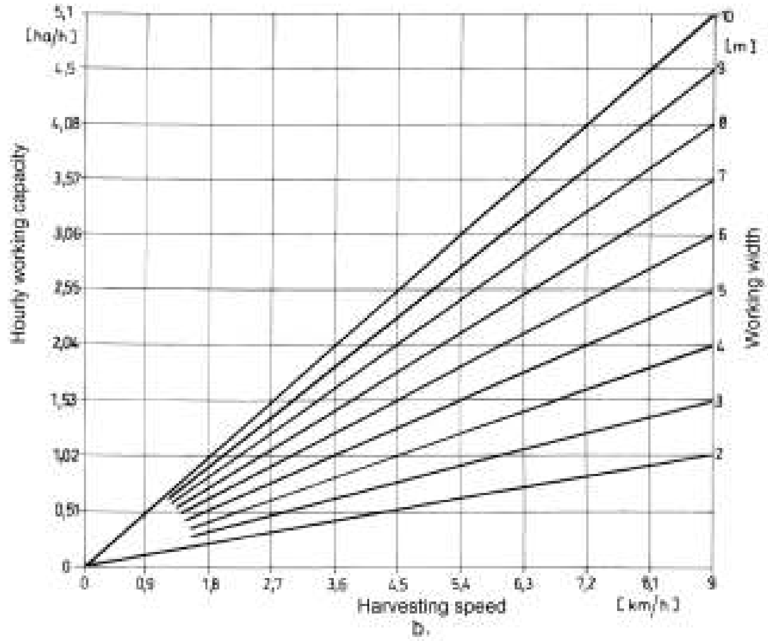

Figure 2. Variation of hourly actual working capacity W_{rh} (in ha/h) based on designed harvesting speed v_t in km/h for different working widths (header width) B_c (in m) [4].

Figure 1 presents the graphical diagrams (nomograms) for determining the actual hourly working capacity W_{rh} (ha/h) based on the combine calculated speed (theoretical speed recommended by design) during harvesting (m/s) constructed based on relation (18) (fig.1, a) and respectively, in km/h, constructed based on relation (20) (fig.1, b). Nomograms are drawn for different header working widths (design width) B_c (B_c range = 2,0 ... 10,0 m). It was considered an average factor of utilizing the header working widths during harvesting (cutting lenghts) C_{Bmed} = 0,9 and a weighted average coefficienf of partially using the theoretical combine harvesting speed C_{vmed} = 0,90 (spinning wheels δ = 10%) and an average coefficient of using the combine time K_s = 0,7.

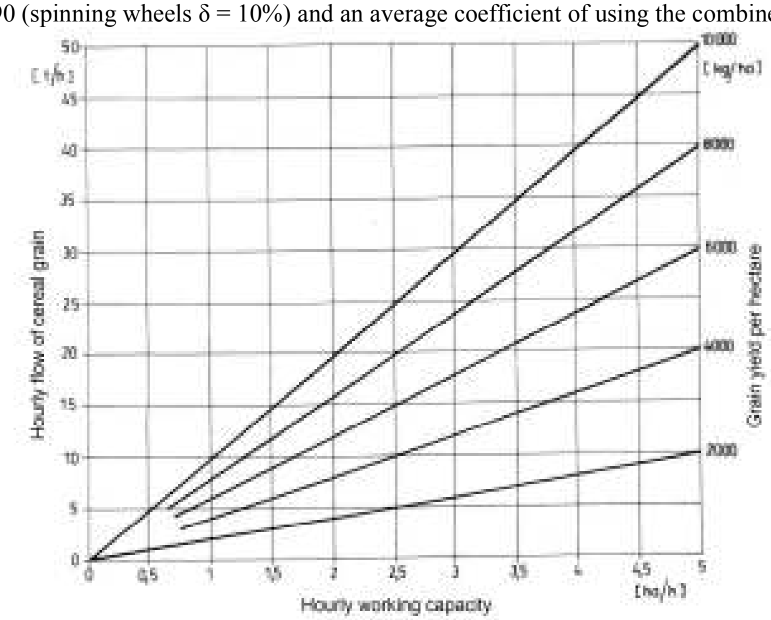

Figure 3. Variation of hourly capacity of threshing grain W_{bh} (in t/h) based on hourly working capacity W_{rh} (in ha/h) for different quantity of grain yield per hectare P_b (in kg/ha) [4]

In practice, the actual hourly working capacity of a harvesting combines can be expressed in mass amount of grain harvested per unit of time W_{bh}, (measured in t/h) expressed in terms of hourly working capacity in units of harvested area W_{rh} (ha/h) and the grain yield per hectare of harvested crop P_b (kg/h), using the relation:

$$W_{bh}=W_{rh}.P_b.10^{-3} \text{ [t/h]}. \quad (21)$$

Figure 3 presents the graphical diagrams (nomograms) for determining the actual hourly working capacity W_{rh} (ha/h) based on the combine hourly working capacity W_{rh} (in ha/h) constructed based on the function W_{bh} = f (W_{rh}) given by the relation (21) for different production yields per hectare P_b (in kg/ha)(in the range of P_b =2000 ... 10000 kg/ha).
For computation guidance is considered that, for normal use, combine harvesters in cereal grains can achieve hourly working capacities of 0,3 h.

3. CONCLUSIONS

- The hourly combine harvesters working capacity can be determined either by analytic, based on mathematical models of computation and graphical way, using nomograms built on these analytical relations.
- The hourly working capacity of combine harvesters, expressed in units of surface area (in ha/h), based on the harvesting speed (in m/s or km/h), can be determined by using charts (nomograms) constructed for different specific values of header cutting widths.
- The hourly working capacity of harvesting combines in cereal grains, expressed in units of harvested grain mass (in t/h or kg/h) as function of the hourly working capacity expressed in units of harvested surface area (in ha/h), can be determined by using a graph (nomograms) designed for different quantity of grain production per hectare (kg/ha) specific to the type of harvested cereal crops.

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