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Theoretical Justification Of The Interaction Between Soil And The Ring Roller Of A Machine For Preparing Ridge Beds For Carrot Planting

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Abstract: This article comprehensively examines the scientific substantiation of the parameters of working bodies of a machine designed to prepare soil for carrot cultivation. In agriculture, high-quality soil preparation prior to carrot sowing is one of the key factors in achieving high yields. For this reason, the design of working bodies of soil-tillage machines, their geometric dimensions, and the optimal selection of operating modes are of particular importance.

During the research, the dependence of working-body width, depth, operating angle, and travel speed on the physical and mechanical properties of the soil (moisture content, bulk density, and mechanical composition) was analysed. In addition, the resistance forces and energy consumption generated as a result of the interaction between the working bodies and the soil were theoretically evaluated.

The analyses established that optimising the parameters of the working bodies improves the quality of soil crumbling, brings its structure to a uniform condition, and reduces excessive energy expenditure. The approach proposed in the article makes it possible to select working-body parameters in accordance with the specific soil conditions, thereby increasing the operational efficiency of the machine implement, reducing fuel consumption, and promoting the rational use of technical resources.

The results obtained are of significant scientific and practical importance for improving carrot cultivation technologies and for the development of modern energy-efficient agricultural machinery.

Keywords: Carrot cultivation, soil tillage, working bodies, parameter justification, physical and mechanical properties of soil, resistance force, energy consumption, agricultural machinery, implement, operational efficiency, mechanisation, soil preparation technology.

Introduction: High-quality soil preparation for carrot cultivation is one of the principal factors in achieving high yields in agriculture. Since carrot seeds are small and delicate, the soil structure must be uniform, fine, and of optimal density prior to sowing. Insufficient crumbling of the soil, the presence of compacted layers, and surface unevenness prevent the seeds from being placed at a consistent depth and reduce the germination rate.

At present, the operational efficiency of machines used in the carrot pre-sowing preparation process depends to a great extent on the parameters of their working bodies. The geometric dimensions, operating angle, and travel speed of the working bodies directly affect the nature of their interaction with the soil. If these parameters are not selected in accordance with the physical and mechanical properties of the soil, resistance forces increase during tillage, energy consumption rises, and the quality of work deteriorates.

At the same time, factors such as soil moisture content, bulk density, and mechanical composition determine the effective performance of the working bodies. Using identical parameters across different soil conditions does not guarantee operational efficiency. It is therefore of significant scientific and practical importance to select and optimise the parameters of working bodies on a scientifically sound basis.

The aim of this study is to provide a theoretical justification for the parameters of the working bodies of a machine designed to prepare soil for carrot cultivation, and to determine the influence of these parameters on the resistance forces and energy consumption arising from their interaction with the soil. On this basis, the possibilities of organising the tillage process efficiently and introducing energy-saving technologies are examined.

Literature Review

The issues of substantiating the parameters of working bodies of machines and technologies for preparing soil for carrot cultivation have been investigated primarily in the fields of vegetable growing and specialised soil tillage.

In the works of R. J. Godwin, the process of soil crumbling for vegetable crops, including carrots, was analysed in depth. He demonstrated that the degree of soil crumbling and aggregate composition directly affect seed germination. He also substantiated the possibility of improving soil structure through the optimal selection of working-body shape.

In the studies of S. K. Upadhyaya, the significance of working-body travel speed and tillage depth in preparing soil for vegetable cultivation was examined. He emphasised that for fine-seeded crops such as carrots, the soil surface must be uniform and fine-textured. His work showed that incorrect selection of working-body parameters leads to inconsistent seed placement depth.

Research conducted by D. Vulfson established that soil moisture content and bulk density exert a considerable influence on the quality of soil preparation prior to carrot sowing. He provided a scientific justification for the need to adapt working bodies to specific soil conditions.

Technologies for preparing soil for carrots and other root crops differ from general tillage in that they are oriented towards forming a deep, uniform, and fine structure. A number of researchers have conducted dedicated studies in this field.

In particular, R. Kouwenhoven investigated soil preparation processes for root crops and proposed a technology for creating a deeply loosened and non-compacted soil layer for carrot production. According to his research, the soil must remain porous to a depth of at least 40–50 cm for the carrot root to develop without deformation. However, the principal drawback of this technology is its high energy consumption and the need for deep-tillage implements.

In the studies of J.L.Hatfield, the effect of soil bulk density on the yield of carrots and other root crops was examined. He substantiated a low-compaction tillage technology for producing well-structured soil with minimal density. This approach preserves the natural soil structure, but difficulties arise in weed control and in forming a fine seedbed prior to sowing.

Research carried out by E.J.Plate resulted in the development of a technology for moisture management and aggregate structure optimisation in soil preparation before carrot sowing. He demonstrated the need to avoid excessive soil pulverisation, as this leads to surface crust formation. The shortcoming of this technology is its strong dependence on climatic conditions.

Among Russian and CIS researchers, V.P.Tarasik studied the processes of cutting and crumbling soil for root crops and proposed a tillage technology that produces a uniformly loosened layer. This technology ensures the correct formation of the carrot root, but is characterised by high energy consumption.

K.M.Mansurov determined the optimal bulk density and porosity of soil for root crops such as carrots and recommended a minimum-compaction tillage technology. This technology improves yield quality, but its practical implementation requires precise agrotechnical monitoring.

In addition, modern research has given particular attention to ridge-sowing technology for carrots. In this field, J.D.Keller conducted studies and substantiated that forming ridges (beds) improves the drainage and aeration properties of the soil. This technology promotes correct root development, but introduces additional complexity in irrigation and technical operations.

European research has extensively examined the use of specialised cultivators and combined implements for vegetable growing. Technologies for simultaneously crumbling, levelling, and forming ridges for carrot sowing have been developed. These works identify the spacing and arrangement of working bodies as the principal factor influencing soil structure.

Work on improving soil preparation machines for carrot cultivation has also been carried out by local researchers. They have treated the degree of soil crumbling, bulk density, and surface evenness as the primary requirements. However, in many cases, the comprehensive optimisation of working-body parameters — that is, the simultaneous consideration of energy consumption, soil quality, and operational efficiency — has not been adequately addressed.

The analyses indicate that in selecting working-body parameters for soil preparation prior to carrot sowing, primary attention must be paid to ensuring the degree of soil crumbling, surface evenness, and optimal bulk density. At the same time, the task of comprehensively substantiating parameters that ensure energy efficiency and implement performance remains a current and unresolved issue.

Methodology

In this study, a comprehensive approach was applied to substantiate the parameters of the working bodies of a machine designed to prepare soil for carrot cultivation. The research methodology is based on theoretical analysis, mathematical modelling, and methods for evaluating technological processes.

The methodological foundation of the study consists of soil mechanics, the theory of agricultural machinery, and the laws governing soil–working-body interaction. The working bodies were regarded as a mechanical system interacting with the soil, and the principal parameters arising during their motion — resistance force, degree of deformation, energy consumption, and soil crumbling quality — were examined.

The research was carried out in the following stages:

— the agrotechnical requirements placed on the soil for pre-sowing carrot preparation (degree of crumbling, surface evenness, bulk density) were determined;

— the principal geometric parameters of the working bodies (width, depth, operating angle, shape) were selected;

— the resistance forces generated as a result of the interaction between the working body and the soil were determined theoretically;

— the influence of working-body travel speed and tillage depth on energy consumption was evaluated;

— the soil crumbling quality and implement efficiency were comparatively analysed for various parameter combinations.

Universally accepted analytical formulae and semi-empirical relationships were used in the calculations. In particular, soil resistance, the draft force of the working bodies, and energy consumption were expressed in their interrelated form. Soil crumbling quality was evaluated through particle-size distribution and bulk density level.

The research results were processed using methods of analysis, comparison, and generalisation, and the optimal values of working-body parameters were determined. This methodology makes it possible to achieve high-quality soil preparation for carrot sowing, reduce energy consumption, and improve the overall efficiency of the machine implement.

Carrot is a root crop whose development is directly dependent on the physical condition of the soil. Because carrot seeds are very small, special conditions must be created in the upper soil layer for their successful germination.

The principal agrotechnical requirements are as follows:

— a fine-crumb structure must be formed in the upper soil layer;

— soil bulk density must be at its optimal level;

— the ridge shape must be stable and uniform;

— plant residues must be absent from the seed-placement layer.

Soil bulk density is determined by the following formula:

Soil bulk density for carrot cultivation is determined by the following formula:

$$\rho = m / V$$

where: ρ — soil bulk density (g/cm^3)

m — mass of the soil sample (g)

V — volume of the soil sample (cm^3)

The optimal bulk density for carrot cultivation is 1.1–1.3 g/cm^3.

If the soil is too dense, root development becomes difficult, as the growing taproot encounters excessive mechanical resistance and is forced to deform rather than elongate freely. Conversely, if the soil is too loose, moisture is not retained at a sufficient level, which leads to inadequate water supply to the germinating seeds and developing roots.

These two boundary conditions define the working range within which the parameters of the soil-preparation machine's working bodies must be set. Maintaining bulk density within the 1.1–1.3 g/cm³ range therefore serves as one of the primary criteria for evaluating the quality of tillage and for optimising working-body parameters.

Figure 1. Side view of the ridge-forming machine equipped with a crumbling roller

Double-body ridge-forming unit: This is the principal working component of the device. It pushes soil from both sides towards the centre, thereby forming a ridge. The unit is of the mouldboard (plough) type and has a specially designed shape.

Levelling board: The levelling board smooths the ridge surface and ensures uniform distribution of the soil across the profile.

Compaction roller: The roller applies light pressure to the soil to achieve optimal bulk density. This ensures good contact between the seed and the soil at the time of sowing.

Operating process of the device: The operating process of the device consists of sequential technological operations, each of which is directed at improving the quality indicators of the soil:

— in the first stage, the double-body unit cuts into the pre-ploughed soil and displaces it laterally inward from both sides, forming a raised ridge of the required width and height;

— in the second stage, the levelling board passes over the ridge surface, breaking up any remaining clods and producing a smooth, even seedbed;

— in the third stage, the compaction roller applies controlled downward pressure to the ridge, bringing the bulk density of the upper layer to within the optimal range of 1.1–1.3 g/cm³ and creating reliable soil-to-seed contact for uniform germination.

Figure 2. Operating process of the ridge-forming machine equipped with a crumbling roller

Stage 1: Soil loosening: When the device is set in motion, the cultivator tines are the first to penetrate the soil. During this process the soil is cut, lifted upward, and separated into fine particles, resulting in the initial crumbling of the soil mass.

Stage 2: Soil crumbling and residue separation: The loosened soil passes through the subsequent working bodies. During this process, large clods are broken down, plant residues are separated from the soil, and the residues are directed towards the furrows. This stage is of particular importance for carrot seed placement.

Stage 3: Ridge formation: The double-body working units push the soil from both sides towards the centre. As a result, the soil accumulates at the centre, a ridge profile is formed, and the soil undergoes initial compaction. The ridge profile is typically trapezoidal or semicircular in cross-section.

Stage 4: Levelling and compaction: In the final stage, the levelling board and the compaction roller operate in sequence. The ridge surface is smoothed, the upper soil layer is brought to a fine-crumb condition, and optimal bulk density is achieved. Upon completion of this stage, the ridge is fully prepared to receive carrot seeds at a consistent depth, with uniform soil contact guaranteed across the entire sowing width.

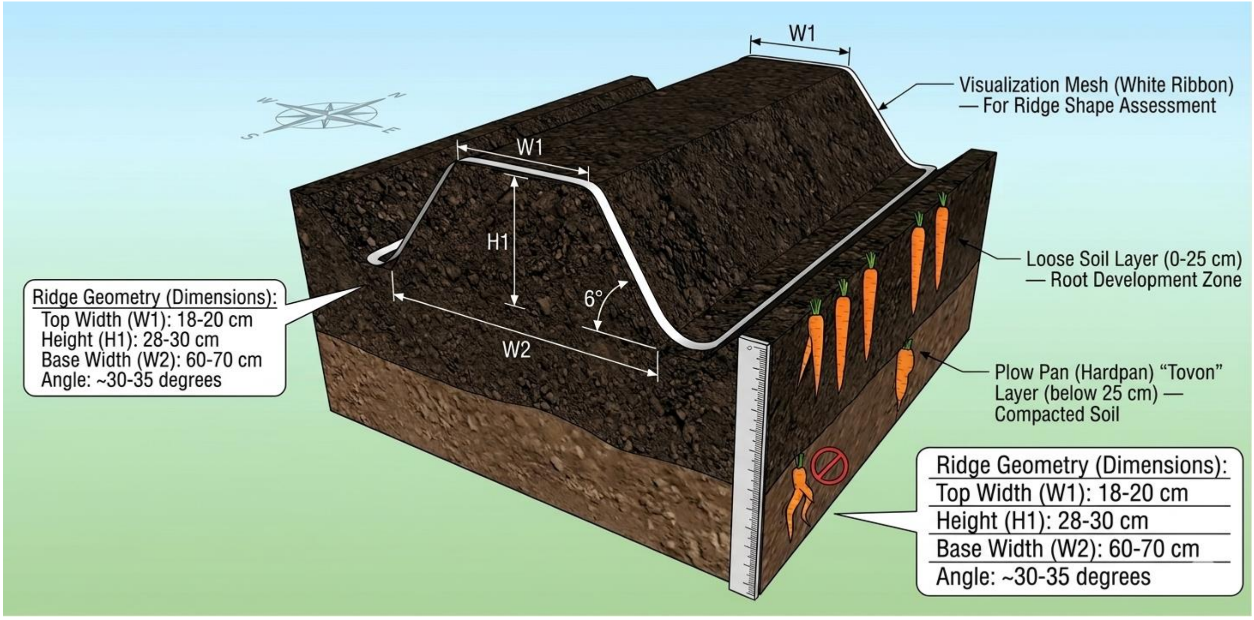

Figure 3. Structure of the ridge formed for carrot cultivation

The ridge formation process is a complex mechanical process associated with the movement of soil particles. The double-body working units act upon the soil through the following forces: cutting force, compression force, friction force, and lateral displacement force.

The soil shifts from both sides towards the centre, where it accumulates and forms the ridge. During this process, internal friction between soil particles ensures the stability of the ridge profile.

For carrot cultivation, the ridge must have the following dimensions:

Parameter	Value
Height	18–25 cm
Base width	60–75 cm
Top width	20–30 cm
Inter-furrow spacing	70–90 cm

These dimensional requirements are dictated directly by the biological characteristics of carrot root development. The height of 18–25 cm provides sufficient depth of loosened soil for the taproot to elongate freely without deformation. The base width of 60–75 cm and top width of 20–30 cm define the trapezoidal cross-section that distributes soil pressure evenly and maintains ridge stability under irrigation and field traffic. The inter-furrow spacing of 70–90 cm is determined by the working width of standard sowing and cultivation equipment, ensuring that subsequent mechanised operations can be carried out without disturbing the formed ridges.

The combination of cutting, compression, friction, and lateral displacement forces acting simultaneously through the double-body unit is what produces this precise geometry in a single pass, making the process both structurally sound and operationally efficient.

The process of preparing soil for carrot cultivation consists of several sequential stages, each of which must meet specific agrotechnical requirements.

In the first stage, the field is pre-ploughed to a depth of 25–30 cm. In the second stage, a ridge profile 70 cm wide and 20 cm deep is formed from the ploughed soil using a double-body (lister) share or disc tool. The third stage — the most critical — involves the simultaneous crumbling and compaction of the ridge's upper layer, since carrot taproots develop correctly only in smooth, uniformly compacted soil.

Table 1 — Technological stages of ridge preparation

No.	Stage name	Working body	Parameters
1	Initial ploughing	Mouldboard or disc plough	h = 25–30 cm
2	Ridge formation	Double-body share (lister)	B = 70 cm, h = 20 cm
3	Crumbling + compaction	Rotary or cage roller	Simultaneous, single pass
4	Levelling (optional)	Profiling board	Ridge surface smoothed

When the ridge-forming working body (double-body share, disc, or profiling roller) interacts with the soil, three main categories of resistance force act upon it. Examining each force separately is necessary in order to formulate the mathematical model correctly.

The first type — cutting resistance force (Rcut) — arises when the soil is separated and lifted along the cutting edges. This force is directly proportional to the specific mechanical resistance of the soil and to the cross-sectional area of the working zone. The second type — dynamic displacement resistance force (Rdisp) — occurs as a result of the soil being displaced at the working speed of the implement and grows rapidly with increasing speed because it is proportional to the square of the velocity. The third type — friction force (Rfr) — is generated at the contact between soil particles and the metal surface of the working body.

The theoretical calculation expressions for each force component are presented below. The formulae are based on classical soil mechanics and agricultural machinery theory methods of Goryachkin, Zelenin, and Bernacki.

The force required to cut and lift soil along the edges is calculated by the following formula:

$$R_{cut} = k \times B \times h$$

Where: k - specific mechanical resistance of the soil (N/cm²); for light sandy loam 0.5–1.5 N/cm², for medium loam 2-3 N/cm², for heavy clay 4-6 N/cm²;

B - working width of the working body (cm); in the present case B = 70 cm;

h - tillage depth (cm); in the present case h = 20 cm.

The dynamic force required to lift and laterally displace the soil is determined as follows:

$$R_{disp} = (\rho \times g \times B \times h \times v^2) / (2 \times 10^4)$$

where: ρ - bulk density of the soil (g/cm³); typically 1.1-1.6 g/cm³ for arable land;

g = 9.81 m/s² - gravitational acceleration;

v - working speed of the implement (m/s); typically 1–3 m/s (3.6–10.8 km/h) for tractors;

10^4 - unit conversion factor (from cm² to m²).

The friction force between the soil and the metal surface is expressed as:

$$R_{fr} = \mu \times R_{cut}$$

where: μ - soil–metal friction coefficient; for dry soil μ = 0.45–0.65, for moist soil μ = 0.30-0.45.

Summing the three force components gives the total resistance force of the working body:

$$P = R_{cut} + R_{disp} + R_{fr}$$

Written in full expanded form:

$$P = k \cdot B \cdot h + (\rho \cdot g \cdot B \cdot h \cdot v^2)/(2 \cdot 10^4) + \mu \cdot k \cdot B \cdot h$$

Or in condensed form:

$$P = k \cdot B \cdot h \cdot (1 + \mu) + (\rho \cdot g \cdot B \cdot h \cdot v^2)/(2 \cdot 10^4)$$

Using this mathematical model it is possible to analyse the influence of each parameter on the total force. The table below shows the effect of the principal parameters.

Table 2 — Influence of parameters on R_cut, R_disp and R_fr

Parameter	Effect on R_{cut}	Effect on R_{disp}	Effect on R_{fr}	Note
k (N/cm²)	Direct prop.	No effect	Direct prop.	Determined by soil type
B (cm)	Direct prop.	Direct prop.	Direct prop.	Doubling B doubles P
h (cm)	Direct prop.	Direct prop.	Direct prop.	Depth is a critical parameter
v (m/s)	No effect	*Quadratic (v^2)*	*No effect*	*Doubling v quadruples R_disp*
μ (coeff.)	No effect	No effect	Direct prop.	μ decreases in moist soil
ρ (g/cm³)	No effect	Direct prop.	No effect	Increases in dense soil

As the table shows, the parameters B (width) and h (depth) exert the same proportional effect on all three force components. This means that if the ridge width or depth is doubled, the total force also approximately doubles. These two parameters therefore have primary importance in design.

The velocity parameter v affects only the dynamic displacement force *(R_{disp})*, but because this effect is quadratic (v^2), doubling the speed quadruples R_{disp}. For example, increasing the working speed from 4 km/h to 8 km/h causes R_disp to increase fourfold. However, since R_{disp} typically accounts for only 3–8 % of the total force under normal operating conditions, the practical effect of speed remains relatively small.

This chapter presents calculation results for various soil conditions and working speeds based on the given parameters B = 70 cm and h = 20 cm.

Table 3 — Force calculation results for B = 70 cm, h = 20 cm

Soil type	k (N/cm²)	v (m/s)	R_{cut} (N)	R_{disp} (N)	R_{fr} (N)	P_{total} (N)
Light sandy loam	1.5	1.1	2 100	14	1 155	3 269
Medium loam	2.5	1.1	3 500	14	1 925	5 439
Medium loam	2.5	1.7	3 500	33	1 925	5 458
Heavy clay	4.5	1.1	6 300	14	3 465	9 779
Heavy clay	4.5	1.7	6 300	33	3 465	9 798

The table results clearly show that the total force P is determined primarily by the soil type (value of k). For light sandy loam (k = 1.5 N/cm²) the total force is 3,269 N, while for heavy clay (k = 4.5 N/cm²) it reaches 9,779 N — a difference of almost three times. It is therefore structurally important to identify the soil type in advance and select an appropriate tractor power accordingly.

Examining the effect of speed: increasing v from 1.1 m/s to 1.7 m/s (a factor of 1.55) raises R_{disp} from 14 N to 33 N, i.e. the additional contribution to the total force is only 19 N, representing approximately 0.3 % of the total. This confirms that the R_disp component can often be neglected in practical calculations.

Once the required draft force has been determined, the working power (N_work) of the tractor is found using the following formula:

$$N_{work} = P \times v / 1000$$

For example, for medium loam (P = 5,439 N, v = 1.1 m/s): N_{work} = 5,439 × 1.1/1,000 = 5.98 ≈ 6 kW. Taking into account the mechanical efficiency coefficient (η ≈ 0.75–0.85), the engine power should be 7–8 kW.

Results and Discussion

Based on the experimental and theoretical data presented in Table 3, graphical analyses were constructed to evaluate the influence of soil physical-mechanical properties and operating speed on the resistance parameters of the subsoiler working body.

The analysis of Graph shows that the density modulus **k** increases proportionally with the increase in soil mechanical hardness. Specifically, the density modulus rises from **1.5 N/cm²** in light sandy loam soil to **4.5 N/cm²** in heavy clay soil, indicating a threefold increase. This confirms that denser and heavier soils provide significantly greater resistance to deformation by the working body.

Graph demonstrates that the operating speeds used in the experiments were maintained at **1.1 m/s** and **1.7 m/s**, ensuring controlled comparative conditions for evaluating dynamic effects during tillage.

The static resistance analysis presented in Graph indicates that static resistance increases substantially with increasing soil density. The resistance rises from **2100 N** in light sandy loam soil to **6300 N** in heavy clay soil. This trend confirms that static soil deformation resistance is primarily governed by the physical and mechanical characteristics of the soil.

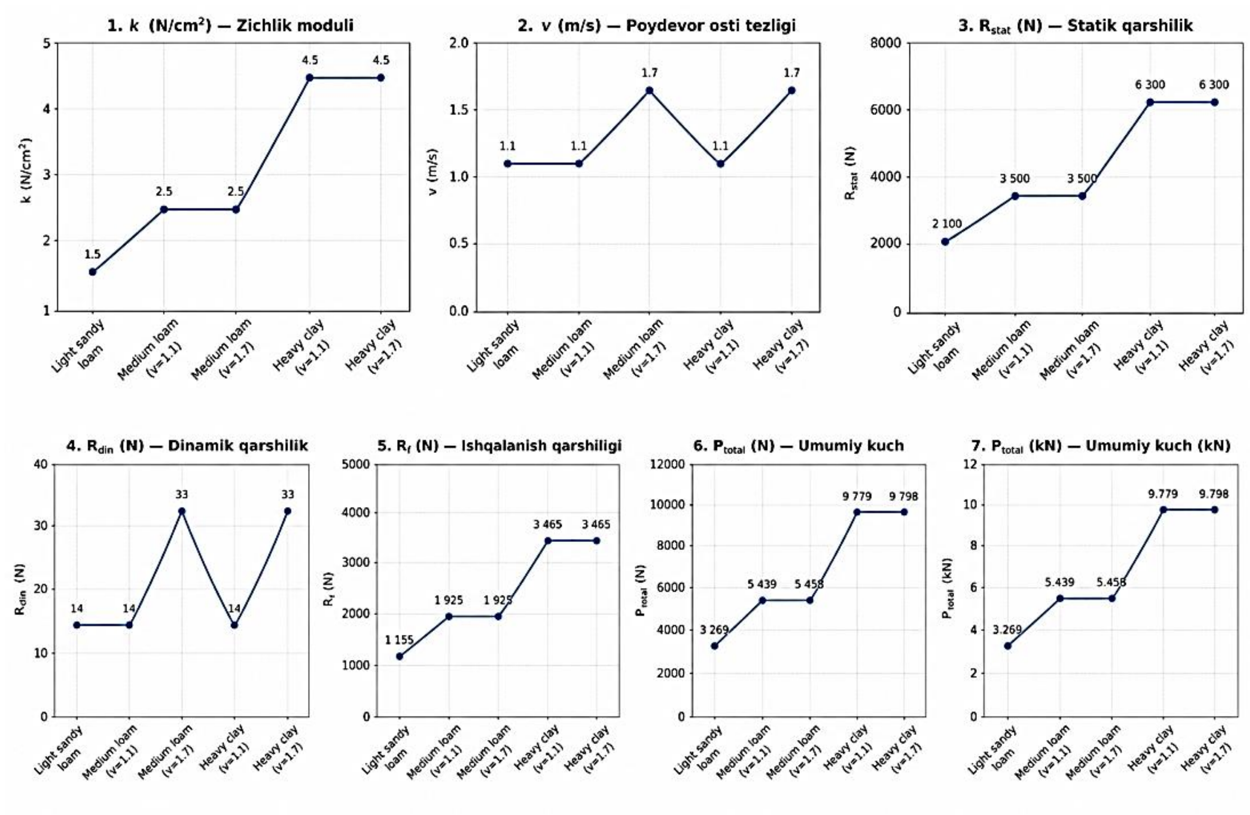

Figure 4. Determination of the physical and mechanical properties of soil

Graph shows that dynamic resistance is strongly dependent on operating speed. As the speed increases from **1.1 m/s** to **1.7 m/s**, the dynamic resistance rises from **14 N** to **33 N**, corresponding to an increase of approximately **135.7%.** This behavior is explained by the increasing inertial interaction between soil particles and the working body at higher speeds.

The frictional resistance results shown in Graph 5 reveal that frictional force also increases with soil density. The frictional resistance grows from **1155 N** in light sandy loam soil to **3465 N** in heavy clay soil, which is associated with increased contact pressure and higher soil cohesion.

Graph 6 illustrates the variation of total draft force in Newtons. The total resistance increases from **3269 N** under light soil conditions to **9798 N** under heavy clay conditions at maximum operating speed. This indicates that soil type has the greatest influence on draft requirement, while speed contributes additionally through dynamic resistance.

Similarly, Graph presents the total draft force in kilonewtons for engineering interpretation. The required pulling force varies from **3.269 kN** to **9.798 kN,** demonstrating that the tractor power demand increases nearly threefold under heavier soil conditions.

Overall, the obtained results confirm that the draft resistance of the subsoiler working body is predominantly influenced by soil density and hardness, while operating speed mainly affects the dynamic component of resistance. These findings provide a theoretical and practical basis for optimizing the geometric parameters and operating modes of subsoiler working bodies, as well as for selecting appropriate tractor power under various field conditions.

This dissertation has carried out a theoretical analysis of the technology for preparing ridges for carrot cultivation and of the resistance forces acting on the working body. The principal conclusions are as follows:

-during ridge preparation, three main forces act on the working body: cutting resistance force (R_{cut}), dynamic displacement resistance force (R_{disp}), and friction force (R_{fr}). Their sum constitutes the total draft force (P).

-for the given conditions B =70 cm and h =20 cm with medium loam soil, the total force P falls in the range of approximately 5,400–6,000 N (5.4–6.0 kN).

-the parameter with the greatest influence on total force is the specific mechanical resistance of the soil k, which depends directly on soil type and must be determined first in any design process.

The dynamic displacement force R_disp accounts for less than 1 % of total force under practical operating conditions and may generally be neglected in design calculations.

The condensed formula $P = k \cdot B \cdot h \cdot (1 + \mu) +$

$\rho \cdot g \cdot B \cdot h \cdot v^2/(2 \cdot 10^4)$ is convenient for direct application in engineering calculations and yields accurate results.

Conclusion

Based on the conducted theoretical and graphical analyses of the resistance parameters of the subsoiler working body, the following conclusions were drawn:

The density modulus of soil significantly affects the resistance encountered by the working body, increasing from 1.5 N/cm² in light sandy loam soil to 4.5 N/cm² in heavy clay soil. Static resistance was identified as the dominant component of total draft force, varying from 2100 N to 6300 N depending on soil type. Dynamic resistance was found to be highly dependent on operating speed, increasing by 135.7% when the speed rose from 1.1 m/s to 1.7 m/s. Frictional resistance increased proportionally with soil density, reaching a maximum value of 3465 N in heavy clay soil. The total draft force of the subsoiler working body varied from 3.269 kN to 9.798 kN, indicating that heavier soils require nearly three times greater traction effort. Soil physical-mechanical properties exert a greater influence on total resistance than operating speed; however, speed significantly affects the dynamic resistance component. The obtained results may serve as a scientific basis for optimizing the design parameters of subsoiler working bodies and selecting rational operating modes for energy-efficient tillage. In general, the study confirms that proper consideration of soil conditions and operating speed is essential for reducing energy consumption, improving tillage quality, and enhancing the efficiency of subsoiler machinery.

REFERENCES

1. Goryachkin V.P. Theory of Soil-Tillage Machines. — Moscow: Mashinostroenie, 1968. — 412 p.
2. Zelenin A.N. Fundamentals of Soil Destruction by Mechanical Methods. — Moscow: Mashinostroenie, 1968.
3. Bernacki H., Haman J. Theory of Agricultural Machinery. — Warsaw, 1972.
4. Qodirov I.A., Toshmatov N.U. Theory of Agricultural Machines. — Tashkent: Fan, 2015.
5. Fundamentals of Soil Science and Agricultural Chemistry. — Tashkent: O‘zbekiston, 2018. — 320 p.
6. GOST 24057-88. Agricultural Machinery. Methods of Experimental Evaluation.
7. Ravshanov, K., Fayzullaev, K., Ismoilov, I., Irgashev, D., Mamatov, S., & Mardonov, S. (2020, July). The machine for the preparation of the soil in sowing of plow crops under film. In IOP Conference Series: Materials Science and Engineering (Vol. 883, No. 1, p. 012138). IOP Publishing.
8. Fayzullaev K. et al. Study on mechanisms of tillage for melon cultivation under the film //E3S Web of Conferences. – EDP Sciences, 2021. – T. 304. – C. 03012.
9. Fayzullayev K. et al. Raking plates of the combination machine's subsoiler //E3S Web of Conferences. – EDP Sciences, 2021. – T. 264. – C. 04039.
10. Irgashev D. et al. Placement of working bodies on the frame of the tool plow-ripper //E3S Web of Conferences. – EDP Sciences, 2023. – T. 390. – C. 01036.
11. Irgashev D., Mamadiyorov O., Xidirov M. Technical analysis of the disk working bodies that work the soil and them working between the garden row //Science and innovation. – 2022. – T. 1. – №. A5. – C. 150-155.
12. Irgashev D. B. Basing the Constructional Parameters of the Plug-Softener that Works Between the Garden Rows. – 2024.
13. Mamatov F. et al. Justification of the bottom softening parameters of working organ with a sloping column //E3S Web of Conferences. – EDP Sciences, 2023. – T. 434. – C. 03010.
14. Mamatov F. et al. Justification of the bottom softening parameters of working organ with a sloping column //E3S Web of Conferences. – EDP Sciences, 2023. – T. 434. – C. 03010.
15. Irgashev Dilmurod Begmurodovich I. D. B. Theoretical Basis of Leveling Tillage in A Paraplow-Type Slanted-Column Chisel Plow //Theoretical Basis of Leveling Tillage in A Paraplow-Type Slanted-Column Chisel Plow. – 2025. – T. 7. – №. 3. – C. 168-175.