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Theoretical Justification of the Forces Generated on the Cylinder Surface of a Double Row Cat

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Abstract: The quality of tillage directly depends on the agricultural machinery used. Thus, the development of new effective agricultural machinery makes it possible to increase the productivity of cultivated crops. "An important technological operation of the soil cultivation process is rolling. With high-quality implementation of this technological operation, the yield of grown crops increases. This technological operation is used in all climatic zones for all types of soil to ensure optimal soil density and structure according to agricultural requirements." Rolling is carried out using soil-cultivating rollers and special tools, but the known designs do not fully meet agrotechnical requirements.

Keywords: cultivation, agricultural machines, soil, cylinder, friction, interaction, lump, equation.

The productivity of cultivated crops depends on a large number of factors, for example, climatic conditions, soil type, seed quality, as well as technological operations performed, etc. One of the most important factors in obtaining high yields of agricultural products is the use of high-quality seed material. The main sowing qualities of seeds include: purity, germination, germination energy, humidity, weight of 1000 seeds, infestation with diseases and pests. To obtain a good harvest, it is necessary that the above seed indicators meet the requirements of the relevant standards.

An equally important role when sowing agricultural crops is played by the depth of seed placement, which is also set by agrotechnical requirements.

For surface tillage of soil in modern agriculture, the following technologies are widely used: cultivation, harrowing, peeling, milling, rolling. The list of agrotechnical requirements for pre-sowing treatment is as follows:

- pre-sowing tillage should be carried out at a constant depth. The deviation from the specified depth should not be more than 10 mm;
- it is necessary to ensure a loose state and fine-lumpy structure of the surface layer,
- it is necessary to ensure the same thickness of the loosened layer.

The surface topography should not affect its thickness. If the loosened soil layer has different thicknesses, it will be impossible to ensure the same planting depth, as a result of which the plants will develop unevenly; - it is necessary to ensure that there are no blocks, furrows, or ridges on the field surface. If these are not eliminated, this will cause drying out of the soil, increase the surface area for moisture evaporation, and negatively affect the quality of sowing. Cultivation is one of the most common methods of surface tillage. Cultivation is used for pre-sowing soil preparation, application of fertilizers, herbicides, and for loosening the soil in the rows and tree trunks of the garden.

This operation is carried out by agricultural machines called cultivators. Cultivators loosen the soil to a depth of 60 mm to 120 mm.

- During the cultivation process, it is necessary to ensure a number of agrotechnical requirements: - pruning of weeds must be complete;
- these procedures must be carried out within the prescribed time frame, to the prescribed depth (to the depth of seed placement or to a depth of up to 120 mm);
- turning out the bottom wet layer of soil should be avoided;
- it is necessary to ensure a flat surface of the field and the bottom of the furrow; the ridges in the upper loosened layer should not be more than 40 mm in height;
- it is necessary to eliminate uneven tillage depths exceeding 10 mm, to ensure uniform loosening depth and a fine-lumpy structure of the top soil layer.

Based on the analysis of the designs of soil-cultivating rollers, in order to improve the efficiency and intensity of destruction of soil lumps and increase the uniformity of soil density after surface treatment with a soil-cultivating roller, an innovative eccentric roller was created. An eccentric roller combines the advantages of the different effects of its working parts on the same areas of soil.

For normal operation and to meet the requirements for the quality of soil treatment, the proposed roller must destroy soil lumps, creating a mulch layer on the soil surface and compact the soil in the seed placement area to the value specified by agricultural requirements. When a roller acts on a large lump of soil, it can be crushed into smaller fractions or pressed into the surface layers of the soil without destruction. The implementation of the processes of crumbling or pressing a soil lump depends on many different factors: on the amount of forces applied to the soil lump by the roller, on the properties of the soil, as well as on the design parameters of the roller and its operating modes. “Crumbling of a soil lump under the influence of a soil-cultivating roller can only occur when the stress $\sigma_к$, occurring due to the pressure of the outer surface of the roller, exceeds the temporary resistance to compressive deformation of the soil σн, which is higher than the permissible compressive stress that destroys soil lumps σ_{com}»

$$\sigma_к > \sigma_{поч} > \sigma_{ком}. \qquad (1)$$

Often the above inequality is not satisfied due to the fact that overdried lumps have increased hardness. Under this condition, the permissible compressive stress that destroys soil lumps σcom increases significantly, which often leads to the indentation of large lumps. As a result of indentation, the soil becomes overconsolidated, which critically affects the yield of cultivated crops. For high-quality crumbling of soil clods with a soil-cultivating roller, it is necessary to determine the condition for pinching the soil lump between the outer surface of the hollow cylinder of the soil-cultivating eccentric roller and the soil surface. The pinching condition depends on the diameter of the hollow cylinder.

When a hollow cylinder acts on a lump of soil, a force arises $F_ц$, which characterizes the effect of a hollow cylinder on a soil lump and the impact of soil $F_п$ on the soil lump (Figure 1). When we expand these two forces, we get their normal components $F_{ц.н}$ and $F_{н.п}$ and friction forces $F_{ц.т}$ and $F_{п.т}$. If, when adding the projections of two friction forces on the x-axis, the resulting sum will be greater than the value of the sum of the forces that are projected on the x-axis and aimed at pushing the soil lump out from under the hollow cylinder of the soil-cultivating roller, then in this case the soil lump will remain undestroyed, as a result of which it will be pressed in into the top layer of soil. But if, on the contrary, the sum of forces aimed at pushing out the soil lump and projected onto the x-axis turns out to be greater than the sum of the friction forces projected on the same axis, then the soil lump, without collapsing, will be pushed forward of the hollow cylinder of the soil-cultivating roller. As a result of pushing out the soil clod, a soil roller will be formed in front of the hollow cylinder of the soil cultivating roller.

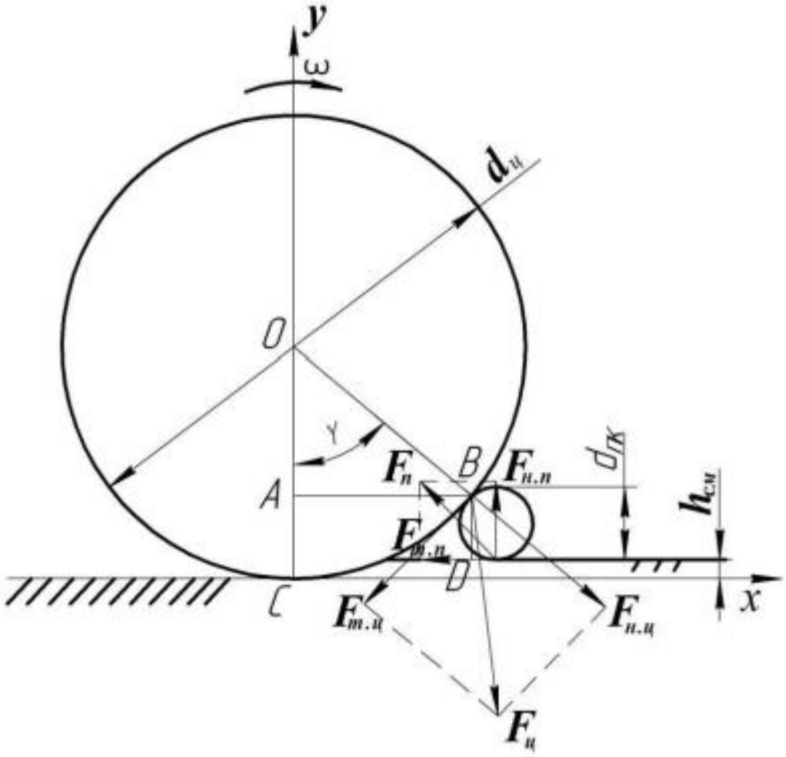

Figure 1 – Interaction of a hollow cylinder with a soil lump

Next, we should consider the initial conditions for the interaction of the proposed soil-cultivating eccentric roller with the soil lump. To simplify the calculation, we assume that the tillage eccentric roller rolls along the soil surface without slipping, the soil surface does not deform, and the soil lump lying on its surface has the shape of a ball, the maximum diameter d_{Pmax} of which does not exceed the maximum specified by agrotechnological requirements. The pinching condition is determined from the equations of projections of the sum of all forces on the x and y axes, except for the weight of the soil lump, which we neglect:

$$\Sigma F_{kx} = F_{\text{н.ц}} \sin\gamma - F_{\text{т.ц}} \cos\gamma - F_{\text{т.п}} = 0; \quad (2)$$

$$\Sigma F_{ky} = F_{\text{н.п}} - F_{\text{н.ц}} \cos\gamma - F_{\text{т.ц}} \sin\gamma = 0, \quad (3)$$

where $F_{\text{ц.н}}$ – normal component of the force of action of a hollow cylinder on a soil lump, N;

$F_{\text{ц.т}}$ – friction force of a hollow cylinder on a soil lump, N;

$F_{\text{п.т}}$ – friction force of the soil lump on the soil surface, N;

$F_{\text{н.п}}$ – normal component of the impact of the soil surface on the soil lump N;

– pinch angle of the rim of a hollow cylinder with a soil lump, deg.

Let us express the friction forces of the roller and the soil through the well-known formula:

$$F_{\text{т.ц}} = \mu_1 F_{\text{н.ц}} \quad (4)$$

$$F_{т.п} = \mu_2 F_{н.п} \quad (5)$$

where μ_1, μ_2 – friction coefficients of the hollow cylinder of the roller on the soil lump and the soil lump on the soil surface, respectively.

Substituting expressions (4) and (5) into equations (2) and (3), we obtain the following:

$$\Sigma F_{kx} = F_{н.ц} \sin\gamma - \mu_1 F_{н.ц} \cos\gamma - \mu_2 F_{н.п} = 0; \quad (6)$$

$$\Sigma F_{ky} = F_{н.п} - F_{н.ц} \cos\gamma - \mu_1 F_{н.ц} \sin\gamma = 0. \quad (7)$$

From the resulting equation (7) we express the force that characterizes the interaction of the soil lump with the soil surface:

$$F_{н.п} = F_{н.ц} \cos\gamma + \mu_1 F_{н.ц} \sin\gamma. \quad (8)$$

We substitute the resulting equation (8) into equation (6):

$$\Sigma F_{kx} = F_{н.ц} \sin\gamma - \mu_1 F_{н.ц} \cos\gamma - \mu_2 F_{н.ц} \cos\gamma - \mu_1 \mu_2 F_{н.ц} \sin\gamma = 0. \quad (9)$$

Mathematically transforming equation (9), we obtain:

$$(1 - \mu_1 \mu_2) \sin\gamma = (\mu_1 + \mu_2) \cos\gamma. \quad (10)$$

Dividing both sides of equation (10) by $\cos\gamma$, we get:

$$\mathrm{tg}\,\gamma = (\mu_1 + \mu_2)/(1 - \mu_1 \mu_2). \quad (12)$$

Thus, for reliable pinching of a lump of soil and the rim of a hollow cylinder, it is necessary that

$$\mathrm{tg}\,\gamma \geq (\mu_1 + \mu_2)/(1 - \mu_1 \mu_2).$$

It follows that reliable pinching of the soil lump by the eccentric roller occurs if the angle of contact of the hollow cylinder of the eccentric roller with the soil lump:

$$\gamma \geq arctg[(\mu_1 + \mu_2)/(1 - \mu_1 \mu_2)]. \quad (13)$$

Hollow cylinder diameter $d_ц$ can be determined based on the relationship connecting the thickness of the layer deformed by a hollow cylinder h cm, as well as the diameter of the soil lump $d_{ПК\ max}$ and optimal pinch angle.

The analysis showed that with an increase in the thickness of the deformable soil layer and the radius of the soil lump, the pinch angle increases approximately in the same way as the radius of the hollow cylinder. However, as the radius of the hollow cylinder increases, the change in the pinch angle becomes insignificant.

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