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Spatial Differentiation of Soil by Physical Properties in Intensive Apple Orchards by the Time of Their Uprooting

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ABSTRACT

Background: The study was conducted between 2019 and 2025 in intensive non-irrigated apple orchards in the Lipetsk and Tambov regions. The research focused on soil conditions in orchard aisles and trunk strips, analyzing soil structure and water retention before uprooting 16-year-old trees.

Methods: Soil properties were examined at various depths (up to 90 cm) in both the row-to-row zones and trunk strips. Key parameters analyzed included aggregate water resistance, soil structure coefficient, solid phase density, bulk density, total porosity, hygroscopicity, maximum hygroscopic moisture and soil moisture retention. The correlation between total humus content and water-physical parameters was also assessed.

Result: The water resistance of aggregates >0.25 mm was significantly lower in the row-to-row zones compared to trunk strips, particularly in the 0-20 cm layer. The soil structure coefficient in row spacings was 1.7-4.4 times lower than in trunk strips, with differences observed up to 60 cm deep. Solid phase density in row spacings was 0.1-0.15 g/cm³ higher than in trunk strips, with bulk density differences of 0.1-0.2 g/cm³ up to 90 cm deep. The total porosity in the 20-50 cm layer of row spacings was 5.8% lower than in trunk strips. Soil hygroscopicity in the 0-90 cm layer was 0.55-0.7% lower in row-to-row zones compared to trunk strips, with the 0-30 cm layer in row zones having 2 times lower hygroscopicity than in its virgin form. Maximum hygroscopic moisture in the 0-30 cm row-to-row layer was 4 times lower than in the virgin type and in the 30-60 cm layer, 5.6 times lower. The lowest moisture capacity in the 0-60 cm row-to-row layer was 9.0-15.0% lower than in the trunk strip, where it remained at virgin soil levels. Soil moisture at the rupture of capillary bonds in the 0-60 cm range was 2.2-2.3 times lower in the intensive orchard than in row-to-row zones. The correlation coefficient (r) between total humus content and water-physical parameters ranged from 0.55 to 0.7.

Key words: Apple tree, Intensive orchards, Row-by-row zones, Soil type, Trunk strips, Water-physical properties of the soil.

INTRODUCTION

The pixel pyramid net system can also be attributed to the intensification of gardening, which improves the recognition of apple tree diseases through pixel-level segmentation and spatial pyramid integration methods (Devi *et al.*, 2025). The intensification of horticulture implies not only the introduction of culture *in vitro* (Sebastian *et al.*, 2025). With the transition from extensive gardening to intensive gardening, the density of apple tree planting increases and the anthropogenic load on the soil increases (Warang, 2025), which necessitates a more thorough study of soil changes under orchards (Neilsen *et al.*, 2017). During the operation of intensive apple orchards, the physico-chemical parameters deteriorate in different soil layers. It is important to constantly monitor these characteristics in order to prevent soil degradation and ensure the sustainability of the garden (Cosmulescu *et al.*, 2024).

Soil mulching provides weed control (Bijalwan *et al.*, 2025). The effect of various mulching materials (black plastic film, sawdust, biochar, corn straw, wild grasses) on the content of microorganisms in the soil were tested in the gardens (Xie *et al.*, 2022). The use of mulch in the form of wood shavings in apple orchards has always contributed to maintaining soil moisture at a high level (Hoagland *et al.*, 2008). In the conditions of New Zealand, the influence of three soil content systems on soil bulk and water permeability was studied. It was found that mulching the soil between rows with pea straw increased the number of earthworms in the soil (Goh *et al.*, 2001). In southwestern Poland, in a 12-year intensive unpowered apple orchard, mulching of trunk strips with black polypropylene fabric along with blackening with common vole and sheep fescue were compared with herbicidal steam. It was found that

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blackening with grasses that were mowed and used as mulch in combination with polypropylene fabric increased soil porosity, increased humus content and optimized pH (Żelazny *et al.*, 2018). In Washington State, using the Golden Delicious variety as an example, a comprehensive application of measures wasstudied: Mulching the soil with bark, applying composted bird droppings and synthetic mineral fertilizers and machining row spacing. At the same time, the improvement in soil quality was associated with an increase in its water resistance, structurality, the amount of microbial biomass and the number of earthworms (Glover *et al.*, 2000). In the conditions of South Australia, it has been established that, compared with other forest species, the soil under apple orchards has its own electrical conductivity, organic carbon content and distribution of aggregates larger than 2 mm over the soil layers (Umali *et al.*, 2012). On the loess plateau of Northern China, in a non-irrigated apple orchard, subsurface tillage with mulching with straw proved to be the most optimal of the six treatment methods studied to improve the moisture capacity, hygroscopicity, structurality and bulk of the soil (Liu *et al.*, 2013). In the same region, the effect on the soil of apple orchards of different ages (up to 10 years, 10-15 years and more than 15 years) was compared. An increase in organic carbon reserves in the soil, an increase in enzymatic activity and a decrease in soil density with increasing age of trees have been found (Shi *et al.*, 2015). The cultivation of apple trees in place of field crops contributed to an increase in the number of larger soil aggregates (Zhu *et al.*, 2018). The soil in gardens aged up to 10, 10-20 and more than 20 years was also studied here. As the age of the garden increases, an increase in the volume mass, density of the solid phase, soil hardness, a decrease in soil porosity and water resistance of aggregates larger than 0.25 mm is established. Due to the formation of a very dense soil layer at a depth of 20-40 cm, accumulation of physical clay was noted here (Wei *et al.*, 2022). Unlike field crops, as the age of the apple tree increases (22-25 years), dry anhydrous zones form in the deep layers of the soil to a depth of 5 m (Wang *et al.*, 2020; Yang *et al.*, 2022) and up to 7 m at a distance from the tree trunk (Tian *et al.*, 2024). In this region, the use of manure in combination with mineral fertilizers on the Fuji apple variety contributed to a decrease in soil density and an increase in available moisture reserves in the soil layer of 0-100 cm (Li *et al.*, 2017). In the conditions of Northern Iran, it was found that, compared with 10-year-old walnut plantations and perennial pastures, apple orchards aged 10-25 years formed a more fertile soil with high biological activity (Kooch *et al.*, 2023). In central Iran, it has been established that, compared with non-irrigated pastures and agricultural field lands, under the condition of steep terrain, there is almost no water erosion in apple orchards and the maintenance of more favorable soil properties (Ayoubi *et al.*, 2022). The purpose of our research was to establish how much the physical properties of the soil in the aisles differ from the soil properties of the trunk strips of intensive apple orchards in Central Russia at the time of their uprooting.

MATERIALS AND METHODS

The research was conducted at Bunin Yelets State University in 2019-2025. The objects of research were soils in intensive apple orchards of the Timiryazev agricultural processing supply and marketing consumer cooperative (soil-leached chernozem), in a closed joint-stock company Agrofirma imeni 15 let oktyabrya» (the soil-grey forest) Lipetsk Region and Dubovoe Joint Stock Company (the soil - is typical chernozem) Tambov region.

Garden planting scheme 4.5×2.5 m. Rootstock 62-396. drip irrigation and trellis were not used in the gardens. The aisles of all gardens were kept under black steam: Spring harrowing with tooth harrows to a depth of 3-5 cm and 5-6-fold treatment to a depth of 10-12 cm during the summer, which consisted of alternating cultivations and disk harrowing. Once every 4 years, autumn dump plowing was carried out to a depth of 20-25 cm. The research was conducted on the Lobo variety. The soils had a medium loamy granulometric composition. All types of moisture capacity were determined by the thermostatic-weighing method, water resistance by the wet sieving method, structural analysis by the dry sieving method, soil density by the cutting cylinder method, solid phase density by the pycnometric method (Revut, 1964), humus content by the titrimetric method according to the I.V. Tyurin method modified by V.N. Simakov (Aleksandrova, 1976). The soils were analyzed before uprooting intensive gardens, that is, at the age of the trees 16 years. All measurements were repeated 4 times. Statistical data processing was performed using the Statistica 8.0 program.

RESULTS AND DISCUSSION

As a result, changes in the physical properties of different types of soils were found under intensive apple orchards in the Lipetsk and Tambov regions. During the 16-year operation of intensive apple orchards, the soil cover was differentiated into 2 technical zones: the aisle and the trunk strip. On average, over a layer of 0-60 cm, the humus content in the row-to-row zone on leached chernozem was 5.0% and in the trunk band 6.0%; on typical chernozem in the row-to-row 5.5%, in the trunk band 6.1%; on gray forest soil in the row-to-row 3.4% and in the trunk band 4.6%. In the conditions of the Timiryazevskij agricultural processing supply and marketing consumer cooperative, the water resistance of units with a diameter larger than 0.25 mm in leached chernozem turned out to be significantlylower in row spacing compared to trunk strips (LSD05= 6.0%). These differences can be traced to a depth of 90 cm and are especially large in the upper layer of 0-20 cm (1.6 times) (Fig 1).

The water resistance of aggregates shows the amount of erosion resistance of the soil. Its reduction entails an increase in the erosion hazard in gardens with a slope of more than 30. In the case of a large bugle type, the first is chernozem, which is typical in the Dubovoye farm. The water collection unit is larger than 0.25 mm. It's that simple. By the way, it was insignificant, something more than 40 per cent

of the total (LSD 05= 3.0%) (Fig 2). The coefficient of structurality (the ratio of thenumber of agronomically valuable aggregates (0.25-10 mm in diameter) to the number of others) also differed significantly in row spacing and trunk strips at the time of uprooting. Leached chernozem under conditions of the Timiryazevskij agricultural processing supply and marketing consumer cooperative has the most significant differences down to a depth of 50 cm. In the row spacing, the soil structure coefficient was 2.8-4.4 times lower than in the trunk strips (LSD05= 0.5) (Fig 3). On typical chernozem in the Dubovoe joint-stock company, due to the appearance of a plow sole, the 20-40 cm layer of the row-by-row zone contained 3 times more agronomically valuable fractions of soil aggregates than in the trunk strip (Fig 4).

In the upper layer (0-20 cm) of this buffer soil type, the soil structurality of the row spacing did not differ significantly from this indicator in the trunk strips (LSD05 = 9.5%).

For a more objective assessment, the structurality of the untouched soil under the forest area (oak petiolate and linden cordate) was studied on gray forest soil in the advanced economy of the Lipetsk region. It is clearly seen that the structurality of the gray forest soil in the trunk strips of the garden was at the same high level as in the virgin form (Fig 5).

The content of agronomically valuable aggregates on gray forest soil in the aisles of an intensive garden at the time of its uprooting turned out to be 1.7-1.8 times lower than in the trunk strips (LSD05 = 6.0%). This could be traced to the depth of the root word-60 cm. The density of the solid phase of the soil depends on the amount of organic matter in the soil. As the density of the solid phase of the soil increases, its porosity inevitably decreases and its bulk mass increases. This indicator on leached chernozem in the aisles was 0.1-0.15 g/cubic cm higher than in the trunk strips, where the soil is richer in organic residues of apple trees (LSD05= 0.06 g/ cubic cm). These differences can be traced to a depth of 90 cm (Fig 6).

Changes in the density of the solid phase also affected the bulk of the soil. It was 0.1-0.2 g/ cubic cm higher in the aisles than in the trunk strips (LSD05= 0.05 g/cubic cm). The differences in leached chernozem disappeared only deeper than 90 cm (Fig 7).

However, the soil density in the 0-90 cm layer in both garden areas remains at a level quite favorable for he roots of the apple tree. The density of the solid phase and the bulk of the leached chernozem were reflected in the final indicator-the total porosity. It was 5.8% lower in the row-to-row zone in the 20-50 cm layer than in the trunk bands due to the formation of a dense layer in this layer (LSD05= 4.0%) (Fig 8).

It should be noted here that in the root layer (0-90 cm), the total porosity of the soil remains optimal for apple tree roots only in the trunk strip and in the row-to-row zone it goes beyond the optimum (less than 55.0%). The absence of organic residues in the aisles and frequent treatments to the same depth led to the fact that the hygroscopicity of

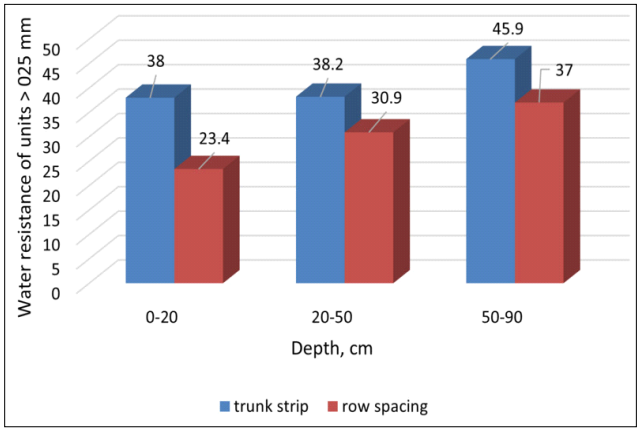


Fig 1: The water resistance of aggregates is larger than 0.25 mm in chernozem leached in an intensive apple orchard before uprooting, depending on the technical area.

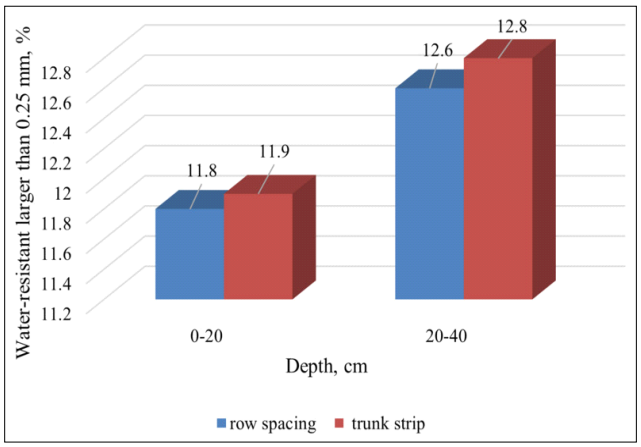


Fig 2: Water resistance of aggregates in chernozem typical in an intensive apple orchard before uprooting, depending on the technical area.

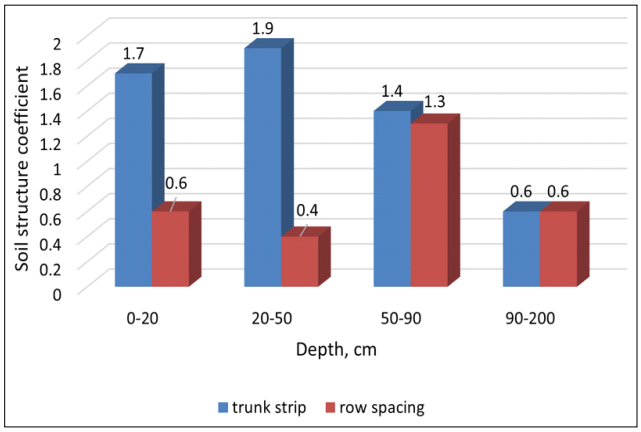


Fig 3: The structure of the leached chernozem in an intensive apple orchard before uprooting, depending on the technical area.

leached chernozem in the aisle zone is 0.55-0.7% less than in the trunk strip to a depth of 90 cm (LSD05 = 0.4%) (Fig 9).

For an apple tree, there are no gradations in the amount of hygroscopicity and moisture capacity of the soil relative to the optimum, minimum and maximum. However, these water-physical parameters of the soil should always be as high as possible. In the most fertile and buffered type of soil, typical chernozem, hygroscopicity in the row-to-row zone turned out to be lower than in the trunk zone only in the 30-60 cm layer (by 0.64%; LSD05 = 0.4%) (Fig 10).

These differences are explained by the over-compaction of the 30-60 cm layer in the aisles and the increased mineralization of the soil in this zone. The hygroscopicity of the gray forest soil has changed even more: In the 0-30 cm layer in the row-by-row zone of the garden, at the time of its uprooting, it turned out to be 2 times lower than in its virgin form and in the trunk strip it occupied an intermediate position (LSD05= 1.0%) (Fig 11).

A similar trend, but slightly weaker, was observed in the 30-60 cm soil layer. The maximum hygroscopic soil moisture is similar to hygroscopicity, but is determined at high humidity in the desiccator. This water-physical soil parameter was at the same level for chernozem leached in both technical areas of the garden at the time of uprooting (LSD05= 1.5%) (Fig 12).

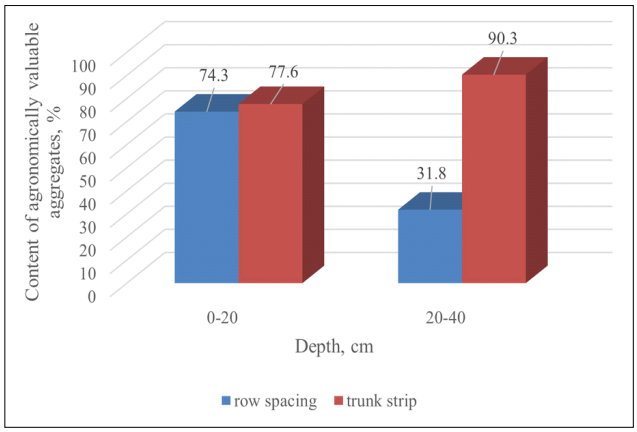


Fig 4: The content of agronomically valuable soil aggregates in chernozem typical in an intensive apple orchard before uprooting, depending on the technical area.

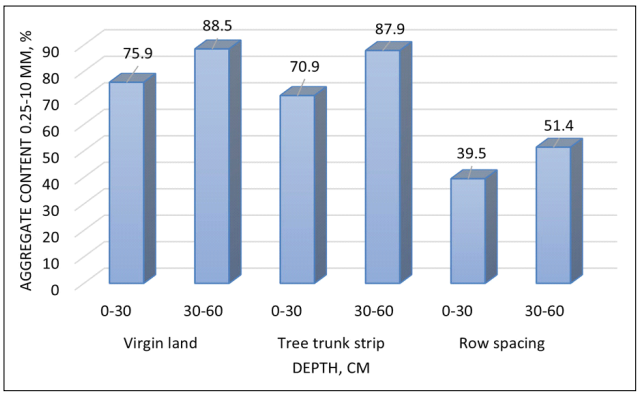


Fig 5: The content of agronomically valuable aggregates in gray forest soil in an intensive apple orchard depends on the technical area of the garden in comparison with virgin land.

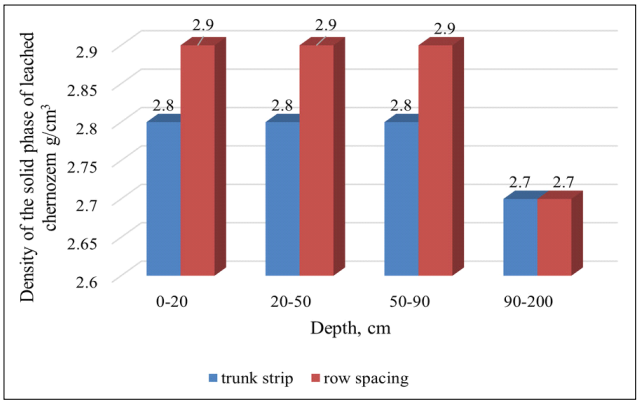


Fig 6: The density of the solid phase of chernozem leached in an intensive apple orchard before uprooting, depending on the technical area.

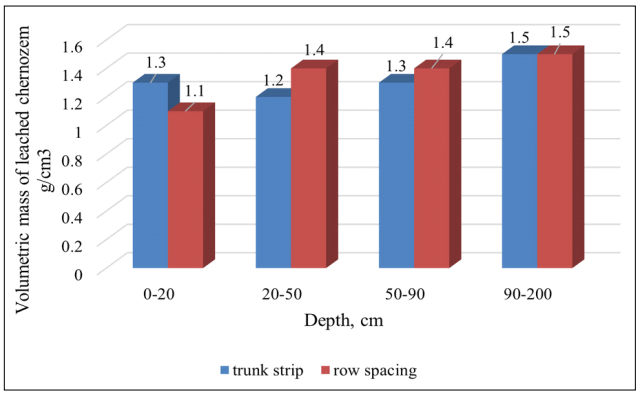


Fig 7: The bulk of chernozem leached in an intensive apple orchard before uprooting, depending on the technical area.

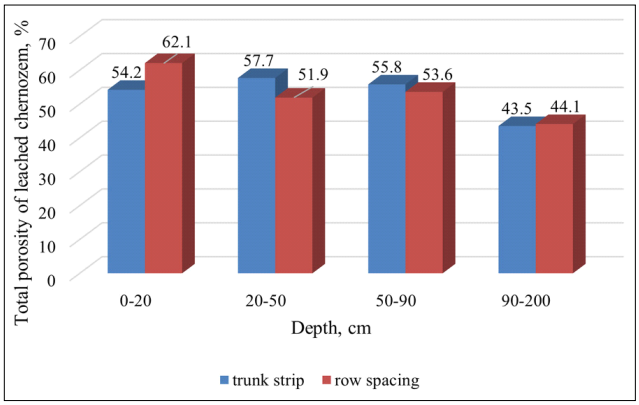


Fig 8: The total porosity of chernozem leached in an intensive apple orchard before uprooting, depending on the technical area.

The maximum hygroscopic humidity of typical chernozem in the 0-60 cm layer in the row-to-row zone turned out to be 2.0% lower at the time of garden uprooting than in the trunk strips (LSD05= 1.5%) (Fig 13).

The maximum hygroscopic humidity of gray forest soil in the row-to-row zone in the 0-30 cm layer was 4 times lower and in the 30-60 cm layer it was 5.6 times lower than in the virgin form (LSD05= 2.0%) (Fig 14).

This indicator in the soil of the trunk strip was higher than in the row spacing, but 2-2.7 times lower than the virgin soil. The lowest (marginal field) moisture capacity of the soil indicates the amount of water that is retained in the soil after the runoff of free gravity water. This water-physical parameter of leached hernozem in both technical zones of the garden was the same in all layers of the soil profile at the time of its uprooting (LSD05= 4.5%) (Fig 15).

However, in typical chernozem, this indicator in the 0-30 cm layer of the row-by-row zone was 2.5% lower than in the trunk strip and in the 30-60 cm layer the differences were completely within the experimental error (LSD05= 2.1%) (Fig 16).

The marginal field moisture capacity of gray forest soil in the 0-60 cm layer of the row-by-row zone of the garden before its uprooting was 9.0-15.0% lower than in the trunk strip. In the trunk lane, this indicator was at the level of itsvirgin counterpart (LSD05= 4.8%) (Fig 17).

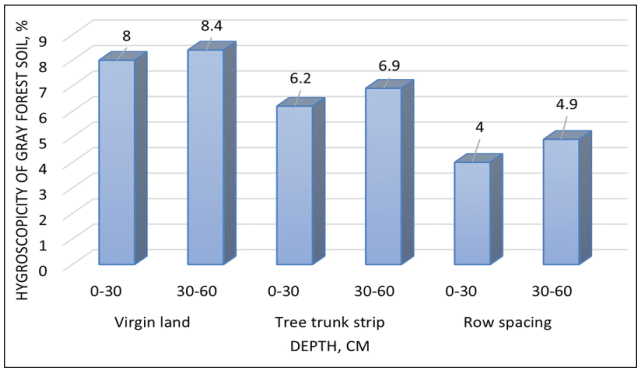


Fig 11: Hygroscopicity of gray forest soil in an intensive apple orchard, depending on the technical area of the garden in comparison with virgin land.

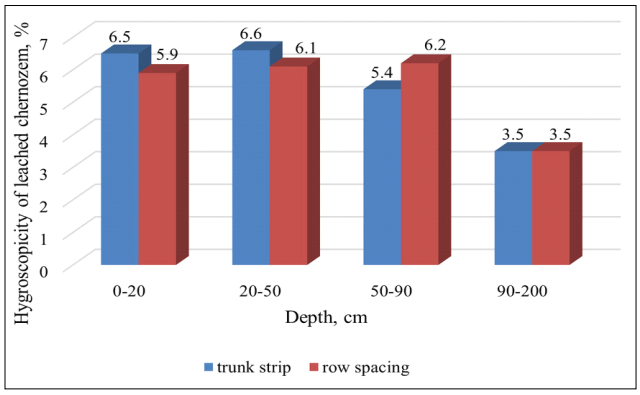


Fig 9: Hygroscopicity of leached chernozem in an intensive apple orchard before uprooting, depending on the technical area.

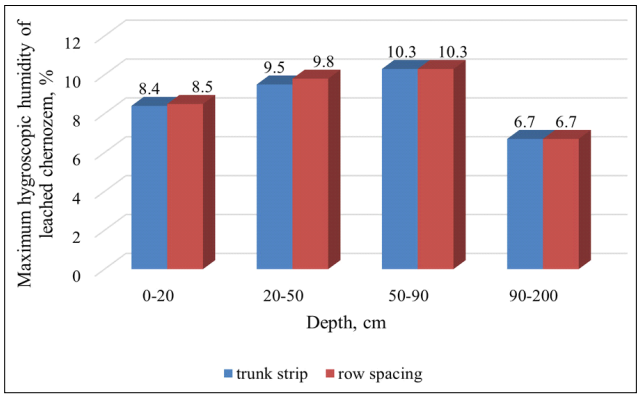


Fig 12: The maximum hygroscopic humidity of leached chernozem in an intensive apple orchard before uprooting, depending on the technical area.

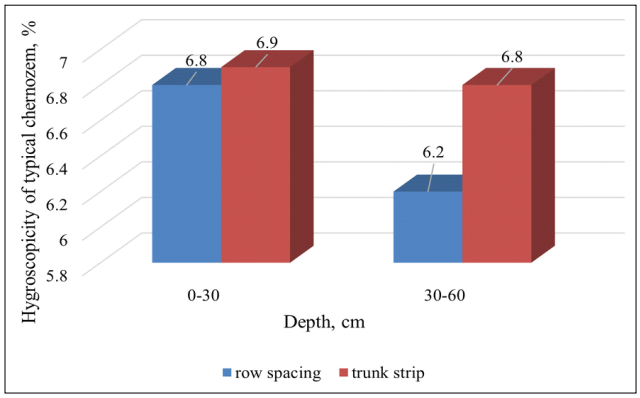


Fig 10: Hygroscopicity of chernozem typical in an intensive apple orchard before uprooting, depending on the technical area.

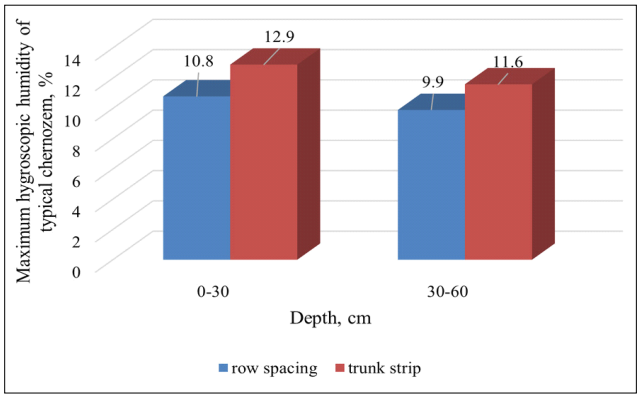


Fig 13: The maximum hygroscopic humidity of chernozem typical in an intensive apple orchard before uprooting, depending on the technical area.

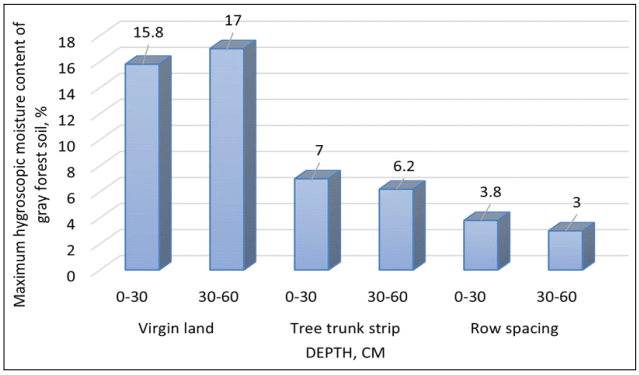


Fig 14: The maximum hygroscopic humidity of gray forest soil in an intensive apple orchard, depending on the technical area of the garden in comparison with virgin land.

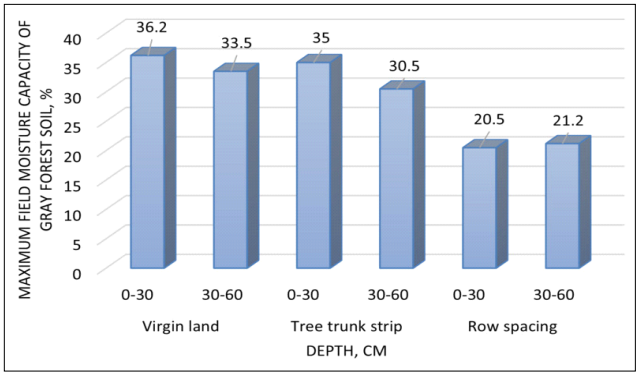


Fig 17: The maximum field moisture capacity of gray forest soil in an intensive apple orchard, depending on the technical area of the garden in comparison with virgin land.

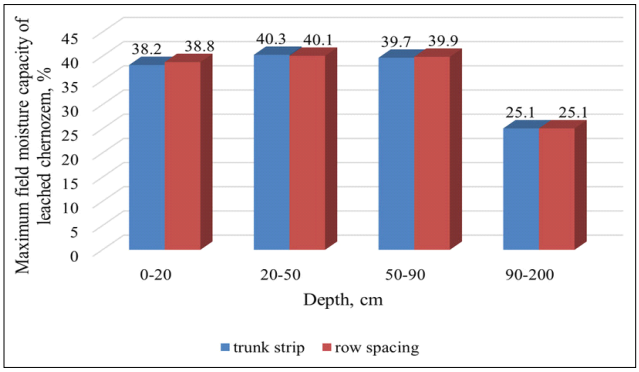


Fig 15: The maximum field moisture capacity of chernozem leached in an intensive apple orchard before uprooting, depending on the technical area.

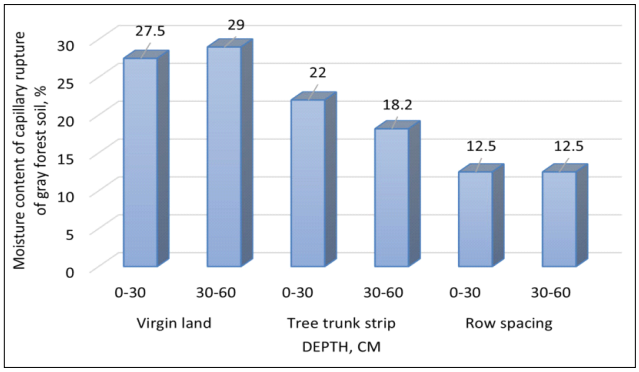


Fig 18: Humidity of the rupture of capillary bonds of gray forest soil in an intensive apple orchard, depending on the technical area of the garden in comparison with virgin land.

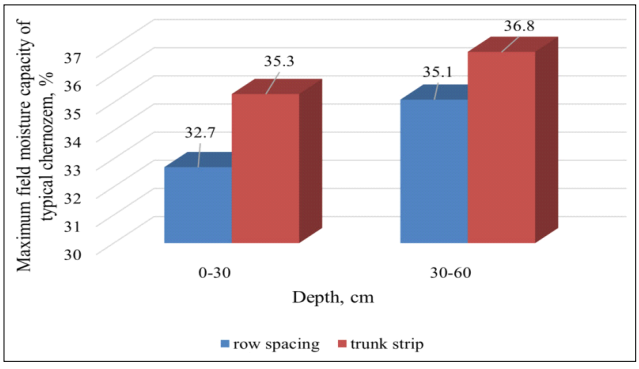


Fig 16: The maximum field moisture capacity of chernozem typical in an intensive apple orchard before uprooting, depending on the technical area.

The moisture content of the rupture of capillary bonds is approximately 50-60% of the lowest moisture capacity of the soil and characterizes the condition of the soil when the movement of water through the capillaries stop. We have shown this water-physical parameter using the example of gray forest soil. The graph shows that the movement of water through the capillaries stopped first in the soil of the row–by-row zone, then in the trunk strip and last of all in its virgin form (Fig 18).

The moisture content of the rupture of capillary bonds of gray forest soil in an intensive apple orchard in a layer of 0-60 cm at the time of uprooting was 2.2-2.3 times lower than in the row-to-row zone (LSD05= 4.0%). We were able to establish a relationship between the humus content in the soil and all the other indicators that we listed above: The coefficient of structurality (r= 0.55), the content of agronomically valuable aggregates (0.25-10 mm in diameter) (r= 0.55), water resistance of aggregates larger than 0.25 mm (r= 0.7), hygroscopicity (r= 0.59), maximum hygroscopic moisture (r= 0.58), lowest moisture capacity (r= 0.6), capillary bond rupture moisture (r= 0.6), solid phase density (r= 0.65), the volume mass of the soil (r= 0.63), the total porosity of the soil (r= 0.64).

CONCLUSION

1. When keeping the garden aisles under black steam, the water resistance of aggregates with a diameter larger than 0.25 mm turned out to be significantly lower in the aisles compared to the trunk strips. This phenomenon extends to a depth of 90 cm.

2. The coefficient of soil structure in the aisles up to a depth of 60 cm was 1.7-4.4 times lower than in the trunk strips. The density of the solid phase of the soil, the volume mass of the soil in the aisles up to a depth of 90 cm, was 0.1-0.2 g/cm^3 higher than in the trunk strips. The total porosity in the row-to-row zone in the 20-50 cm layer was lower than in the trunk bands by 5.8%.
3. The hygroscopicity of the soil in the 0-90 cm layer in the row-to-row zone was 0.55-0.7% less than in the trunk strip. In the 0-30 cm layer in the row-by-row zone of the garden, it turned out to be 2 times lower than in its virgin form and in the trunk strip it occupied an intermediate position.
4. The lowest moisture capacity of the soil in the 0-60 cm layer of the row-by-row zone was 9.0-15.0% lower than in the trunk strip. In the trunk lane, this indicator was at the level of its virgin counterpart.
5. The correlation coefficient (r) between the total humus content and all other listed water-physical parameters ranged from 0.55 to 0.7.

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Disclaimers

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal Care and Handling Techniques were approved by the University of Animal Care Committee.

Conflict of interest

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