Study of the influence of various factors on the emission of carbon dioxide by the aggregate during direct sowing of grain crops

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Abstract. The article deals with issues related to the reduction of carbon dioxide emissions into the atmosphere during the operation of sowing machine and tractor units. To identify ways to reduce CO_2 emissions, computational experiments were conducted using a mathematical model of sowing units compiled according to the efficiency indicator. This is the integral emission of carbon dioxide as the sum of CO_2 in the manufacture, maintenance, repair, control of the unit, when burning fuel and the amount of CO_2 not absorbed from the atmosphere during the formation of the grain crop due to its losses from improperly selected equipment and its parameters. The influence of a number of factors on the integral emission of CO_2 is investigated. These are the area of the treated area or field, the specific resistance of the planter, the volume of seasonal load on the unit, the annual load of the tractor in hours, the physical and mechanical properties of the soil, the pressure in the tires of the wheel propulsion engines, etc. Effective values of factors for reducing the emission of carbon dioxide by the sowing unit are revealed. The use of the totality of all the recommendations received will reduce the emission of carbon dioxide into the atmosphere by the aggregate during the technological operation of direct sowing of grain crops by 600-650 kg/ha.

1 Introduction

Among the many threats to humanity, one of the most significant is the threat of global warming, which, according to climatologists, will be accompanied by various cataclysms, such as the melting of glaciers at the poles of the Earth, rising sea levels, the intensification of seismic processes on the surface of the earth and much more [1–6].

Agricultural production makes a significant contribution to this process. In addition to freeing up part of the forest area for agricultural needs [7, 8], a rapid increase in the number of livestock, an increasingly intensive mechanical and chemical effect on the soil, accompanied by a decrease in carbon dioxide absorption and an increase in the emission of greenhouse gases such as methane [9, 10], mobile machines are used in agriculture. This is due to the high level of mechanization, performing a variety of functions and at the same time intensively burning fossil fuels [11–20]. As a result of the combustion of carbon fuels, carbon dioxide, which is a reference greenhouse gas, is emitted.

In this regard, agricultural producers face the task of reducing carbon dioxide emissions by the engines of agricultural mobile and stationary machines, maximizing its binding by cultivated plants. The article is devoted to the search for ways to reduce CO_2 emissions by machine-tractor units at the time of direct sowing of grain crops.

2 Materials and methods

To identify ways to reduce carbon dioxide emissions by machine-tractor units engaged in direct sowing of grain crops, computational experiments based on the use of a mathematical model of sowing machine-tractor units are used. The mathematical model of the sowing unit was developed according to the criterion of the efficiency of its work – the integral emission of carbon dioxide into the atmosphere. This indicator takes into account both the direct emission of CO_2 during the operation of the unit, and its indirect release at the time of manufacture, maintenance and repair of equipment. And it also takes into account CO_2 not absorbed from the atmosphere by part of the potential harvest due to its losses associated with the choice of non-optimal parameters of equipment [21, 22].

3 Results and discussion

To identify ways to reduce the emission of carbon dioxide into the atmosphere by sowing units in the course of their operation, it is necessary to study the influence of various factors on the efficiency of the unit.

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The main initial data for the calculation are selected as typical of the region.

Initial data:
Field area = 1÷100 ha;
Rutting length = 1 km;
Aggregate crossing distance = 3 km;
Crop seed density = 800 kg/m^3;
Strength coefficient of the bearing surface of the field = 0.9;
Volume of work performed by the unit = 1000 ha;
Number of tractors performing the operation = 1;
Number of hours of operation of the unit per day = 16 h;
Planned yield of the main and by-products = 40 c/ha;
Pressure in the tractor tires = 0.16 MPa;
Number of wheels on one side of the tractor propulsion = 1;
Coefficient adhesion of the tractor wheels to the soil = 0.65;
Coefficient of resistance to rolling wheels of the tractor = 0.15;
Soil density = 1.4 g/cm^3;
Specific gravity of CO_2 absorbed by the crop (wheat) = 243 kg/c;
Tractor weight = 120 kN;
Engine power = 500 hp;
Maximum working width of the unit = 18 m;
Maximum speed of the unit = 12 km/h;
Specific resistance of the seeder = 4 kN/m.

As the first factor, we select the area of the treated field, setting it by varying from 1 to 100 hectares.

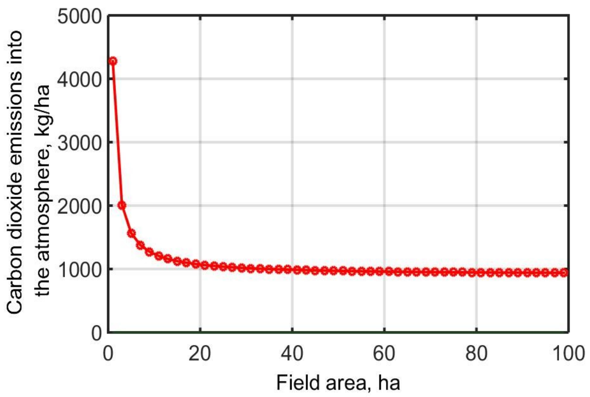

Fig. 1. Dependence of CO_2 emission on the area of the treated field.

As can be seen from Figure 1, the change in the area of the field from 1 to 100 hectares leads to a decrease in CO_2 emissions from 4300 kg/ha to 939.14 kg/ha. A particularly intense, parabolic decrease in CO_2 emissions is observed with an increase in the field area from 1 hectare to 15 hectares and this is a weighty argument for the use of plots and fields with an area of more than 15 hectares at agricultural enterprises.

The effect of the specific resistance of the planter on the release of carbon dioxide into the atmosphere is shown in Figure 2. With an increase in the resistivity of the planter, the CO_2 emission of the unit increases in stages, which is caused by a step change in the optimal width of the seeder." With an increase in the specific resistance of the planter from 3.5 kN/m to 7.5 kN/m, there is an increase in CO_2 emissions of almost 2.2 times. The resistivity of agricultural machines depends on a large number of factors, including the physical and mechanical properties of the soil (density, hardness, moisture, type of soil and its mechanical composition, etc.), on the condition and type of coulters. In the work [23] it is established that "the energetically optimal level of soil moisture when the sowing unit works with anchor coulters is 23.6%, and with paw coulters 23.4%. The direct energy consumption of a sowing unit equipped with anchor coulters is 15-20% lower than that of lancet paws". Thus, it is necessary to strive to reduce the resistivity of seeders due to organizational, structural and other measures leading to a reduction in CO_2 emissions into the atmosphere.

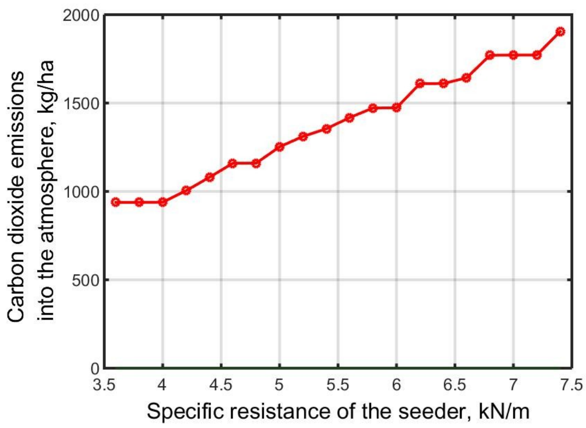

Fig. 2. Dependence of CO_2 emissions during direct sowing of grain crops on the resistivity of the planter.

Oddly enough, the release of carbon dioxide into the atmosphere is affected by the amount of seasonal load per sowing unit (Figure 3). The minimum CO_2 emission by the unit in the amount of 730 kg/ha corresponds to the load on one sowing unit equal to 200 hectares. The increase in the integral value of CO_2, as the seasonal load on the sowing unit increases above the optimal value, is explained by an increase in the amount of lost crop due to an increase in the agrotechnical period of the technological operation. That is, in this case, the cultivated crop will absorb less carbon dioxide from the atmosphere, which is equivalent to its ejection. Reducing the seasonal load less than the optimal value leads to an increase in the indirect component of the integral CO_2 emission (at the time of manufacture, maintenance and repair of equipment) due to a decrease in the annual output of the sowing unit.

The value of integral CO_2 emissions into the atmosphere is also affected by the intensity of tractor use during the year, although this influence is not so significant. Increasing the annual load of the tractor from 200 to 1600 hours leads to a reduction in carbon dioxide emissions into the atmosphere by 40 kg/ha, see Figure 4.

A significant influence on the integral amount of CO_2 emitted by the sowing aggregate is exerted by the soil density (Figure 5), which is in close correlation with the hardness of the soil. As soil density increases, potential yield losses increase due to deteriorating crop growth conditions, so increasing soil density from 1.2 g/cm^3 to 1.78 g/cm^3 leads to a tenfold increase in CO_2 emissions from 1,000 to 10,000 kg/ha.

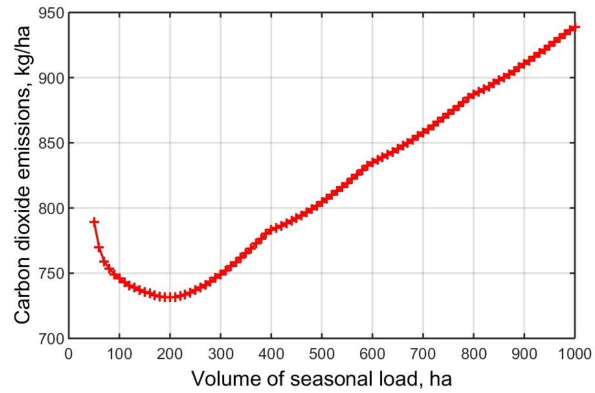

Fig. 3. Dependence of CO_2 emissions during direct sowing of grain crops on the volume of seasonal load per hectare.

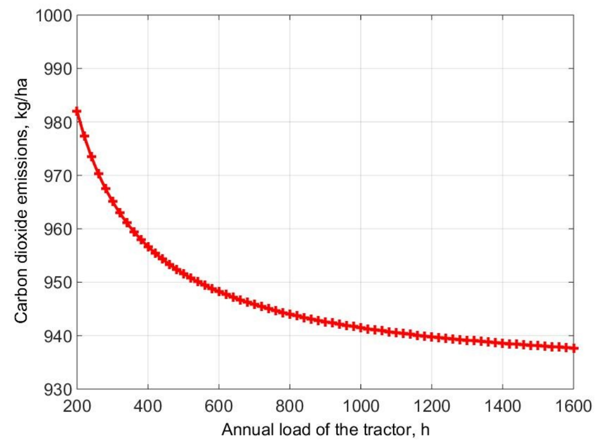

Fig. 4. Dependence of CO_2 emissions during direct sowing of grain crops on the annual load of the tractor per hour.

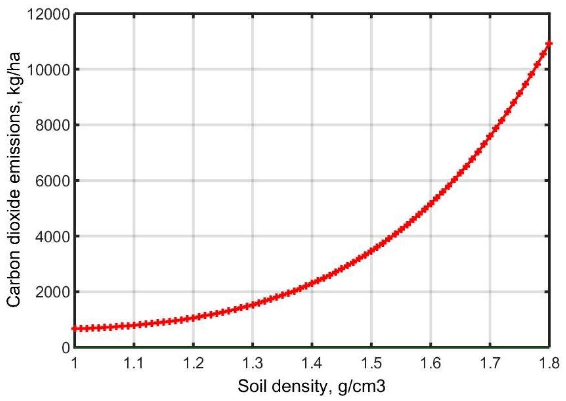

Fig. 5. Dependence of integral CO_2 emission during direct sowing of grain crops on soil density in g/cm^3.

Figures 6, 7, 8 show the dependence of carbon dioxide emissions on the number of aggregates with an annual sowing volume at an agricultural enterprise of 500 hectares in Figure 6, 1000 hectares in Figure 7 and 2000 hectares, Figure 8. As can be seen from the figures, the optimal number of units to handle the entire annual volume of work does not always grow in direct proportion to the growth in the volume of work. To process 500 hectares of area, 2 sowing units are required, 1000 hectares of area – 4 sowing units, and for sowing 2000 hectares of area it is optimal, from the point of view of minimizing the integral emission of CO_2 into the atmosphere – 7 sowing units. At the same time, the minimum value of CO_2 emitted per sowing per 1 hectare increases from 750 kg/ha (500 ha) to 830 kg/ha (2000 ha), i.e., by 80 kg/ha, which is explained by an increase in the indirect components of the integral CO_2 emission (for manufacturing, maintenance and repair).

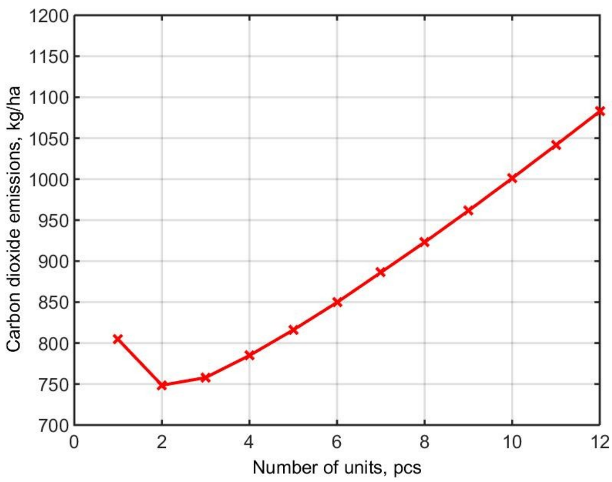

Fig. 6. Dependence of CO_2 emissions during direct sowing of grain crops on the number of aggregates engaged in sowing an area of 500 hectares.

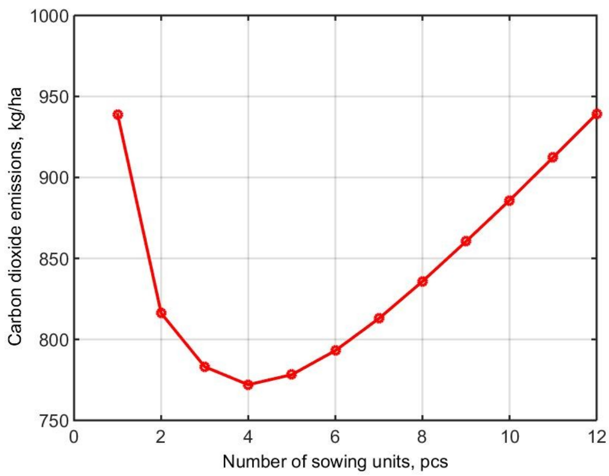

Fig. 7. Dependence of CO_2 emissions during direct sowing of grain crops on the number of aggregates engaged in sowing an area of 1000 hectares.

An increase in the tire pressure of the wheel drive (see Figure 9) from the minimum allowable value of 0.06 MPa to the upper value of 0.2 MPa leads to an increase in CO_2 emissions from 760 to 1100 kg/ha. The difference is 340 kg / ha and this is a significant value. In this regard, within the permissible limits, it is always necessary to reduce the pressure in the tires [24–26].

Of interest is the influence of the shift coefficient of the use of the sowing unit or the total operating time of the unit during one day on the emission of carbon dioxide. From Figure 10 it can be seen that this relationship is nonlinear and with an increase in the total operating time of the unit per day, the emission of carbon dioxide into the atmosphere is reduced by hyperbolic dependence. With the single-shift use of the sowing unit for 8 hours, 1200 kg/ha of CO_2 is emitted into the atmosphere. The use of the unit in two shifts for 8 hours leads to a reduction in CO_2 emissions by 260 kg/ha. It is possible to organize the operation of the unit in three shifts.

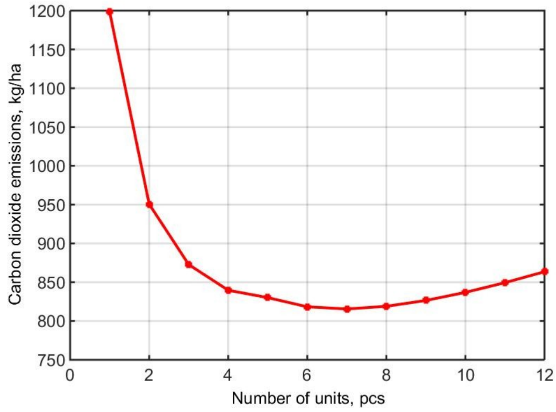

Fig. 8. Dependence of CO_2 emissions during direct sowing of grain crops on the number of aggregates engaged in sowing an area of 2000 hectares.

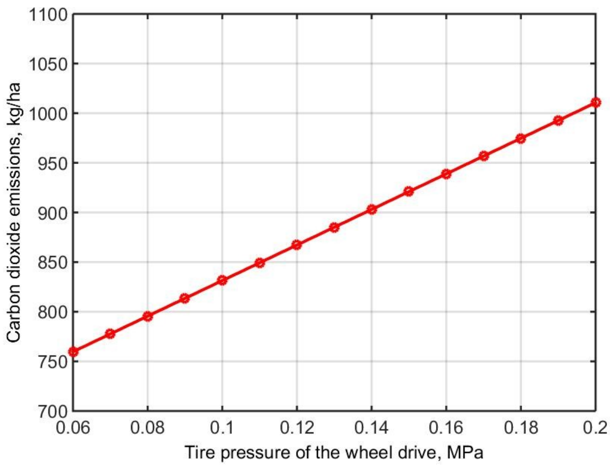

Fig. 9. Dependence of CO_2 emissions during direct sowing of grain crops on the tire pressure of the tractor wheeled propulsion.

Let us repeat the previous calculation with the optimal values of factors in the initial data.
Updated initial data:
The field area = 100 ha;
The rutting length = 1 km;
The moving distance of the unit = 3 km;
The seed density = 800 kg/m^3;
The coefficient of strength of the bearing surface of the field = 0.89;
The amount of work performed by the unit = 200 hectares;
The 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;
The tractor tire pressure = 0.06 MPa;
The number of wheels on one side of the tractor propulsion = 1;
The coefficient of adhesion of the wheels of the tractor with the soil = 0.66;
The coefficient of resistance to rolling wheels of the tractor = 0.16;
The soil density = 1.2 g/cm^3;
The specific gravity of CO_2 absorbed by the crop (wheat) = 243 kg/c;
The tractor weight = 120 kN;
The engine power = 500 hp;
The maximum working width of the unit = 18 m;
The maximum speed of the unit = 12 km/h;
The specific resistance of the seeder = 4 kN/m.

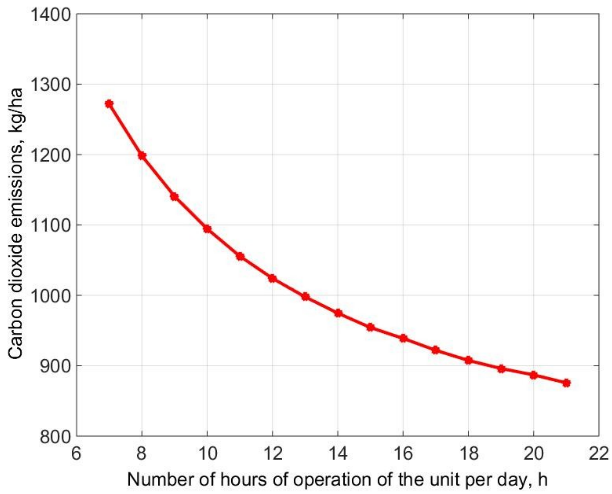

Fig. 10. Dependence of CO_2 emissions during direct sowing of grain crops on the number of hours of operation of the unit in the field with the optimal combination of factor values.

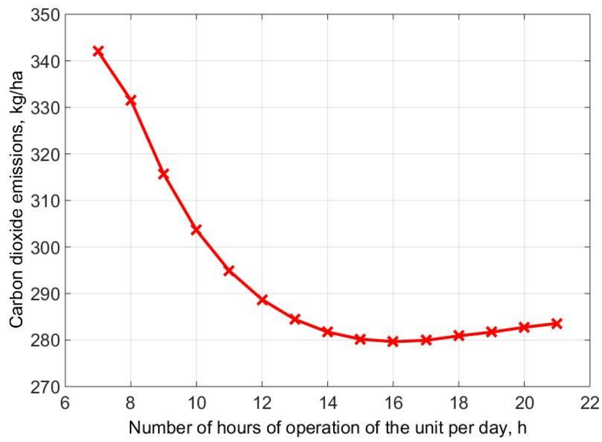

Fig. 11. Dependence of CO_2 emissions during direct sowing of grain crops on the number of hours of operation of the unit in the field with the optimal combination of factor values.

The result of the calculation is shown in Figure 11. As you can see, comparing Figures 10 and 11, the absolute value of CO_2 emissions into the atmosphere decreased from 940 to 280 kg / ha, which is a very significant decrease. The difference is 660 kg/ha. At the same time, it is most effective to use the sowing unit in two shifts of 8 hours.

4 Conclusion

The conducted computational experiments using a mathematical model of the sowing unit, compiled according to the efficiency criterion, the integral emission of carbon dioxide by the aggregate into the atmosphere showed that in order to reduce CO_2 emissions, it is necessary:

- to take organizational, operational and structural measures to reduce the resistivity of seeders;
- to use fields with an area of more than 15 hectares for sowing grain crops;
- for each type of a sowing machine and tractor unit to determine the optimal volume of seasonal load on this technological operation in hectares;
- to maximize the annual load of the tractor in hours, using in various types of work;
- to reduce the density of the soil in the field and its hardness to reduce the compacting effect of the sowing aggregate on the soil, reduce the loss of potential yield and the amount of CO_2 not absorbed from the atmosphere;
- to set the minimum allowable pressure in the tires of the wheels of the tractor propulsion system based on the recommendations of the tire manufacturer;
- to select the optimal number of units to perform a given amount of work on a technological operation, which can be calculated using the developed mathematical model of the unit;

The use of all the recommendations in the aggregate will reduce the emission of carbon dioxide into the atmosphere during the technological operation of direct sowing of grain crops. Reducing the dissipation of CO_2 emissions in the atmosphere by means of the sowing complex with an optimal tractor weight of 120 kN, an engine power of 500 hp, a working width of 18 m at a speed of 12 km/h will be 940–280 = 660 kg/ha.

References

1. J. T. Houghton, Y. Ding, D. J. Griggs et al. (Eds.) *Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge Univ. Press, 2001)
2. Assessment of the risks of climate change in 2021. Retrieved from: https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021/03-direct-climate-impacts (2021)
3. Y. A. Israel, S. M. Semenov Example of the calculation of critical boundaries of the content of greenhouse gases in the atmosphere with the help of a minimal simulation model of the greenhouse effect, *Reports of the Academy of Sciences* **4,** 533–536 (2003)
4. I. K. Rodin, Emissions of greenhouse gases and Russia's contribution to the fight against global warming. Ecological state of the natural environment and scientific and practical aspects of modern agrotechnologies, M*aterials of the V International Scientific and Practical Conference, Ryazan, Individual entrepreneur Konyakhin Alexander Viktorovich,* pp 353–355 (2021)
5. Zh. I. Sadykhova, Warming of the climate as a problem of threat to the biosphere, *Proceedings of the International Symposium "Reliability and Quality",* pp 243–245 (2020)
6. I. Maksimov, N. Adigamov, A. Mustafin, D. Khaliullin, I. Gayaziev, A. Matyashin, R. Lukmanov, Theoretical fundamentals for determining soil erosion potential, *Grupo Tchê Química* **16 (31),** 540–557 (2019)
7. The World Bank proposed to reduce greenhouse gas emissions by preserving forests, *Bulletin of Environmental Education in Russia* **4,** 11 (2007)
8. V. D. Burkov, V. F. Krapivin, V. S. Shalaev, The role of forest ecosystems in the regulation of the greenhouse effect, *Bulletin of Moscow State Forest University – Forest Herald* **1,** 20–31 (2008)
9. S. I. Shiyan, K. A. Ilyinsky, I. O. Pashurenko, Processing of waste of the livestock complex as a solution to the problem of the greenhouse effect and the way to obtain a source of energy, *Science. Technique. Technologies (Polytechnic Bulletin)* **4,** 219–227 (2016)
10. E. V. Klimova, Saving agriculture, greenhouse effect, reduction of CO_2 emissions and protection of the environment: politics and prospects (Soil protection agriculture) *Ecological safety in APK, Abstract journal* **4,** 914 (2006)
11. LNG will save the world from the greenhouse effect *AvtoGasRefueling Complex + Alternative Fuel* **1 (61),** 80–82 (2012)
12. O. K. Bezyukov, V. A. Zhukov, Thermal engines and greenhouse effect, *Bulletin of Mechanical Engineering* **7,** 84–88 (2013)
13. G. G. Galeev, To substantiate the needs of peasant and small farms in tractors, *Bulletin of Kazan State Agrarian University* **4 (18),** 106–107 (2010)
14. G. G. Galeev, To the calculation of transport support for harvesting units in the agro-industrial complex, *Bulletin of Kazan State Agrarian University* **3 (21),** 75–77 (2011)
15. F. Kh. Khaliullin, Estimation of design parameters of the crank-connecting rod mechanism of engines for mobile agricultural machines, *BIO Web of Conferences* **17,** 00076 (2021)
16. I. G. Gainutdinov, Beet production efficiency and ways to increase it in case of negative market conditions in the commodity market, *BIO Web of Conferences* **17,** 00108 (2020)
17. I. G. Gainutdinov, R. R. Gadelshin, Prospects for the development of production and processing of

potatoes in Russia, *Vector of economy* **6 (48),** 30 (2020)

18. I. G. Galiev, A. A. Mukhametshin, I. R. Iskhakov, A. R. Shamsutdinov, Increasing the efficiency of tractors in modern conditions, *Bulletin of Kazan State Agrarian University* **1 (12),** 169–172 (2009)
19. M. N. Kalimullin, R. K. Abdrakhmanov, I. G. Galiev, Perfection of potato cultivation technology *Technics and Equipment for the Village* **4,** 6–9 (2017)
20. D. Khaliullin, A. Belinsky, A. Valiev, R. Lukmanov, Optimization of plow adjustment and Gaston Bourges, *BIO Web of Conferences* **27,** 00103 (2020).
21. K. A. Khafizov, Reduction of total energy costs on technological operations in the agro-industrial complex - the way to reduce greenhouse gas emissions in the atmosphere*, Bulletin of Kazan State Agrarian University* **3 (63),** 43–47 (2021)
22. K. A. Khafizov, System mathematical model of vehicles according to the optimization criterion - minimum emission of carbon dioxide into the atmosphere, Dynamics of mechanical systems: *materials of the II International Scientific and Practical Conference dedicated to the memory of Professor A. K. Yuldashev, Kazan State Agrarian University,* pp 122–130 (2021)
23. D. A. Yakovlev, *Energy assessment of coulters during the operation of sowing units in conditions of different soil moisture of the steppe zone of Siberia*: PhD Dissertation (Barnaul, 2020)
24. R. I. Safin et al., Control of soil over compaction in resource-saving agriculture, *Methodical recommendations Kazan State Agrarian University* **48** (2018)
25. C. Khafizov, R. Khafizov, A. Nurmiev, R. Usenkov, Optimization of main parameters of tractor and unit for deep processing of soil according to criterion - total energy costs, *Engineering for rural development*, pp 603–608 (2020)
26. Tractor Belarus 3522.5 – Operating instructions (3522.5-0000010 RE) (2011)