Reducing the negative impact of undercarriage systems and agricultural machinery parts on soils

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Abstract. The article discusses the causes and consequences of excessive soil compaction. Ecological safety of the environment provides for the protection of land resources from potential negative technogenic and anthropogenic impacts. The accumulation of humus decreases due to the increasing compaction of soil. Soil compaction is a type of physical degradation. Soil degradation occurs as a result of excessive pressure. Soil compaction increases erosion. The aim of the study is to develop methods for the effective operation of mechanisms to prevent soil compaction. The negative effects of excessive soil compaction under arid conditions have been analysed. The interaction of working parts with soil should be considered as a process of deformation of a viscoelastic substance. Ways to reduce soil compaction are discussed. Perennial herbs reduce soil compaction. Deep tillage with a chisel reduces compaction by 21%. The maximum pressure of movable parts on soil at a humidity of 18.6-21.7% should not exceed 120-140 kPa. Soil compaction decreases porosity and air permeability. The optimum density of soil is 1.10-1.25 g/cm³, and the critical, not more than 1.35 g/cm³. Stresses decrease due to relaxation. Without treatment, soil density may decrease from 1.40-1.50 to 1.20-1.28 g/cm³. It is necessary to use wide tires and increase the contact patch. With the experimental tires, there is a large contact area (by 3.14%), lower maximum pressure of moving parts on soil (by 3.05%) and a decrease in the normal stress at a depth of 0.5 m (by 0.85%). In this case, the maximum stress does not exceed acceptable values.

1. Introduction

Ecological safety of the environment ensures protection of land resources from potential negative technogenic and anthropogenic impacts. The most important task is to ensure the reproduction of soil fertility, including accumulation of humus, which decreases due to over-compaction of soil. The existing low level of farming culture results in a decreased humus content, loss of soil structure, and further over-compaction of soil. Soil compaction is a type of physical degradation, leading to a decrease in porosity [1] and moisture permeability. Excessive soil compaction leads to accelerating dryness of the arable layer in spring, which is unacceptable in the conditions of a limited rainfall. Degradation is characterized by a change in soil properties as a result of excessive pressure arising...
from all types of land use destroying soil cover, deteriorating its physical condition and agro-technical indicators. At the same time, there is a deterioration of the water-air regime and conditions of soil biota leading to increased soil erosion [2-5].

The purpose of the present research is the development of methods for the efficient operation of machinery that would prevent soil compaction.

2. Materials and Methods

A monographic survey of the causes of physical soil degradation during the operation of machinery was carried out, negative effects were analysed and ways to reduce the over-compaction of soil identified.

The stress state of soil was considered as a result of the interaction of working parts of equipment with soil on the basis of the main principles of the theory of elasticity and on the basis of rheology. According to a universal rheological model and principals of share stress, the deformation is considered based on the analysis of viscoelastic and plastic properties of soil [6, 7]. The existing models [8] of the interaction of working parts with soil can be divided into three groups: soil as a solid body; soil as viscoelastic medium; and soil as a uniform incompressible flowing medium.

Studies have demonstrated that the interaction of working parts with soil in conditions of insufficient moisture should be considered as a process of deformation of a viscoelastic material. The relationships between stresses and deformations for viscoelastic materials are usually formulated using a crawl function, which determines the deformation of soil when a single step impact (stress) is applied, or using a relaxation function expressing a change in stress. The complex stress state of soil is defined by two independent functions that determine the behaviour of soil during shear stress [9, 10] and volumetric deformations. These functions correspond to the shear modulus and the volumetric modulus (deformation modulus) for ideally elastic materials. Studies have demonstrated that it is sufficient to consider the equation of the stress state of a soil layer only for volume deformations and use the Maxwell model. In this case, it is assumed that the tangential stresses do not exceed the limit, otherwise the soil will shift and a drag prism will be formed [11].

3. Results and discussion

Worldwide, damage from crop shortages in agriculture due to soil compaction is estimated at about $2 billion. In Sweden, the annual loss due to soil compaction is estimated at approximately 100 million crowns. In the eastern provinces of Canada, damage from soil compaction is 1.4 times greater than from erosion. Due to the excessive density of soil, the yield shortage of perennial grasses can reach 64%.

The degree of over-compaction created, for example, by moving aggregates, depends on the content of humus and physical clay in soil, which is explained by their colloidal properties. At the same time, resistance to forced over-compaction becomes evident when there is a sufficient amount of organic matter and moisture in soil. In the arid zone, the processes of humus mineralization prevail over the processes of its formation, therefore over-compaction has negative consequences for soil. Soil compaction can lead to physical degradation, which is a process of negative transformation of soil structure resulting in a decrease in the number of agriculturally valuable aggregates. Without treatment, a soil layer can no longer decompress to the compaction value of its natural state, but it can still decompress from 1.40-1.50 to 1.20-1.28 g/cm³ [12]. According to the standards of changes in the physical properties of chernozems, depending on the nature of anthropogenic impact, the range of values of the optimum density of the processed soil layer in the Rostov region is 1.10-1.25 g/cm³; and critical density, more than 1.35 g/cm³ with a humus content of 3.5-4.5%.

With existing cultivation technologies, different agricultural mechanisms pass through a field many times. Since the average pressure generated by crawler tractors reaches 60-80 kPa and by wheeled tractors, 85-165 kPa (maximum - 320-560 kPa due to uneven distribution of pressure on the supporting surfaces), the density of soil in the arable and subsoil horizons increases. It has been established that when a flat wedge moves at a depth of 110 mm, the pressure reaches 300-600 kPa, and about 800-1000
kPa on the ploughshare. Contact pressure on the surface of the working parts of a machine is often greater than that developed by the engines of tractors and agricultural machines, which leads to the formation of a plough sole and compacted soil lumps. The density of soil in clumps is 1.24 times higher than in the same layer before treatment, and the soil density at the bottom of a furrow is 1.5-2.0 times greater than before the passage of a machine. According to the accepted standards (GOST 26955), for soils containing 30-40% of physical clay, which include chernozem, the maximum pressure of tracked and wheeled vehicles at a humidity of 18.6-21.7% should not exceed 120-140 kPa.

Destruction of soil structure and compaction under the influence of agricultural machines lead to a decrease in both total and differential porosity. First of all, both the inter-aggregate moisture and air-conducting porosity, which mainly determines the water-holding capacity of soil, decrease. With an increase in soil density to 1.3-1.4 g/cm³, the content of water and air-conducting pores decreases 1.5-2.0 times; at a density of more than 1.5 g/cm³ pores almost disappear. As a result, the moisture and air permeability of soil deteriorates. Soil compaction leads to deterioration of its nutritional regime. A decrease in the absorption of phosphate fertilizers due to over-compaction has been observed.

When soil density changes from its optimal value by 0.1-0.3 g/cm³, yields decrease by 20-40%. An increase in soil density as a result of compaction of chernozem soils by 0.01 g/cm³ leads to a decrease in the yield of grain crops by 0.9 centner/ha. In the process of soil compaction, not only the total volume of pores decreases, but also the size of pores. This is especially important, as root hairs cannot grow if the soil pores are smaller than 10 microns in size. Pores less than 3 microns in size are no longer accessible to microorganisms.

Soil decompaction is also possible due to the process of self-decompaction. Perennial grasses have a positive effect on self-decompaction of soil, they increase soil fertility, contribute to a decrease in density, improve the macrostructure, aeration and water permeability.

The analysis showed that, under the influence of deep chiselling, the compaction of the processed soil layer decreases to 21%, the porosity increases to 10%, and the permeability of soil increases several times. The number of agriculturally valuable aggregates after chiselling of ordinary chernozem with a weak humus layer on loess-like clays to a depth of 34 cm increased from 75.0 (before processing) to 83.4% (after processing), which indicates an improvement in soil structure.

During tillage and other agricultural operations, it is necessary to choose wide tires and adjust the pressure, by increasing the contact patch. When rolling wheels, the energy is spent mainly on the deformation of the soil and tires, due to their viscoelastic properties. According to the research of an author [13], when the normal load on the moving parts of agricultural machines in the process of performing technological processes is reduced, the stresses in the soil at a depth of 0.5 m sharply decrease (by 50-70%). At the same time, the maximum pressure in the contact zone between tire and soil decreases by 11-20%.

When the process of interaction between workers and the soil is considered, a relationship was obtained that characterizes the distribution of contact stresses when a roller is moving along a viscoelastic base, taking into account the relaxation time of the layer $T$, as well as the modulus of soil elasticity $E$, parameters (radius $R$) and modes of operation (speed $V$):

$$\sigma(x) = \frac{E}{R} e^{-\frac{x}{VT}} (x + VT)$$

The area of stress distribution of the contact interaction of a working part with soil in dry conditions was determined (Figure 1).
Figure 1 demonstrates that the point of cessation of the contact between a roller and soil surface is located farther from the extremum than the point at which the contact starts, that is, the stress distribution graph is asymmetric. This is explained by the presence of stress relaxation in viscoelastic materials upon rolling contact.

When interacting with a working part, the deformation of soil occurs, stress $\sigma(x)$ arises, tending to restore the former shape of a soil layer due to the elastic properties (negative values of the argument in Figure 1). When the development of the deformation reaches its highest value, the soil exhibits the property of relaxation due to the viscosity, leading to a decrease in stresses, that is, there is an aftermath of loading (positive values of the argument in Figure 1). Relaxation of the soil layer proceeds more slowly than compression, which results in the asymmetry of the contact area of a working part with soil, represented by the area under the curve $f = \sigma(x)$ and limited by the x-axis, that is, the duration of the aftermath exceeds the loading duration.

Studies have been carried out on the compacting effect of experimental pneumatic tires on soil, which was estimated by the maximum pressure and normal stress at a depth of 0.5 m. The results are shown in the Table 1.

**Table 1. Compacting effect of pneumatic tires on soil.**

| Parameters                              | Serial 16.9R30 | Experimental 16.9-30DP | Change, % |
|----------------------------------------|----------------|------------------------|-----------|
| Contact area, m²                       | 0.159          | 0.164                  | 3.14      |
| Maximum pressure, kPa                  | 117.787        | 114.196                | -3.05     |
| Maximum normal stress at a depth of 0.5 m, kPa | 20.220         | 20.049                 | -0.85     |

Table 1 shows that when a tractor operates on experimental tires, a larger contour area of contact (by 3.14%), a lower maximum propulsion pressure (by 3.05%) and a decrease in the normal stress in the soil at a depth of 0.5 m (by 0.85%) are observed. In this case, the maximum pressure does not exceed the allowable values [14].

4. **Conclusions**

- When designing technical equipment it is necessary to take into account the allowable pressure of mechanisms on soil. It is necessary to choose wide tires and adjust the pressure, by increasing the contact patch.
- Perennial herbs have a positive effect on self-decompression of soil.
- Under the influence of deep chiselling, the compaction of the treated soil layer decreases to 21%.
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