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# Ways to reduce carbon dioxide emissions from arable machinery and tractor units

*Camill* A. Khafizov, *Ramil* N. Khafizov, *Azat* A. Nurmiev*, and *Stanislav* A. Sinitsky

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

**Abstract.** The article is devoted to the search for ways to reduce carbon dioxide emissions in the technological operation of plowing. Ways to reduce $CO_2$ emissions were determined on the basis of computational experiments conducted using a mathematical model of an arable unit compiled according to the efficiency criterion - the minimum integral emission of carbon dioxide. Integral $CO_2$ emission, in addition to direct and indirect $CO_2$ emissions over the life cycle of the arable unit, includes $CO_2$, which could be absorbed from the atmosphere by the crop lost due to the influence of the parameters of the unit. The influence of the parameters of the tractor and the unit on the emission of carbon dioxide during its manufacture, technical and production operation is analyzed. Computational experiments were conducted to identify the influence of some external factors (field area, seasonal load volume, etc.) on the efficiency of the arable unit.

## 1 Introduction

The world community was puzzled by a new problem – there is a global warming, the results of which can be catastrophic for many countries and peoples [1-4]. Many see the main reason for the coming changes in the active participation of people in the process of increasing carbon dioxide in the atmosphere, through the burning of fossil fuels, deforestation, increasing the number of livestock in order to feed the ever-increasing population on the globe. Mobile machines powered by fossil fuel energy are also widely used in agricultural production. One of the most energy-intensive technological operations is plowing, which cannot be completely abandoned for a number of reasons, including over compaction of the soil by tractor propulsion and the concomitant decrease in crop yields [5–8].

In this regard, the article considers ways to reduce the emission of integral carbon dioxide during this most energy-intensive, technological operation.

## 2 Materials and methods

To identify ways to reduce carbon dioxide emissions into the atmosphere, the method of mathematical modeling of the operation of the arable machine-tractor unit (MTU) based on the use of an integral criterion for optimizing the parameters of equipment is used - the total emission of carbon dioxide [9-11].

The amount of carbon dioxide emitted into the atmosphere during the manufacture, technical and production operation of arable units is a dependence:

$$CO_2=CO_{2m.Trac}+CO_{2m.am}+CO_{2m.tr}+CO_{2rmo}+CO_{2a.d.}+CO_{2dr}+CO_{2\,fuel}+CO_{2agr}+CO_{2s.c.}\rightarrow min, \quad (1)$$

where $CO_2$ is the specific total carbon dioxide emission, kg/ha;

$CO_{2m.Trac}$, $CO_{2m.am}$, $CO_{2m.tr.}$ are the amount of $CO_2$ emitted respectively in the manufacture of a tractor, agricultural machine, trailer, per 1 ha, kg/ha;

$CO_{2rmo}$ is the amount of $CO_2$ emitted into the atmosphere during the repair and maintenance of a tractor, trailer and agricultural machine, kg/ha;

$CO_{2a.d.}$ is the amount of $CO_2$ emitted into the atmosphere during the assembly and disassembly of the unit, kg/ha;

$CO_{2dr}$ is the amount of $CO_2$ emitted by the machine operator when driving a tractor, kg/ha;

$CO_{2fuel}$ is the amount of $CO_2$ emitted during the combustion of fuel by the tractor engine, kg/ha;

$CO_{2agr}$ is the amount of $CO_2$ from the atmosphere not bound by the harvest, due to its losses due to the violation of the agrotechnical terms of the technological operation, kg/ha;

$CO_{2s.c.}$ is the amount of $CO_2$ not bound by the harvest from the atmosphere due to its losses owing to soil compaction by tractor propulsion, kg/ha.

The proposed sum of the various components of the integral emission of carbon dioxide into the atmosphere will be the criterion for optimizing the parameters and operating modes of machine and tractor units in order to minimize harmful emissions.

When developing a mathematical model of an arable unit according to the specified indicator of the efficiency of its work, the relationship of each component of the optimization criterion with the parameters of the tractor and agricultural machine, as well as environmental

* Corresponding author: azat-nurmiev@mail.ru

factors, was revealed. In parallel, mathematical models of the arable unit were built on other indicators of the effectiveness of its work for comparative analysis.

## 3 Results and discussion

On the basis of the developed mathematical models of arable machine-tractor units according to the optimization criteria we identified minimum direct and indirect total energy costs, taking into account the energy of the lost crop; minimal emission of carbon dioxide at the stages of manufacture and operation of equipment. We take into account the amount of carbon dioxide that could be absorbed from the atmosphere, the crop yield lost during the operation of the unit; maximum capacity of the unit in one hour of shift time.The minimum fuel consumption per hectare of the area treated by the unit and the maximum traction efficiency of the tractor [12, 13], computational experiments were specified, some of the results of which are given in Table 1.

As can be seen from the table, the optimal values of the aggregate parameters, including the optimal basic parameters of the tractor, coincide according to three optimization criteria. This is due to the need to provide the arable unit with maximum productivity. In the case of the use of integral optimization criteria, maximum productivity ensures minimal crop losses due to violation of agrotechnical terms for the implementation of technological operations, which occupies a dominant position in the structure of total energy costs and carbon dioxide emissions, see Figure 1.

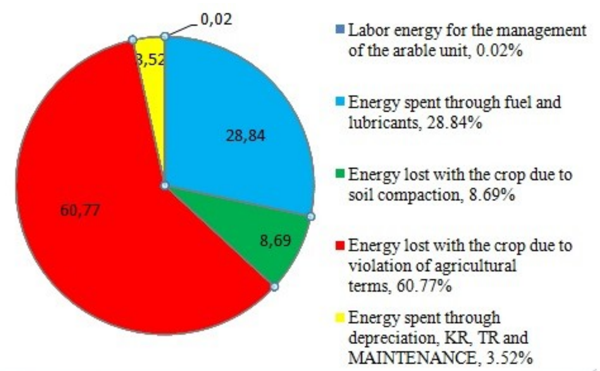


**Fig. 1.** Structure of total energy costs for technological ploughing operations.

To reduce the emission of carbon dioxide, it is necessary first of all to reduce crop losses due to violation of the agrotechnical terms of ploughing and fuel consumption for the implementation of the technological operation.

Figure 2 shows the dependence of carbon dioxide emissions on the weight of the tractor and the power of its engine.

The graph shows that $CO_2$ emissions are largely dependent on both the weight of the tractor and the power of its engine.

We will carry out the same calculations with an increased range of the main parameters of the tractor (the weight of the tractor is up to 260 instead of 220 kN and the power of its engine is up to 560 instead of 400 hp). The results of the calculation are presented in Figure 3.

The following results are obtained:

the optimal plough grip width (Bopt) = 5.25 m;

the optimal speed of the unit (Vopt) = 9.5 km / h;

the optimal tractor weight (Mtiopt) = 140 kN;

the optimum engine power (Neopt) = 520 hp;

the total emission of carbon dioxide ($CO_{2min}$) = 379.15 kg/ha.

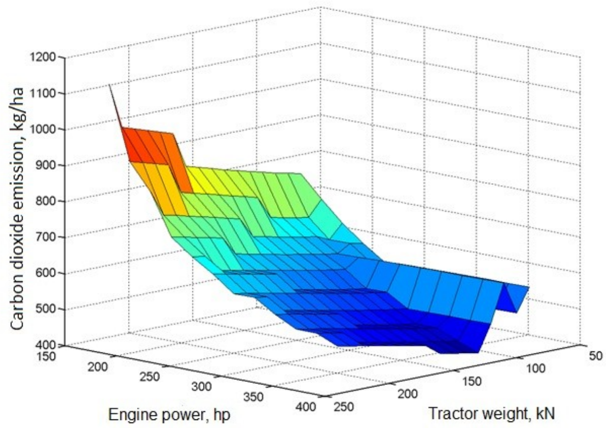


**Fig. 2.** Dependence of carbon dioxide emission on the main parameters of the tractor whenplowing.

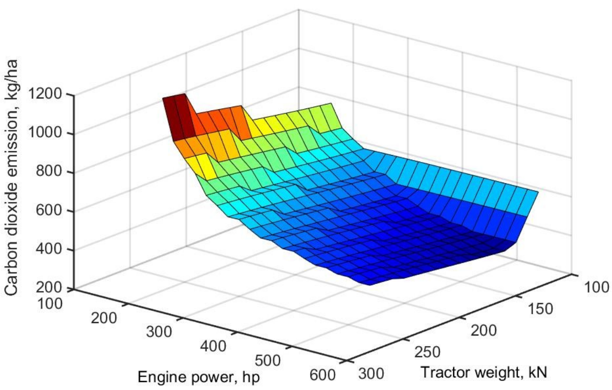


**Fig. 3.** Dependence of carbon dioxide emission on the main parameters of the tractor when plowing with an increase in their maximum limits.

As you can see, the optimal parameters of the tractor increased, $CO_2$ emissions decreased from 434.57 kg/ha to 379.15 kg/ha.

We will carry out the same calculations with an increase in the upper limit of the plough grip width from 5.25 to 5.95 m.

Calculation results are:

the optimal plough grip width (Bopt) = 5.95 m;

the optimal speed of the unit (Vopt) = 8.5 km/h;

the optimal tractor weight (Mtiopt) = 150 kN;

the optimum engine power (Neopt) = 520 hp;

the total emission of carbon dioxide ($CO_{2min}$) = 378.08 kg/ha.

As can be seen from the results of the calculations and Figure 4, the optimal parameters of the tractor and the arable unit have changed, while there is a slight decrease in carbon dioxide emissions compared to the previous calculation.

**Table 1.** Optimal parameters of the arable unit according to various optimization criteria for specified working conditions.

| Options | Minimum energy consumption, MJ/ha | Minimum carbon dioxide emissions, kg/ha | Minimum fuel consumption, kg/ha | Maximum tractor efficiency | Maximum productivity, ha/h |
|---|---|---|---|---|---|
| Tractor weight, kN | 130 | 130 | 100 | 110 | 130 |
| Engine power, hp | 398,11 | 398,11 | 214,55 | 266,79 | 398,11 |
| Working width, m | 5,25 | 5,25 | 4,55 | 4,2 | 5,25 |
| Unit speed, km/h | 7,5 | 7,5 | 5 | 6,5 | 7,5 |
| The value of the optimal value of the optimization criterion | 3405,2 | 434,57 | 18.87 | 0.68 | 2.32 |

**Initial data for calculations:**
Field area, = 100 hectares;
Rutting length = 1 km;
Moving distance of the unit = 3 km;
Seed density = 800 kg/m3;
Coefficient of strength of the bearing surface of the field = 0.9;
The amount of work performed by the unit = 500 hectares;
Number of tractors performing the operation = 1;
The number of hours of operation of the unit per day = 16 hours;
The 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;
Coefficient of adhesion of the wheels of the tractor to the soil = 0.7;
Coefficient of resistance to rolling wheels of the tractor = 0.12;
Plowing depth = 0.25 m;
Mass of $CO_2$ absorbed by culture = 243 kg/c
Maximum tractor weight = 220 kN;
Maximum engine power = 400 hp;
Maximum working width of the unit = 5.25 m;
Maximum speed of the unit = 10 km/h.

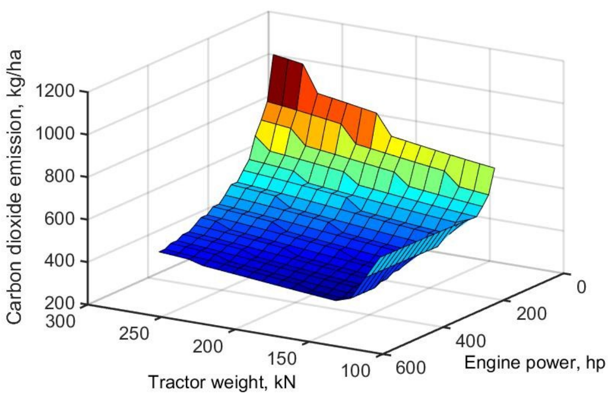


**Fig. 4.** Dependence of carbon dioxide emission on the main parameters of the tractor when plowing and increasing the maximum working width to 5.95 m.

Figure 5 shows the dependence of $CO_2$ emission on the grip width of the unit and its speed. The effect of increasing the plough's grip width on reducing $CO_2$ emissions was more intense than the effect of increasing the speed of the unit.

Let us calculate the optimal load on the arable unit for the autumn season of work for the given conditions of its work. The results of the calculations are shown in Figure 6.

As can be seen from Figure 6, the integral emission of carbon dioxide by the arable unit into the atmosphere largely depends on its seasonal load, reaching a minimum of 200 kg/ha at a load of 40-50 hectares.
We consider how the number of tractors engaged in plowing affects the emission of $CO_2$ when performing a seasonal load of 1500 hectares. The results of computational experiments are shown in Figure 7.

The optimal number of tractors for processing the field area of 1500 hectares is 3 pieces. At the same time, the minimum integral emission of carbon dioxide is 345 kg/ha. An increase and decrease in the number of occupied units leads to an increase in the integral emission of carbon dioxide.

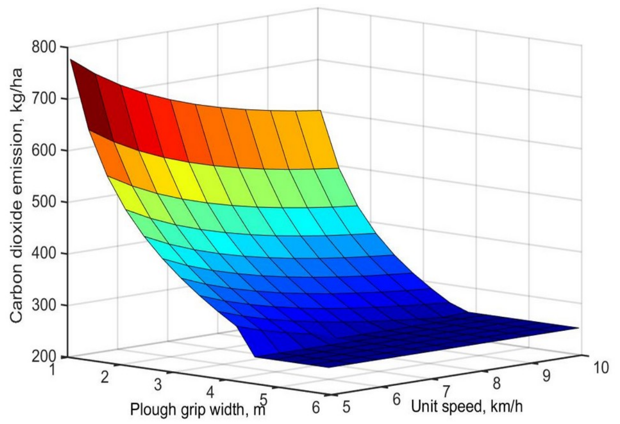


**Fig. 5.** Dependence of carbon dioxide emission on the operating speed and working width of the arable unit.

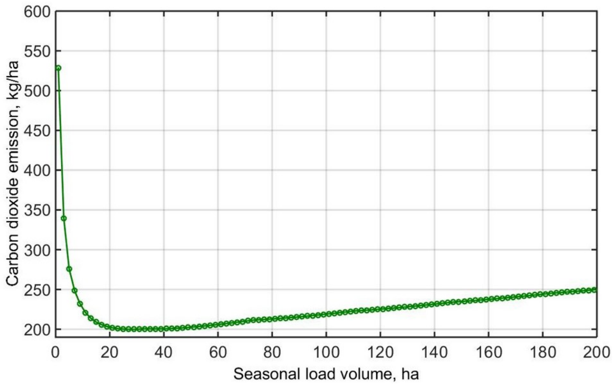


**Fig. 6.** Change in the emission of carbon dioxide into the atmosphere by the arable unit depending on the volume of its seasonal load.

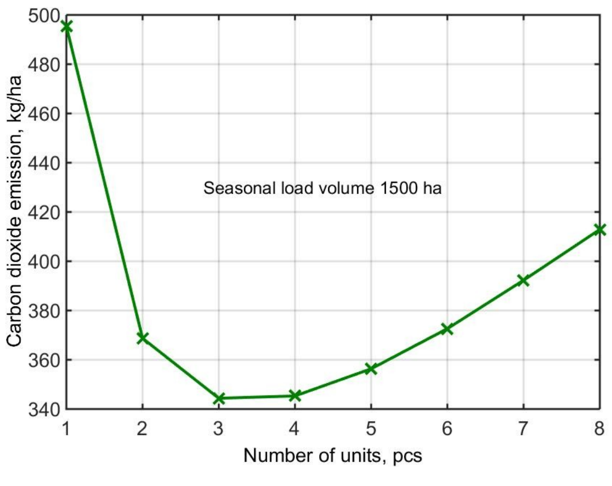


**Fig. 7.** Change in the emission of carbon dioxide into the atmosphere by the arable unit depending on the number of units engaged in the treatment of 1500 hectares of area.

As you can see from Figure 8, the lower the tire pressure of the tractor's wheels, the lower the emission of integral carbon dioxide. The minimum permissible tire pressure depends on the vertical load on the wheel and its values are given in the tire manufacturer's instruction manual [14–16].

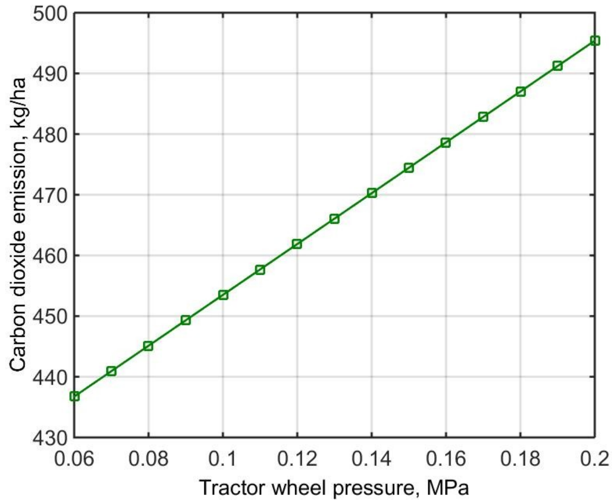


**Fig. 8.** Change in the emission of carbon dioxide into the atmosphere by the arable unit depending on the tire pressure of the wheels of the tractor.

The number of wheels on one side of the tractor also affects the emission of $CO_2$ into the atmosphere, as can be seen from Figure 9. If, with twin and built wheels of a tractor, a minimum pressure of 0.06 MPa is set in its tires, then working with built wheels becomes less profitable than with single and twin wheels on board, due to the increase in the weight of the tractor, as well as the area of the field compacted by the propulsion engines.

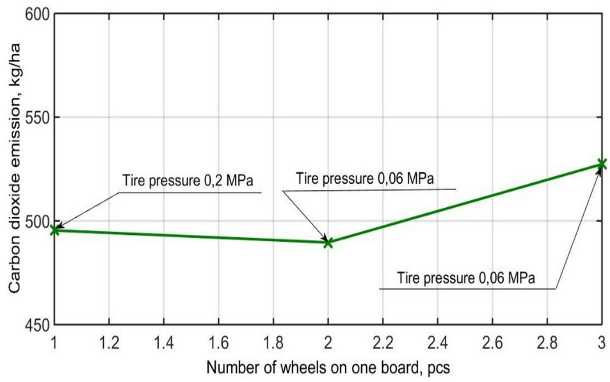


**Fig. 9.** Change in the emission of carbon dioxide into the atmosphere by the arable unit depending on the number of wheels of the tractor on one board.

To modernize tractors, sometimes it is necessary to change the brand and engine power [17–27]. The optimal engine power for a tractor weighing 156.8 kN (K-744R2) is in the range of 495–550 hp, as can be seen from the results of the calculations in Figure 10. With lower engine power, carbon dioxide emissions increase, and increasing engine power above the optimal value does not lead to a decrease in $CO_2$ emissions due to the speed limit of the arable unit within 10 km / h according to the conditions of the initial data.

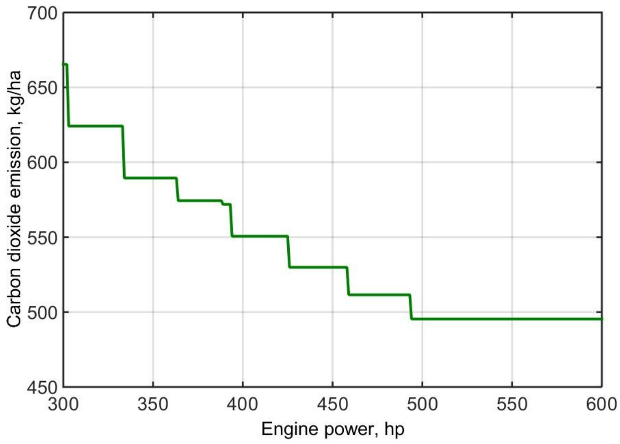


**Fig. 10.** Change in the emission of carbon dioxide into the atmosphere by an arable unit depending on the power of its engine at a weight of 156.8 kN.

In practice, usually the fields have different area and configuration. Figure 11 shows the dependence of carbon dioxide emissions into the atmosphere on the area of the field. From the figure it can be seen that arable tractors of high traction classes, in order to reduce $CO_2$ emissions, must be used in fields with an area of more than 10 hectares.

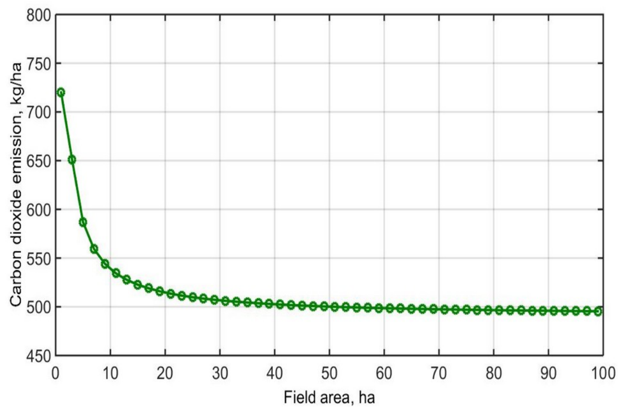


**Fig. 11.** Change in the emission of carbon dioxide into the atmosphere by the arable unit depending on the area of the treated field.

## 4 Conclusion

Computational experiments conducted on the basis of mathematical models of arable units compiled using various optimization criteria, including total energy costs, total carbon dioxide emissions, maximum productivity of the arable unit revealed a coincidence of optimal parameters for all three optimization criteria. The current picture is explained by the need to ensure the maximum productivity of the unit to minimize crop losses from violation of the agrotechnical terms of its work. The energy of the lost crop in the structure of total energy costs for ploughing occupies a dominant share and reaches 60% or more.

To reduce the integral emission of carbon dioxide into the atmosphere, the working arable unit must select the conditions of its operation, a unit with the optimal weight of the tractor, its engine power, grip width and operating speed. The ploughing unit should include a tractor with a weight in the range of 130-150 kN, with an engine power of 400-520 hp; a plough with a width of grip that maximizes the tractor's thrust load within the permissible towing limits to operate at a speed limited by engine power.

To reduce the emission of carbon dioxide, the pressure in the single tires of the tractor must be within the minimum value allowed by the manufacturer and selected on the basis of the vertical load on one wheel of the tractor. Twinning the wheels on the sides of the tractor is effective in reducing the pressure in the tires of the wheels to a minimum value, manifested, among other things, by increasing the force of adhesion of the wheels to the soil, increasing the tractive effort of the tractor with permissible slippage.

4. The volume of seasonal load on a ploughing tractor with these parameters should be at least 20 hectares. An increase in seasonal load leads to an increase in carbon dioxide emissions with an intensity of 322 grams per 1 hectare of load growth. On plowing, with a certain amount of seasonal load, there is always and it is possible to calculate the optimal number of tractors that provide minimal $CO_2$ emissions into the atmosphere. For a work volume of 1500 hectares, the optimal number of arable units is 3 pieces.

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