# OPTIMIZATION OF MAIN PARAMETERS OF TRACTOR WORKING WITH SOIL-PROCESSING IMPLEMENT

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**Abstract.** The article reveals some cases of justification of tractor main parameters (the weight of the tractor and the power of its engine) and tillage implements with combined and disk working bodies. Calculations with the use of the systematic energy-based mathematical model of soil processing units have shown that there is an optimal combination of the tractor's weight, engine power, and the width of the unit, which remain stable even in case of most of the main parameters of the system "Tractor-Implement-Operator-Field-Soil type-Crop" (TIOFSC system) are constantly changing, as well as environmental factors. The optimum weight of the tractor on soil cultivation using combined or disk tools with traction resistance of 5-7 kN·m$^{-1}$ with a change in most of the factors of the TIOFSC system varies insignificantly and remains within 100-120 kN. The greater value of the tractor weight corresponds to the greater value of the specific traction resistance of the tillage machine. The limits of power variation are more significant and actually ranging from 300 to 450 hp. Tractors with lower power are effective with less seasonal load on the unit and an increase in the coefficient of shifts (duration of work during the day). The optimum width of the tillage implements remains in the range from 7 to 9 m, more often in the 7.5 m range. The optimum speed can vary from 6 to 13 km·h$^{-1}$, more often within 8-11 km·h$^{-1}$.

**Key words:** tractor, unit, optimization, total energy costs, tractor mass, power, implement width, operational speed.

## Introduction

The study of the energy efficiency of technologies for cultivating agricultural crops and certain technological operations becomes increasingly important due to an increase in anthropogenic energy costs per unit of energy obtained through crop yields and also due to the possible depletion of fossil fuel reserves [1; 2]. From the variety of methods developed for improving plants growth, an important place belongs to the cultivation of the soil. Fuel consumption for this operation generates more than 40 % of the total direct costs [3]. Indirect losses of potential yield due to the violation of the technological process and the negative impact of tractors on the soil could also be significant [4-18]. In regards to the above, this article investigates the process of soil cultivation by tillage implements with combined and disk working bodies, the traction resistance of which varies from 4.5 to 7.5 kN·m$^{-1}$, in order to identify the optimal values of the main parameters of the tractor (the weight of the tractor and the power of its engine), as well as the working width and working speed of the tillage unit.

## Materials and methods

Research to identify the optimal basic parameters of a tractor performing soil cultivation is carried out on the basis of computational experiments using the energy-based mathematical model of tillage units [19-21]. Calculations are performed in Matlab software based on a code developed in [22].

## Results and discussion

The results of optimization of the main parameters of the tractor and the unit with a combined tool (the KPIR-7,2 type cultivating unit) for the most common operating conditions of these tillage units – the field area of 100 hectares, specific traction resistance of the implement 7 kN·m$^{-1}$, total scope of work 1000 hectares, are shown in Fig. 1.

The initial data for the calculation is a soil cultivator with a KPIR:

- single field area, ha = 100;
- length of the unit run before turn, km = 1;
- moving distance from field to field, km = 3;
- coefficient of strength of the bearing surface = 0.9;
- scope of work, ha = 1000;
- number of tractors performing the operation = 1;

- number of hours of work per day = 14;
- planned productivity of main and by-products, c·ha$^{-1}$. [centner per hectare] = 40;
- pressure in the tires (from 0.08 to 0.2), MPa = 0.16;
- number of wheels on one side of the tractor (1 or 2 or 3, etc.) = 1;
- coefficient of traction of wheels with soil = 0.5;
- coefficient of resistance to rolling of tractor wheels = 0.17;
- coefficient of distribution of coupling weight of wheels = 0.9.

Calculation results (optimal data points):

- width of the tillage implement $B_{opt}$ = 7.5 m;
- working speed $V_{opt}$ = 10.5 km·h$^{-1}$;
- weight of the tractor $G_{tiopt}$ = 110 kN;
- engine power $N_{eopt}$ = 380 hp;
- total energy costs $E_{\min}$ = 8305.6 MJ·ha$^{-1}$.

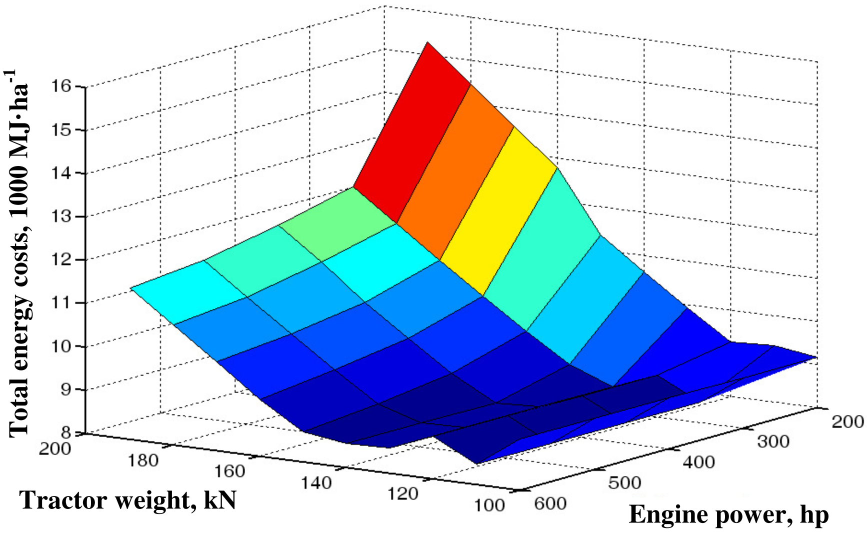


Fig. 1. **Changes in total energy costs of tilling machine with combined tool by weight ratio and power of tractor engine**

As shown in the figure, there is an optimum point –a combination of the weight of the tractor and the power of its engine (under certain corresponding optimum values of the speed and width of the implements).

It can be assumed that optimal combination of the weight of the tractor and power of its engine is influenced by a number of factors, among which the most significant are the field area, the scope of the seasonal load on the unit, the planned yield of the grain crop, the shift factor in the organization of work, the values of the crop loss coefficients from the violation of the technological operations and soil compaction.

Computational experiments were carried out to identify the influence of these factors on the main parameters of the tractor. The results are given below.

Fig. 2 shows the result of calculations to determine the effect of the field area change on the parameters of the soil-processing tractor with an implement of the KPIR type (field area is varying from 10 to 150 hectares; length of the unit run before turn is being also changed accordingly).

It can be seen from the figure that the optimum value of the weight of the tractor G, the engine power N, the width of the unit $B_p$, when the field area is changed, does not change. The optimal value of the weight of the tractor is 110 kN, the required engine power is close to 380 hp, the optimal unit width is equal to 7.5 m. The total energy costs with the increase of the field area are reduced mainly due to the productivity growth of the unit and the reduction of the technological process execution time for a given amount of work.

As it can be seen from Fig. 3, when seasonal load on the unit reaches more than 700 hectares, the optimum value of the weight of the tractor is changing from 100 to 110 kN. The required power is increasing from 290 hp to 380 hp. and this is caused by the need to increase the productivity of the unit, both due to the increase in the width of the implement, and its speed in order to perform larger amount of work at the same time.

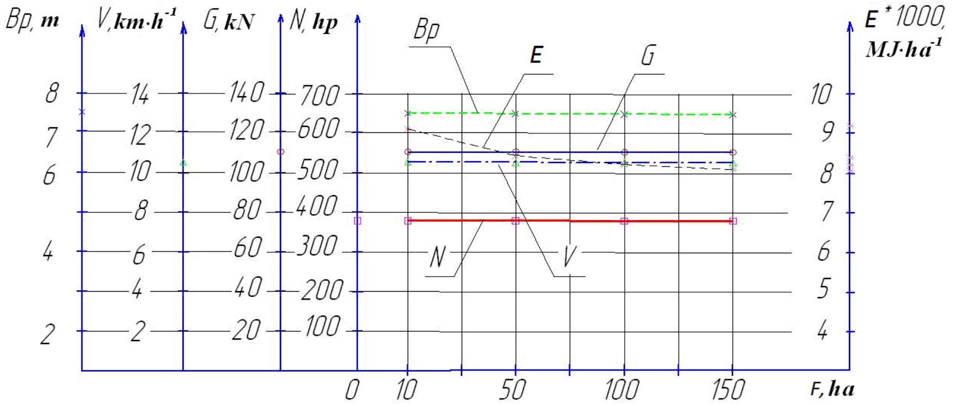


Fig. 2. **Change in parameters of tractor, implement and total energy costs, when changing area of processed field and class of unit run before turn**

With the growth of the seasonal load per unit, the total energy costs are steadily increasing. If the seasonal load exceeds 700 ha, it is necessary to purchase heavier tractors with more powerful engines.

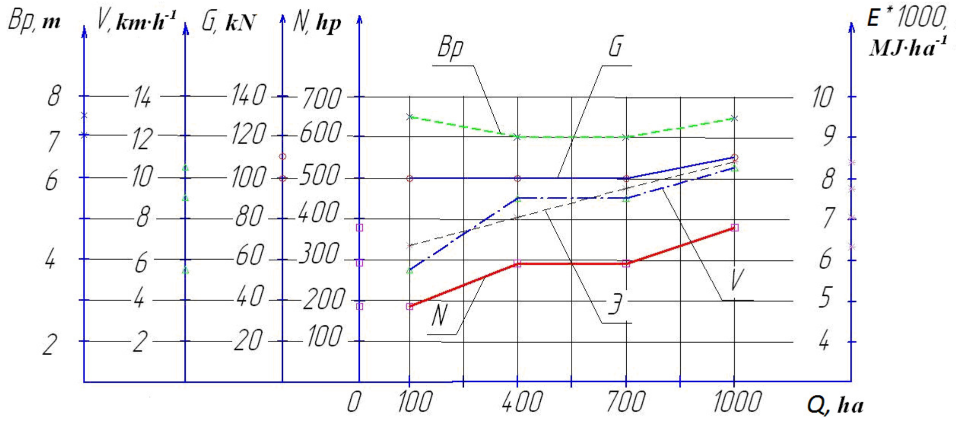


Fig 3. **Change in tractor, aggregate and total energy costs, when changing seasonal load per unit**

Fig. 4 reveals the fact that the increase in the planned yield from 10 to 40 $c \cdot ha^{-1}$ does not entail changes in the optimal parameters of the tractor and the unit – they remain stable.

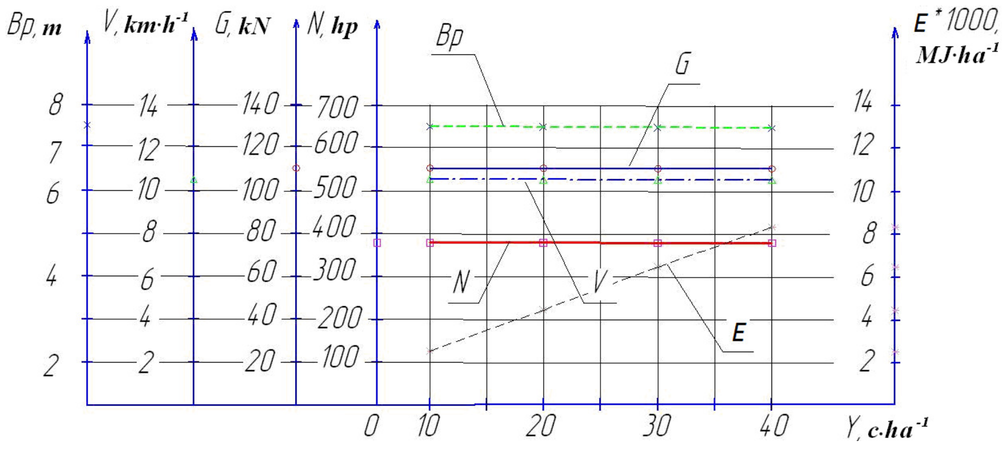


Fig. 4. **Change in parameters of tractor, implement and total energy costs, when changing planned yield of grain crops**

However, as the yield increases, the total energy costs increase significantly. The greater the crop yield, the higher the yield loss in absolute units, which entails an increase in total energy costs.

The higher the coefficient of shift, the less can be the weight of the tractor, the less powerful engine is required; as well as less the width of the implement and the speed of the unit (please, refer to Fig. 5). For instance, using a tillage implement only 7 hours a day instead of 21 hours will lead to the need in increasing the weight of the tractor from 100 to 120 kN. And at the same time, the required engine power grows for 150 hp, the width of the implement increases by one meter, all this leads to an increase in the total energy costs from 7500 MJ·ha$^{-1}$ to 9,985 MJ·ha$^{-1}$.

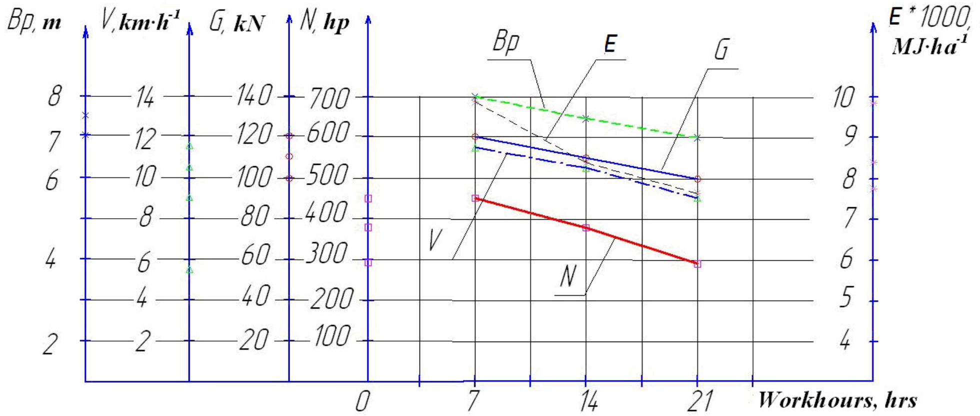


Fig. 5. **Change of parameters of tractor, implement and total power expenses at change of factor of working shifts (i.e. increasing daily use-time of the unit)**

With an increase in the yield loss factor considering, for instance, the disturbance of agricultural technological process (please, see Fig. 6), the calculated values of the optimal parameters of the tractor increase, in connection with the need to ensure greater productivity of the operation in a shorter period. Usually, in soil cultivation this coefficient is in the range from 0.2 to 0.6 %·day$^{-1}$, therefore, the optimal weight of the tractor remains within the range of 100-120 kN, and the engine power is in the range from 280 to 420 hp.

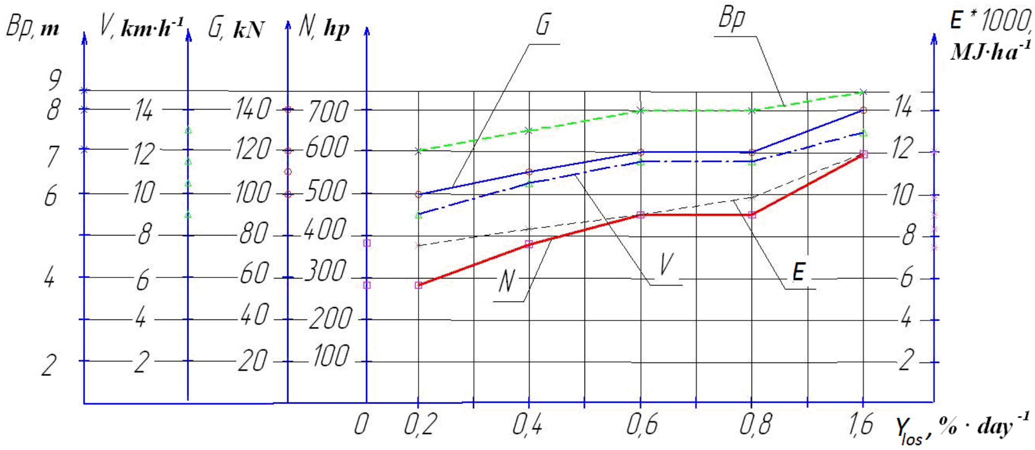


Fig. 6. **Change in parameters of tractor, unit and total energy costs, when changing yield loss factor for one day (due to disturbance of violation of technological process)**

It is clear that a lighter tractor needs to be used, when the yield loss factor grows by one unit of the tractor wheel compaction influence (dampening effect) on the soil (Fig. 7). Within entire range of the change of this coefficient, the optimal weight of the tractor varies from 100 to 110 kN. The width of the implement remains within 7-7.5 m. The total energy costs with the growth of the coefficient value are steadily growing.

Let us consider the effect of the pressure variation in the tires of the tractor from 0.2 to 0.08 MPa on the optimal parameters of the disc soil cultivating implement, as shown in Fig. 8. It is clear that a decrease in the tire pressure from 0.2 to 0.08 MPa leads to a reduction in the total energy costs, when working the tillage unit from 7912.4 to 6292.5 MJ·ha$^{-1}$.

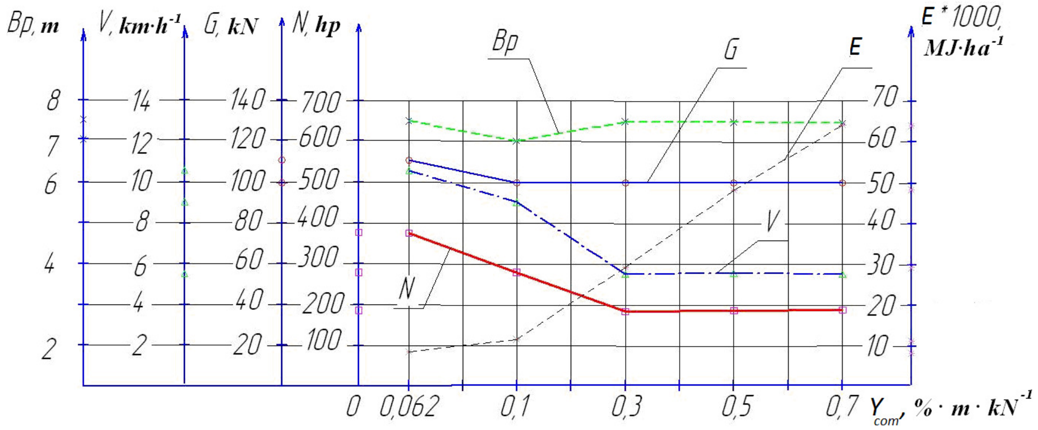


Fig. 7. **Change in parameters of tractor, aggregate and total energy costs, when changing yield loss factor per unit of dampening effect of wheels**

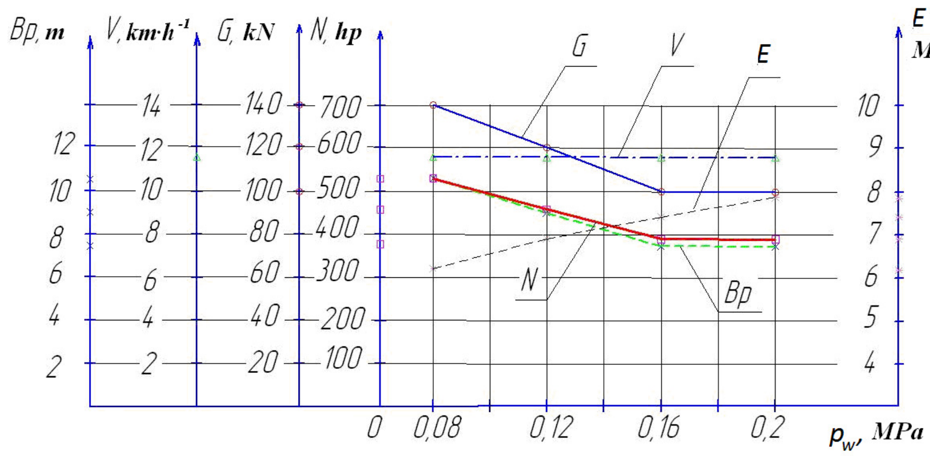


Fig. 8. **Change in main parameters of tractor, unit and total energy costs, when pressure in tires of tractor changes**

When the pressure in the tractor tires decreases from 0.2 to 0.16 MPa, the calculated optimum values of the parameters of the tractor and the unit remain unchanged with a reduction in total energy costs. Further reduction in tire pressure results in the optimum weight of the tractor and the power of its engine increasing and reaching a tire pressure of 0.08 MPa to 140 kN and 500 hp. The speed remains unchanged at 11.5 km·ha$^{-1}$, and the optimum implement width of the unit is increased from 7.5 m to 10.5 m. This change in weight and engine power is due to a reduction in soil compaction with a decrease in the tire pressure and simultaneous increase in the unit capacity, and means a reduction of technological operation execution time; and, accordingly, a decrease in the energy of the lost crop from violation or disruptions of the technological process of soil tillage.

The same calculations were performed for soil-processing units with disc-type implements of the BDM type. Optimum evaluated values of the main parameters of the tractor for soil cultivation by disk tools are in the range from 100 to 120 kN, the required power ranges from 300 to 450 hp, depending on the operating conditions. The optimal grasp width of the unit is 7-9 m. The optimum speed is 11.5 km·ha$^{-1}$.

## Conclusions

1. The computing experiments performed with use of the energy-based mathematical model of soil processing units, which adequacy was set in earlier researches, showed that there is an optimum combination of weight of the tractor and power (capacity) of its engine (at the corresponding best values of the speed and width of the unit) for specifically selected working conditions.

2. During the computing experiments it became clear that the optimum weight of the tractor on soil cultivation with use of the combined and disk tools (traction resistance of 5-7 $kN \cdot m^{-1}$), at change of the majority of factors of the TIOFSC system, changes slightly and remains within 100-120 kN. Bigger value of weight of the tractor corresponds to a bigger value of unit traction resistance of the tillage machine.
3. Limits of change of the power are more considerable and are ranging from 300 to 450 hp. Tractors with smaller power (capacity) are effective at smaller seasonal load of the unit and increase in the coefficient of interchangeability (working in shifts) (period of operation during the day).
4. The optimum width of the soil-cultivating unit remains in the range from 7 to 9 m, to a thicket in the region of 7.5 m. Optimum speed can change from 6 to 13 $km \cdot h^{-1}$, to a thicket in limits of 8-11 $km \cdot h^{-1}$.
5. At pressure decrease in tires to minimum value admissible by the manufacturer, the possibility appears to use heavier tractors weighing up to 140 kN, with the engine power up to 450 hp and more on surface treatment of the soil. At the same time the width of cut of the unit can be increased and total power processing costs of 1 hectare decrease.

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