ANALYSIS OF NEGATIVE CONSEQUENCES IN DEVELOPMENT OF MOBILE ENERGY FROM THE POINT OF VIEW OF AGROTECHNOLOGICAL RESTRICTIONS

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Abstract. Intensive use of energy-rich units and self-propelled machines has led to overconsolidation of the uncultivated layer of more than 60% of arable land. At the same time, in order to realize the energy potential, they are forced to use an additional increase in mass, which increases the compaction of the soil. Critical stresses, at which the processes of soil relaxation do not occur, reach a significant depth and, as a result, a soil horizon from 25-30 to 100-120 cm is formed in the untreated layer with a hardness corresponding to a clay rolled road. The modern theory and practice of using wheeled and tracked vehicles has formed a system of restrictions to reduce the negative impact on the ecological environment: - by specific pressure, taking into account soil moisture and the season of use; - by the amount of skidding of running systems; - according to the range of operating speeds; - across the width of the wheels, tramline and agrotechnical cross-country ability. With a lack of moisture and a decrease in the freezing depth due to climate warming, the natural process of decompaction does not allow restoring the soil structure. The increased hardness makes it difficult for the roots of cultivated plants to penetrate, limits their development zone, which excludes the biological processes of restoring the structure of the soil. Technologies for mechanized soil decompaction processes are highly energy intensive. The energy intensity of chisel tillage to a depth of 40...45 cm requires 1.2-1.5 times more energy than plowing to a depth of 25…30 cm. Technologies and machines for processing to a great depth are practically absent on the market. In this regard, the task of a detailed analysis of these processes and the substantiation of the parameters and operating modes of mobile machine-tractor units, taking into account agrotechnological restrictions, becomes urgent.

Keywords: soil compaction, machine running systems, machine weight, skidding.

Introduction

To create the structure of the arable layer, in practice, multiple treatments are used, including plow plowing and 2…3-fold cultivation and harrowing. Plowing to a constant depth has resulted in a "plow bottom" - a compacted sub-plow horizon. The generality of the discussed problem is confirmed by many foreign researchers [1; 2]. It should be noted that the natural vibrations of the machines contribute to the compaction of the soil. The bearing capacity of the soil is significantly reduced at high humidity. The change in the soil structure factor increases in the layer from 20-30 cm to 86.3-97.2% and constantly up to a depth of 100 cm [3]. With a typical technology, from 87.5 to 95.3% of the entire surface of the field is compacted, with a minimum processing of about 72.8%, and with a moldboard-free – 55.7% [4]. According to Eurostat, it remains the most common traditional technology, including plowing – 74%, 22% of arable land is cultivated using minimum technology and only 4% – no-till technology [5].

The degradation of the fertile layer is a consequence of the use of technology with a large mass. The amount of traction load that the tractor has to overcome helps increase compaction. The formed compacted soil layer violates the water regime in the soil, prevents penetration into the development system. According to Kellera B.C. [5], in soils, due to soil compaction by running systems, by 2010 the soil density in the subsurface horizon increased by 0.2-0.3 $mg \cdot m^{-3}$ in comparison with 1960, the rate of root growth decreased from 40 to 20 $mm \cdot d^{-1}$ (Fig. 1) [5].

The modern theory and practice of using wheeled and tracked vehicles has formed a system of restrictions to reduce the negative impact on the environment in terms of specific pressure, taking into account the humidity, soil type and the season of use [6]. According to the adopted method, the static load on the wheel, the contact area on a solid foundation, is determined and it is corrected for the soil background by a coefficient depending on the wheel diameter. In this case, the dynamic additional loading of the wheels is not taken into account, which ultimately gives an underestimated value of the specific pressure on the soil. The assessment methodology needs to be improved.

An unbalanced increase in the tractor unit power results in increased slippage. In the process of skidding, the soil structure is destroyed with the formation of dust particles. As permissible, skidding is taken at a tractive effort corresponding to the maximum tractive power. As restrictions, it is recommended to slip at the level of 16, 18 and 7%, respectively, for tractors of the 4x2, 4x4 type and caterpillar tractors [7]. However, even when a wheeled tractor is skidding more than 6-7%, the number of particles less than 0.5 mm increases by 2 times [8]. Reducing skidding by ballasting will result in increased soil compaction.

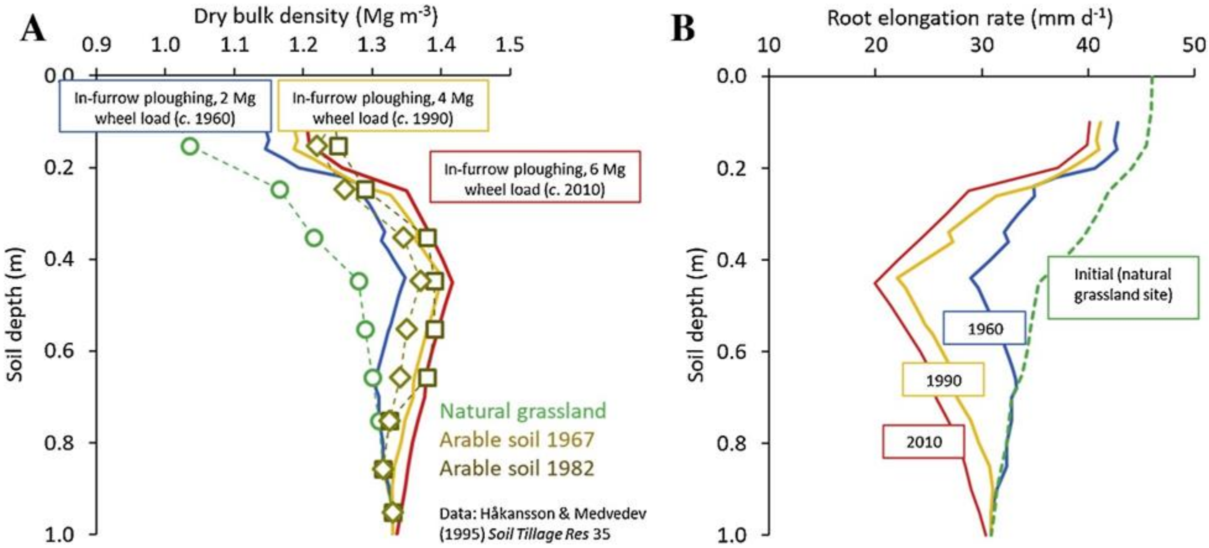

Fig. 1. **Change in bulk density in arable soil (A) (Mg·m^{-3}); root elongation rate (V) (mm·d^{-1}) (initial conditions – green; rhombuses - 1967; squares – 1982; under wheel load: 2 Mg (year 1960) – blue; 4 Mg (year 1990) – yellow and 6 Mg (year 2010) – red)**

The desire to increase the productivity and reduce the labor costs requires an increase in the power of energy resources, but at the same time, in order to realize the tractive potential of the tractor, they are forced to increase its weight or apply technical solutions to increase the coupling weight due to ballasting, a hydraulic or positional re-loader, which leads to an increase in soil compaction and its further degradation. There is a contradiction between the trends in the development of technology and the requirements of agricultural technology.

In addition to environmental damage, the problem has serious economic damage caused by a decrease in yields of up to 30% or more. This is evidenced by research data in more than 40 countries around the world. In the Russian Federation, the annual grain yield shortfall is 13-15 million tons [7], potatos – 10-12 million tons [9].

Materials and methods

The study carried out a correlation analysis of the dependences of the engine power (kW) and weight (t) of tractors and self-propelled machines according to the reference data of the automated reference system “Agricultural machinery” (www.agrobase.ru) [10]. The analysis of modern technologies of deep tillage is carried out according to the data of agrotechnical and energy assessment of machines that have been tested according to standard methods. During the test, the characteristics of the soil were determined: hardness (MPa), density (kg м m-3), humidity (%) for the regulated horizons (cm): 0-10, 10-20 and 20-30; components of the power balance of the machine and tractor unit: power spent on the technological process (kW), specific energy consumption (MJ·ha^{-1}), resistance (kN), fuel consumption (kg·h^{-1}). Before and after the energy assessment, the effective power of the tractor engine was determined. In the process of agrotechnical assessment, the quality indicators of the technological operation were determined: working depth (cm) and working width (cm), soil crumbling (%) based on the analysis of the aggregate composition. Reproducible experiments were carried out in 3-fold repetition in the forward and reverse course of the unit. The results of the experiments were processed by the standard method of statistical analysis.

Results and Discussions

Since the creation of self-propelled machines, the issue of optimal ratios of power, weight and operating speed remains relevant [10]. The potential performance of the machine-tractor unit depends on the engine power. The power of the most popular universal row-crop tractor of class 1.4 of the "Belarus" family increased from 20.0 kW (MTZ-2, 1956) to 59.6 kW (MTZ-920, 2000) 3 times; the mass of MTZ-920 reached 4100 kg (with the possibility of increasing to 7000 kg). Energy saturation has increased from 6.2 kW·t^{-1} (1956) to 19.7 kW t^{-1} (2000).

The operating weight of the 8 th class wheeled tractors reaches 29937 kg - Steiger 550, New Holland N9040 - 24490 kg, while the carrying capacity of the mounted system reaches 8000…9000 kg [9]. The dependence of the operating weight of class 8 wheeled tractors on power is shown in Fig. 2. Regression equation for the dependence of mass on power for tractors of the 8th traction class $y = 3.088 + 0.046 \cdot x$, the pair correlation coefficient $r_{xy} = 0.863$, the variance of adequacy $S^2ad = 2.12$.

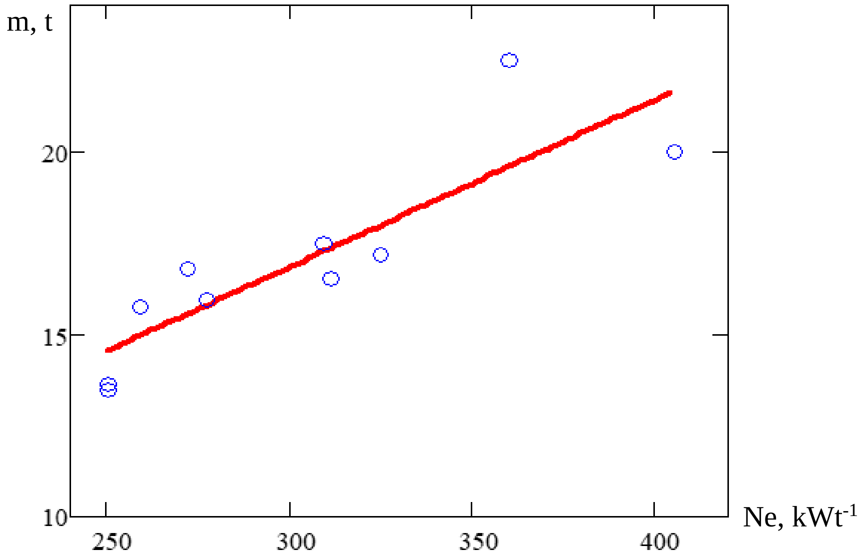

Fig. 2. **Dependence of the operating weight of class 8 wheeled tractors on power**

The engine power of self-propelled harvesters has increased 3.6 times over 30 years (SK-3, 1958, power 47.8 kW, weight 6040 kg; Don-1500, 1985, power 172.8 kW, weight 13440 kg). The power of modern combine harvesters has increased to 400…405 kW (New Holland CX 9090, weight 16700 kg, bunker volume – 12.5 m^3; John Deere S690, weight 21650 kg, bunker volume – 14.1 m^3) [9]. The total weight of the combine includes the weight of the combine with the header and the weight of the grain in the filled hopper. The dependence of the total mass of combine harvesters on power is shown in Fig. 3 and approximated by the equation $y = 9.502 + 0.059 \cdot x$, the pair correlation coefficient is $r_{xy} = 0.841$, the variance of adequacy $S^2ad = 0.331$.

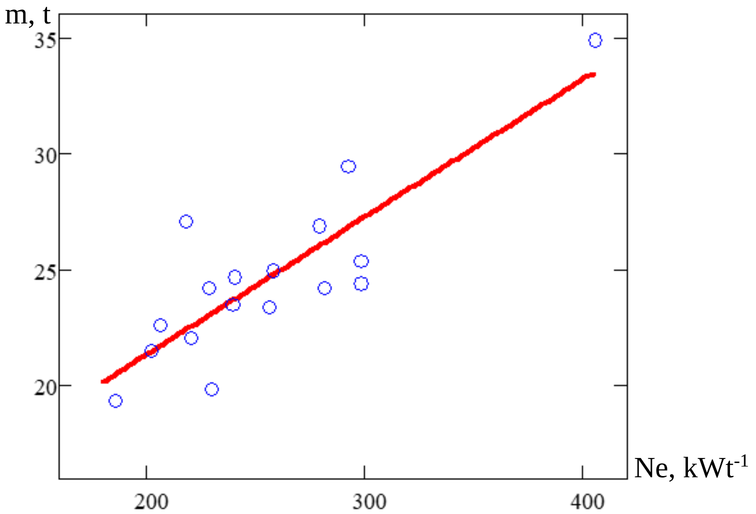

Fig. 3. **Dependence of the total weight of combine harvesters on power**

The compacting effect of class 1.4 and 3 tractors extends to a depth of 45-50 cm, class 4 – up to 50-70 cm, and class 5 to a depth of 1.0-1.2 m. The density increases to 1.35-1.45 g·cm^{-3}, the porosity decreases by 23-25%, the yield decreases from 20 to 40% [10].

Big X forage harvesters have the engine power of 720 kW. The dependence of weight on power for forage harvesters is shown in Fig. 4 and approximated by the equation $y = 8.552 + 0.00842 \cdot x$, the pair correlation coefficient r_{xy} = 0.925, the variance of adequacy $S^2 ad$ = 4.184.

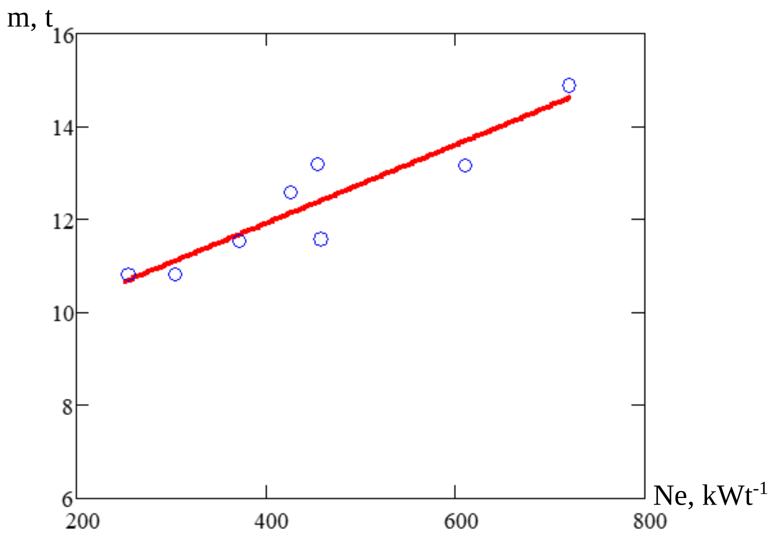

Fig. 4. **Weight versus power for forage harvesters**

Soil compaction in the lower horizons is an integral indicator and the use of new high-performance and heavy self-propelled equipment will continue and accelerate the degradation of the soil. In addition to technological machines, vehicles, and especially trucks that do not meet the requirements, make their contribution [6]. The use of paired wheels, rubber-reinforced tracks, and matching the width of the technological track allow reducing the specific pressure of the running systems on the soil and reducing the compaction area, but the large masses moved as dynamic systems remain as sources of anthropogenic negative impact on the soil.

Natural decompression processes are very slow, and the use of machines for deep processing requires a lot of energy. The table shows the results of tests of the KHTZ-17221 + PLN-(4 + 1)-35 arable unit (Altai MIS), the T150K + PCH-2,5 chisel processing unit (Kursk MIS) and the MTZ1221 + RVN-2 moisture-saving ripper (North Caucasus MIS) conducted in 2015.

Table 1

Test results of tillage aggregates (2015)

Indicator		**HTZ-17221 + PLN-(4 + 1)-40**	**T150K + PH-2.5**	**MTZ1221 + RVN-2**
1. Soil moisture content (%) on the horizon (cm)	0-10	14.6	13.0	17.2
	10-20	14.2	14.2	17.6
	20-30	9.1	15.6	20.0
	30-40	–	16.8	20.4
2. Soil hardness (MPa) on the horizon (cm)	0-10	1.60	1.20	0.98
	10-20	3.62	1.70	2.63
	20-30	7.24	1.90	3.32
	30-40	–	2.60	3.12
3. Working speed, m·s^{-1}		2.03	2.00	2.42
4. Average processing depth, cm		23.90	35.80	41.80
- coefficient of variation, %		8.24	2.54	3.60

Table 1 (continued)

Indicator	HTZ-17221 + PLN-(4 + 1)-40	T150K + PH-2.5	MTZ1221 + RVN-2
5. Soil crumbling, % (fraction size up to 50 mm)	74.4	95.0	55.6
6. Fuel consumption, kg·h^{-1}	30.0	30.2	20.0
7. Productivity for 1 hour of the main time, ha	1.34	1.80	1.74
8. Traction resistance, kN	37.9	38.1	20.7
9. Specific energy consumption of the machine, MJ·ha^{-1}	212.9	149.5	103.5

The analysis of the results of tillage machines shows the low technological efficiency of traditional plowing due to the high energy intensity of the process of 212.9 MJ·ha^{-1}, limited by the size of the arable horizon by the depth of processing and not high soil crumbling – 74.4% compared to chisel processing – 95.0%. Chisel processing allows to loosen a part of the “plow sole” to a depth of 35.8 cm, but requires 149.5 MJ of energy per 1 ha of the treated area.

The use of a moisture-saving ripper RVN-2 allows to increase the processing depth to 41.8 cm with a relatively low energy intensity – 103.5 MJ·ha^{-1}, but with a small degree of crumbling-55.6%. The search for technologies for deep soil loosening should be continued, but the methods for optimizing the parameters and operating modes of machine-tractor units at minimum operating costs [7] should take into account the costs of eliminating the consequences of soil degradation from the use of mechanized technologies implemented by high-performance energy-saturated units, so they need to be improved. To do this, we need a methodology for assessing the negative environmental consequences when using mobile machine-tractor units.

Conclusions

1. Increasing the power of tractors and self-propelled machines allows to increase productivity, but at the same time, further degradation of the soil continues due to its over-compaction. Modern trends in the development of self-propelled agricultural machinery contradict agrotechnical and environmental requirements. When modernizing or creating new models of machines, it is necessary to take into account the negative environmental consequences of their use in the feasibility study.
2. Regulatory and methodological documents on limiting the pressure on the soil of tractor propellers and self-propelled machines require processing.
3. To eliminate the negative consequences of soil over-compaction, it is necessary to reduce the machine load on the soil by using robotic machines with a smaller mass and implement measures to decompress the subsurface horizon.

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