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Selection of the main parameters of tractors for direct sowing of grain crops according to various optimization criteria

Camill A. Khafizov*, Ramil N.* Khafizov*, Azat A.* Nurmiev[*] *and Ilnar N.* Gayaziev

Kazan State Agrarian University, 65, K. Marx St., Kazan, 420015, Republic of Tatarstan, Russian Federation

Abstract. The article discusses the questions of optimization of parameters and operating modes of the tractor as a part of the arable unit by various criteria of optimization. The following parameters have been chosen for consideration. These are minimum total energy costs, taking into account the energy of the lost crop; minimum emission of carbon dioxide into the atmosphere; minimum fuel consumption per 1 ha of crops; maximum performance; maximum traction efficiency of the tractor. The optimal weight of the tractor, the power of its engine, the width of the sowing unit and its working speed were determined by carrying out computational experiments with a change in the resistivity of the sowing complex. It was revealed that the optimal parameters of the tractor and the sowing unit do not coincide according to all optimization criteria with an increase in the specific resistance of the soil to the working bodies of the seeder, the optimal value of the tractor weight and the power of its engine grow. The optimal weight of the tractor should be 120 kN with the possibility of loading up to 150 kN, it is desirable to have a two-level engine of 500 and 600 hp. The working width of the seeder must be able to change from 14 to 18 m.

1 Introduction

In scientific articles and technical literature devoted to improving the efficiency of operation of machine and tractor units [1–11], different indicators are used in technological operations to characterize their work, various criteria for conducting optimization calculations, usually without justifying their choice. There is no comparative analysis of the results obtained using several optimization criteria (performance indicators). In this regard, the proposed article is devoted to the analysis of the optimal basic parameters of the tractor and sowing unit, obtained on the basis of calculations for a number of optimization criteria.

2 Materials and methods

To substantiate the main parameters of the tractor (tractor weight, engine power) and the parameters of the sowing unit (gripper width and operating speed), the method of mathematical modeling of the unit for direct sowing of grain crops according to optimization criteria was used. The criteria are minimum total energy costs, taking into account the energy of the lost crop; minimal emission of carbon dioxide into the atmosphere; minimum fuel consumption per 1 hectare of sowing. There is also maximum performance; the maximum traction efficiency of the tractor [1–4] and computational experiments carried out using the software application "Tractor Calculation", compiled on the basis of the use of mathematical models of sowing machine and tractor units.

3 Results and discussion

We will conduct computational experiments using the software application "Tractor Calculation" setting the operating conditions of the sowing unit and the values of external environmental factors of the tractor-operator-tool-field-soil-harvest (TOOPPU) system within the limits observed for the soil and climatic conditions of the Republic of Tatarstan [12–17]. Calculations were carried out in parallel according to all the criteria for optimizing the parameters of the sowing unit. For a comparative analysis of the obtained data, we will set two values of the specific resistance of the soil to the working bodies of the planter (4 kN/m and 6.25 kN/m). This factor most strongly affects the main parameters of the designed tractor, as well as the width of the gripper and the working speed of the planter for direct sowing. As a prototype of the projected seeder, a planter of the "Agromaster" type with cultivator type coulters was chosen [18–20].

Baseline data for calculations:
specific soil resistance per 1 m of the seeder = 4 kN/m;
field area = 100 ha;
cutting length = 1 km;
moving distance of the unit = 3 km;
seed density = 800 kg/m^3;
strength coefficient of the bearing surface of the field = 0.9;
amount of work performed by the unit = 500 hectares;
number of tractors performing the operation = 1;
number of operation hours of the unit per day = 16 hours;
planned yield of the main and by-products = 40 c/ha;
tractor tire pressure = 0.16 MPa;
number of wheels on one side of the tractor propulsion = 1;

[*] Corresponding author: azat-nurmiev@mail.ru

coefficient of adhesion of the wheels of the tractor with the soil = 0.65;
coefficient of resistance to rolling wheels of the tractor = 0.15;
mass of CO_2 absorbed by the crop (wheat) = 243 kg/c;
maximum tractor weight = 260 kN;
maximum engine power = 550 hp;
maximum working width of the unit = 18 m;
maximum speed of the unit = 12 km/h.

The results of the calculations are shown in Table 1 and in Figures 1-5. The table is divided into two parts according to the specific resistance of the seeder by 1 m of the width of the gripper of the unit. Each line corresponds to the results of calculations for one of the five optimization criteria and in them. In addition to the optimal parameters of the tractor and the unit for this criterion, the values of performance indicators corresponding to other optimization criteria are given.

As can be seen from Table 1 and Figures 1, 2, and 4, for the selected specific resistance of the seeder of 4 kN/m, the optimal values of the parameters: the weight of the designed tractor, the power of its engine, the width of the unit and its operating speed completely coincided according to three optimization criteria. These are the following optimization criteria: minimum total energy consumption ($\sum Ei$), integral carbon dioxide emission ($\sum CO_{2i}$) and maximum unit capacity (W). The first two optimization criteria, unlike the rest of the criteria, take into account the influence of the parameters of the tractor and the unit on the size of the crop being formed, through the loss of a potential harvest due to an incorrectly selected tractor and seeder [21–25].

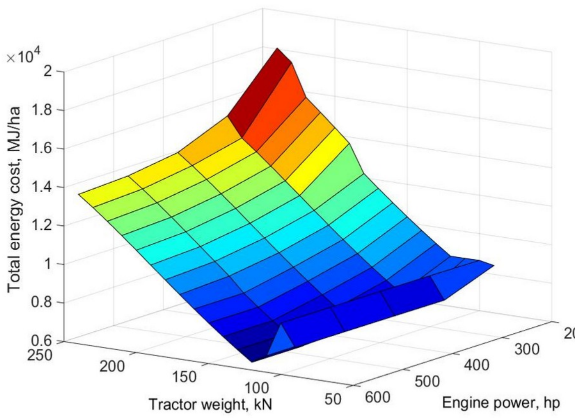

Fig. 1. Influence of the tractor weight and engine power on the change in total energy costs for direct sowing of grain crops.

For the accepted operating conditions for sowing units, the optimal ones are the weight of the tractor being 120 kN, the engine power being 490 hp, the width of the grip of the sowing unit being 18 m, the operating speed being 12 km/h. With such parameters of the tractor and the unit, the minimum total energy costs are ensured, taking into account the energy of the lost crop being 6399 MJ / ha, the minimum emission of carbon dioxide into the atmosphere being 30.4 kg/ha, the maximum capacity of the unit being 12.18 hectares/h.

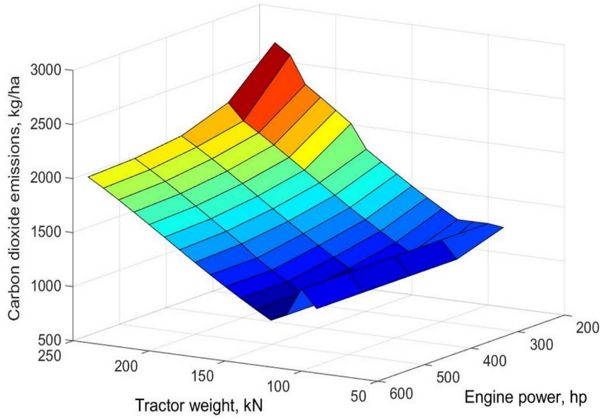

Fig. 2. Influence of the tractor weight and its engine power on the change in carbon dioxide emission into the atmosphere when directly sowing the crops.

To save only direct energy costs through fuel and lubricants, the tractor should have a lower weight of 110 kN, lower engine power of 192 hp. And it, accordingly, can perform work at a lower speed of 5 km/h. Natural fuel economy will be 0.47 kg/ha compared to the previous parameters of the unit, but the total (total) energy costs will increase by 444 MJ/ha, equivalent to 10 kg/ha of natural diesel fuel (see Table 1).

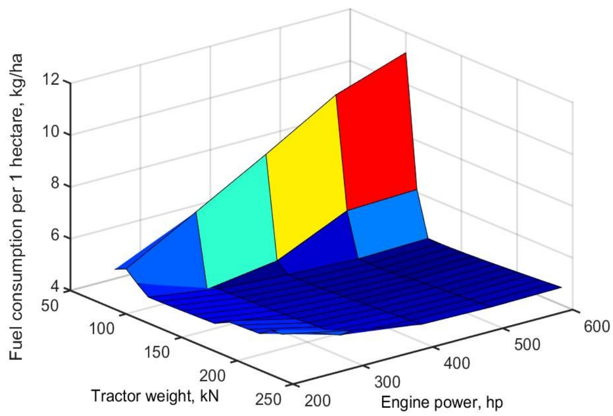

Fig. 3. Influence of the tractor weight and engine power on the change in per-hectare fuel consumption during direct sowing of grain crops.

The choice of the optimization criterion to focus on is the behalf of equipment holders. The optimization criterion is the maximum traction efficiency of the tractor not deserving special attention, because it is a purely specific criterion for optimizing the use of only the tractor itself and does not bring an effect on the scale of the TOOPPU.

Table 1. Optimal parameters of the tractor and unit for direct sowing according to various optimization criteria.

Optimization criterion	Value of performance indicators					Optimal parameters of the tractor and the unit according to the optimization criterion			
	($\sum E_i$), MJ/ha	($\sum CO_{2i}$), kg/ha	(G), kg/ha	(W), ha/h	(η)	Tractor weight, kN	Engine power, hp	Working width of the unit, m	Operating speed of the unit, km/h
	Specific soil resistance of 4 kN/m								
Minimum total energy cost ($\sum E_i$)	6399	932,67	4.33	12.18	0.6970	120	491	18	12
Integral carbon dioxide emission ($\sum CO_{2i}$)	6399	932,67	4.33	12.18	0.6970	120	491	18	12
Minimum fuel consumption per 1 hectare (G)	6843	997,10	3.86	8.84	0.6959	110	192	18	5
Maximum aggregate performance (W)	6399	932,67	4.33	12.18	0.6970	120	491	18	12
Maximum tractor traction efficiency (η)	9214	1344	6.12	4.61	0.6985	100	159	15	5
	Specific soil resistance of 6,25 kN/m								
Minimum total energy cost ($\sum E_i$)	10713	1574,6	6.56	8.89	0.6981	150	596	14	12
Integral carbon dioxide emission ($\sum CO_{2i}$)	10713	1574,6	6.56	8.89	0.6981	150	596	14	12
Minimum fuel consumption per 1 hectare (G)	11234	1643,7	5.98	7.11	0.6951	170	300	18	5
Maximum aggregate performance (W)	11055	1621,7	6.36	9.67	0.6982	180	591	17	10
Maximum tractor traction efficiency (η)	14257	2093,6	8.04	3.42	0.6985	120	382	11	10

In addition, the maximum values of the tractor's traction efficiency are in the zone for the optimal parameters of the sowing unit according to the three main optimization criteria, the difference is 0.0015 (see Table 1), which is an insignificant difference.

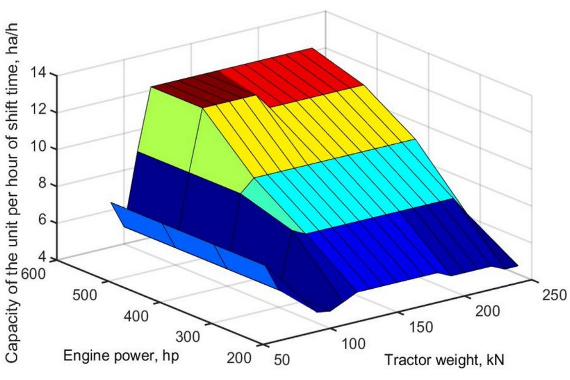

Fig. 4. Influence of the tractor weight and its engine power on the change in the replacement capacity of the unit during direct sowing of grain crops.

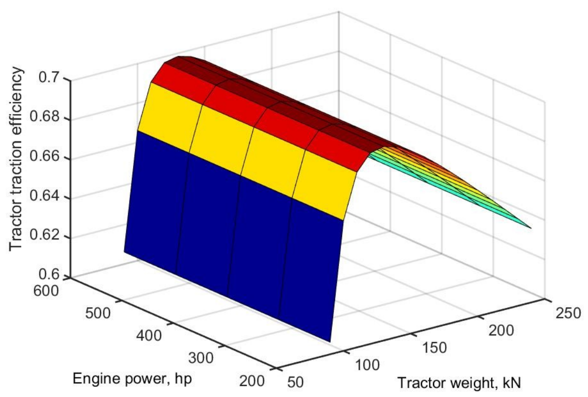

Fig. 5. Influence of the tractor weight and engine power on the change in tractor traction efficiency during direct sowing of grain crops.

Increasing the specific resistance of the seeder from 4 to 6.25 kN/m causes the need to increase the optimal weight of the tractor by 3 tons, engine power by 105 hp, reduce the working width by 4 m according to the optimization criteria: minimum total energy consumption (∑Ei); integral carbon dioxide emission ($\sum CO_{2i}$). To obtain maximum productivity, the tractor must be 6 tons heavier compared to that with the previous calculations and this is explained by the fact that the performance optimization criterion does not take into account the impact of the tractor's weight on crop losses due to the compaction of the soil by its propulsion.

4 Conclusion

A systematic (TOOPPU system) mathematical model of units for direct sowing of grain crops according to various optimization criteria has been compiled. These are minimum total energy costs, taking into account the energy of the lost crop; minimal emission of carbon dioxide into the atmosphere, taking into account CO_2 not absorbed from the atmosphere by the lost crop; minimum fuel consumption per 1 hectare of sowing; maximum performance; maximum traction efficiency of the tractor. Computational experiments were conducted.

The optimal values of the tractor weight were 120 kN, the power of its engine was 481 hp, the width of the grip of the unit was 18 m and its operating speed was 12 km/h at low values of the specific traction resistance of the seeder (4 kN/m). They coincide according to three optimization criteria: minimum total energy costs, taking into account the energy of the lost crop; minimal emission of carbon dioxide into the atmosphere, taking into account CO_2 not absorbed from the atmosphere by the lost crop. The maximum productivity is due to the need to reduce crop losses from violation of the agricultural term of the technological operation, a unit with a maximum replaceable productivity of 12.18 hectares/h is selected.

Increasing the specific resistance of the seeder to 6.25 kN / m leads to an increase in energy costs for the execution of the technological operation, so the optimal values of the tractor weight and the power of its engine increase. According to the first two optimization criteria, the weight growth of the tractor is limited by the increase in crop losses due to soil compaction, so the optimal weight is 150 kN. The criterion for optimizing the maximum capacity of the unit for 1 hour of shift time does not take into account the influence of the tractor weight on soil compaction, so the optimal weight of the tractor for it is the largest being 180 kN. There is an increase in the weight of the tractor and the power of its engine and other optimization criteria.

A good desire to save direct energy costs through fuels and lubricants leads to an increase in total energy costs, an increase in carbon dioxide emissions into the atmosphere, and a decrease in the productivity of the sowing unit. For optimization calculations of the parameters of sowing units, it is necessary to use more complex, systemic optimization criteria, such as minimum total energy costs, taking into account the energy of the lost crop; minimal emission of carbon dioxide into the atmosphere, taking into account CO_2 not absorbed from the atmosphere by the lost crop.

Within the change in the specific resistance of the seeder from 4 to 6.25 kN/m, the optimal weight of the tractor should be 120 kN with the possibility of loading up to 150 kN. It is desirable to have a two-level engine of power of 500 and 600 hp.

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