RESEARCH ARTICLE Agricultural Reviews, Volume 46 Issue 6: 960-967 (December 2025)

Assessment of a Method for Soil Fatigue by the Middle Row Spacing and its Practical Approach in an Intensive Apple Orchard

V.L. Zakharov[1], G.N. Pugachev[2], S. Yu. Shubkin[1], S.S. Buneev[1], V.A. Gulidova[1]

10.18805/ag.RF-380

ABSTRACT

Background: To fulfill the aim of this study rhizospheric soil samples were collected from apple tree to find out the changes in soi properties. This involved comparing soil fertility under trees (trunk strips) with that middle of garden aisles, highlighting the need for a comparative method to evaluate physical, chemical and biological parameters of soil.

Methods: Researchers used middle of uncovered row spacing as a reference point for comparison. They examined various soil parameters under different irrigation conditions (optimal and without irrigation) and compared trunk strips with the blackened row spacing. This comparative analysis, supported by an extensive database, enabled the development of a predictive model to assess soil fertility changes under specific technological parameters.

Result: Hygroscopic soil moisture was consistently higher in the trunk strips and blackened row spacing. Under both optimal irrigation and no irrigation, the maximum field moisture capacity was lower in the blackened soil. At all irrigation levels, soil hydrolytic acidity was higher in areas covered by legumes and grasses, while amount of exchange bases was lower in the blackened soil. Nitrate concentrations were always higher in the blackened aisles. At optimal and no irrigation, more yeast cells were found in the trunk strip soils, whereas blackened aisles consistently harbored a greater abundance of mold fungi.

Key words: Apple tree, Assessment of soil properties, Intensive orchards, Soil depletion, Soil maintenance systems.

INTRODUCTION

When designing intensive gardens, one should know not only moisture capacity of the soil (Lan *et al.*, 2019), but also the microbiological properties (Hong *et al.*, 2018) and chemical parameters. Knowledge of soil moisture status enables a highly efficient water supply system, delivering water as needed and eliminating wasteful water usage when irrigation is unnecessary (Balaji and Pandiarajan, 2022). However, research on soil water-holding capacity has primarily been conducted only in annual crops (Tamiru *et al.*, 2023). The aisles of most gardens are kept under perennial black steam, which leads to soil washing away in the aisles (Kabelka *et al.*, 2019).

Changes in soil properties are observed in trunk strips. Since apple tree leaf litter is a valuable source of mineral elements (Chen *et al.*, 2019) and phytostimulators (Mertoglu *et al.*, 2018), the soils of some orchards are more in content of exchangeable calcium, mobile mineral phosphorus, exchangeable magnesium, absorbed potassium, nitrates (Lan *et al.*, 2019), organic phosphorus (Paul *et al.*, 2018) and number of microorganisms compared to forest soils. One of the causes of soil degradation isthe loss of humus and nitrogen Based on the ratio of organic carbon (Unnikrishnan *et al.*, 2023).

Content and physical clay in soil, it is possible to judge the degree of degradation and potential buffering of the soil. Moreover, in woody communities on clay soils, the reserves of organic carbon and nitrogen due to leaf litter are approximately twice as high as those on sandy soils.

[1]Federal State Budgetary Educational Institution of Higher Education «Bunin Yelets State University (Bunin Yelets State University), Russian Federation, Lipetsk region, Yelets, Kommunarov str., 28.1, Russia.

[2]FSSI “I.V. Michurin FSC” 30. Michurin St., Michurinsk, Tambov Region, Russia.

Corresponding Author: V.L. Zakharov, Federal State Budgetary Educational Institution of Higher Education «Bunin Yelets State University (Bunin Yelets State University), Russian Federation, Lipetsk region, Yelets, Kommunarov str., 28.1, Russia.
Email: zaxarov7979@mail.ru
ORCIDs: 0000-0003-4891-658X, 0009-0001-7685-8834, 0000-0002-4144-9627, 0000-0002-2334-1241, 0000-0001-7585-0956

How to cite this article: Zakharov, V.L., Pugachev, G.N., Shubkin, S.Yu., Buneev, S.S. and Gulidova, V.A. (2025). Assessment of a Method for Soil Fatigue by the Middle Row Spacing and its Practical Approach in an Intensive Apple Orchard. *Agricultural Reviews.* **46(6):** 960-967. doi: 10.18805/ag.RF-380.

Submitted: 19-03-2025 **Accepted:** 28-08-2025 **Online:** 25-09-2025

As the apple tree grows, the lowest moisture capacity of the soil may change. It is known that, without irrigation, the greatest depth of soil desiccation reaches 160-170 cm when the orchard is 9 to 17 years old. Understanding the moisture reserves in apple orchard soils is mportant when studying orchard mulching (Neilsen *et al.*, 2003). Moreover, with increasing orchard age, moisture reserves in the soil tend to decrease (Li *et al.*, 2019). Starting from the 10th year

of the apple tree's life, moisture reserves in the orchard soil become significantly lower than those in arable soils under field crop rotations and this difference further increases by the orchard's 19th year. The most critical aspect of modeling agricultural ecosystems and the environment is the accurate prediction of spatial variability in soil properties (Rajalakshimi *et al.*, 2025) This is precisely why our article addresses the challenges of soil cover heterogeneity in intensive orchards. A specific fungal microflora is formed in the rhizosphere of the apple tree, which accelerates the destruction of cellulose, inherent in all forest ecosystems. The study of the zone of trunk strips of apple plantations allow us to reveal the mechanism of the effect of apple roots on the soil. Apple tree roots secrete oxalic and malic acids into the soil (Li *et al.*, 2019). The bacterium Bacillus methylotrophicus CKAM, isolated from the root endosphere of healthy apple trees, produces mainly gluconic and oxalic acids with small amounts of 2-ketogluconic and formic acids (Mehta *et al.*, 2014). The bacterium Pseudomonas aeruginosa (strain An-15-Mg) is closely associated with roots of apple tree and produces succinic, malonic, citric, malic, chymic, quinic, tartaric, fumaric and lactic acids (Ranjna *et al.*, 2017). For 35 years of operation of the apple orchard, significant acidification occurred in the 15-45 cm soil layer (Niedźwiecki, 1991). The granulometric composition of the soil in any fruit growing area is very important for the longevity of apple orchards. On the Loess Plateau of China, which has in light loamy granulometric composition, the cultivation of apple orchards in dry years leads to deep desiccation of the soil by several meters and the danger of wind erosion (Min *et al.*, 2020). Loamy soils have a richer species composition of soil fungi than sandy loam. On brown clay-alluvial soil, argon chernozem and clay-illuvial chernozem, apple tree plantations are most productive with a physical clay content of 20-40% (Mãrghitaş *et al.*, 2012). The results indicated that, the rankings of soil health index were generally organic > green > conventional and 95% of the orchards were rated as the grades of moderate (40-60) to better (60-80). Soil health index in green orchards with different cultivation durations followed the pattern of gradual increase over 5 years. The mprovement of soil fertility, soil aggregation structure and soil bio-community were crucial improvement of soil health, prevent soil degradation and promote soil sustainability in this region, particularly under the circumstance of encouraging green agriculture development. In Shanghai (China), a local comprehensive methodology used for assessment soil conditions in gardens with organic, environmentally friendly and traditional farming methods has been successfully developed and applied (Cao *et al.*, 2023). In horticultural sites, a common method of assessing tillage involves comparing data collected before the garden is established with data gathered after the operation period ends. However, this method does not comply with a fundamental principle of experimental design-the principle of a single variable difference. This principle requires that only one factor varies between the compared conditions to accurately attribute observed changes to that factor alone. Since many environmental factors (*e.g.*, climate, soil aging) change over time, this method cannot fully isolate the effect of tillage, limiting the reliability of conclusions. If we compare the data before the garden was laid with the data after it was uprooted, can we reliably say that the changes occurred due to the influence of the garden? After all, during the period of operation of long-term plantings, the soil, in addition to agrotechnical factors, is also influenced by the climate, as a result of which the soil changes even if nothing grows on it. In scientific research, control is used for comparative evaluation, which excludes the effect of the studied factor, but is under equal other conditions. Virgin areas located nearby can be used to assess the level of soil exhaustion in industrial plantations, but this is not always possible. We suggest using the row spacing center of an intensive garden as a control, which is especially important from an agrotechnical point of view. The purpose of our research was to suggest evaluating changes in the soil properties of the apple tree rhizosphere in intensive orchards by comparing them with soil fertility in the middle of the garden aisles.

MATERIALS AND METHODS

The research was conducted from 2019 to 2025 in the experimental intensive apple orchard of the I.V. Michurin Federal Scientific Center, located in the Michurinsky district of the Tambov region. The study focused on meadow-chernozem soil, which had a granulometric composition ranging from heavy loam to medium loam. Soil samples were collected from the 0-40 cm layer. The orchard was established in 2007, making the trees 12 years old at the beginning of the study in 2019. The apple trees (variety Lobo) were grafted onto the semi-dwarf rootstock 54-118. The planting scheme was 4.5 m between rows and 2 m between trees within a row. The row spacings were maintained under grass mulch (a mixture of meadow bluegrass, red fescue and meadow clover), while the tree rows were kept under black fallow. Black fallow involved periodic soil loosening to a depth of 10 cm using disc cultivators. Roundup herbicide was applied in the tree rows at a rate of 2.5 L/ha of the treated area.

The experiment was set up in a systematic block design with four replications. The study included three drip irrigation treatments: treatment 1 control): without irrigation, treatment 2 (optimal Irrigation): soil moisture maintained at 80% of the maximum field moisture capacity, treatment 3 (waterlogging): soil moisture maintained at 120% of the maximum field moisture capacity. Drip emitters were spaced 0.5 m apart along the irrigation lines.

The granulometric composition of the soil was determined by the pyrophosphate method (Revut, 1964). Agrochemical soil analyses were performed according to the standard procedures of the Central Institute of

Petrochemical Services of Agriculture (Kolos, 1973). The nitrate nitrogen content was measured using the ionometric method with a nitrate-selective electrode on an Expert-001 ionometer. The abundance of yeast and mold fungi in the soil was determined by plating on Capek's nutrient medium. All measurements were performed in four replicates. Statistical data processing was performed using Statistica software (version 8.0, StatSoft, Inc., 2007). The data were subjected to an analysis of variance and the means were compared using Tukey's HSD test at a significance level of $p<0.05$.

RESULTS AND DISCUSSION

As an example, let's consider the analysis of experimental data using different levels of soil moisture and row spacing systems. In this paper, we will analyze the data using the classical method, that is, relative to the control option (without irrigation), as well as relative to the middle of the aisles, which were kept under black steam.

Hygroscopic soil moisture relative to the middle of the row spacing, which were kept without blackening, was significantly higher in the trunk strips and blackened row spacing (LSD05 = 1.5%) An elevated level of hygroscopic moisture is considered to be 9.9% (Elchininova *et al.*, 2018). This is noted at all irrigation levels. Hygroscopic humidity turned out to be the highest in the row spacing under blackening against the background of waterlogging and the lowest in the row spacing soil when kept under black steam against the background of lack and optimal moisture (Diagram 1). The hygroscopic moisture content in soil depends on air relative humidity and the soil's intrinsic properties. The higher the content of organic and mineral colloids in the soil, the greater its hygroscopic moisture capacity (Grishchenko, 2013). At two different irrigation levels (optimal and without irrigation), the value of the marginal field moisture capacity (the lowest moisture capacity) relative to the middle of the unfilled row spacing turned out to be significantly lower when the soil was blackened (LSD05=2.0%). The use of sodding improves soil structure and increases the proportion of agronomically valuable aggregates to 70-80%. This enhances water stability of aggregates and field capacity, particularly under legume grass sodding (up to 29.4%), compared to black fallow (25.6%) (Kuzin *et al.*, 2017). This parameter turned out to be the highest with row spacing under black steam against the background of optimal humidification and without irrigation (Diagram 2).

When waterlogged, the maximum field moisture capacity is reduced in the black steam version. In the blackened version, the lowest moisture capacity is lower due to the consumption of calcium by grasses, which increases the moisture capacity of the soil. This is also reflected in the amount of hydrolytic acidity, which increases when the row spacing is blackened with leguminous grasses, which consume calcium and there by increase the acidity of the soil. At all three levels of irrigation, it can be seen that, relative to the middle of the unfilled row spacing, the hydrolytic acidity of the soil is significantly higher in the soil thatwas contained under leguminous grasses (LSD05=0.5 mg-eq/100 g of soil). The lowest hydrolytic acidity in the soil of the trunk strips and row spacing, which were kept under black steam against the background of waterlogged soil (Diagram 3). According to our data, surface waterlogging increases both potential (hydrolytic) acidity and exchangeable acidity (pH decreases). In the experiment described in the article, waterlogging is specifically surface-induced. Conversely, groundwater-induced waterlogging reduces acidity due to the predominance of bicarbonate-calcium groundwater (but our experiment involves exclusively surface waterlogging). The observed acidity increase during surface waterlogging is supported by literature: hydrolytic acidity at 0.4-0.5 m

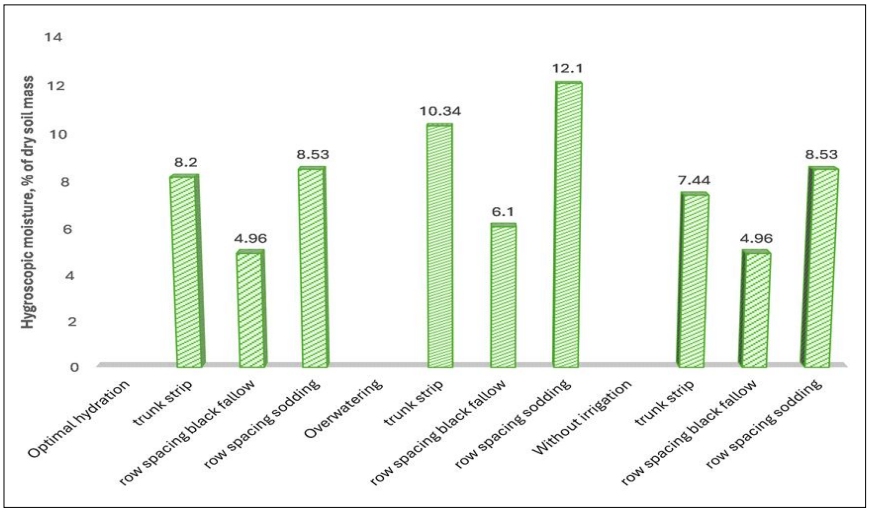


Diagram 1: Hygroscopic soil moisture depending on the degree of moisture and soil maintenance system in an intensive apple orchard.

depth is identical in soils of plain elevations and depressions, but increases by 0.7 mmol/100 g in trough-shaped depressions. This appears related to the fact that actual acidity is governed by carbonic acid and in waterlogged, organically rich soils, CO_2 content in soil air rises to 15-20% (Cheverdyn *et al.*, 2015). Consequently, with increasing hydromorphism, both pH and hydrolytic acidity increase.

At all three irrigation levels, the amount of exchange bases relative to the middle of the blackened row spacing was significantly lower in the blackened soil (LSD05=2.0 mg-eq/100 g). This indicator remained at a high level only in the soil of the trunk strips against the background of waterlogging (Diagram 4). As the degree of soil moisture decreased, the amount of exchange bases decreased. This indicator was lowest when row spacing was blackened with grasses, where there is a legume-grain grass mixture that intensively absorbed alkaline earth metals.

We did not find any significant changes in the value of metabolic acidity under the influence of varying degrees of soil moisture and the soil maintenance system in the garden (LSD05= 0.5). If we compare the midpoints of the unshaded aisles with the other two zones, it can be seen that the differences are also insignificant (Diagram 5).

Compared to the middle of the row spacing without blackening, the nitrate level in the soil is always higher in the blackened row spacing (LSD05=4.1 mg/kg). The greatest amount of nitrate nitrogen in the soil was found when the row spacing was blackened with leguminous grasses against the background of waterlogging of the soil. The increase in the nitrate nitrogen content is due to the influence of the bean component as a nitrogen fixator

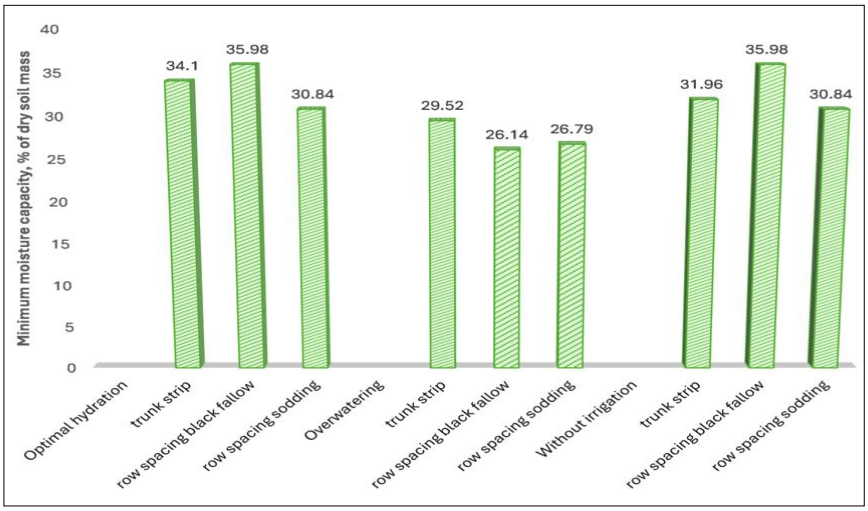


Diagram 2: Marginal field moisture capacity of the soil depending on the degree of moisture and the soil maintenance system in an intensive apple orchard.

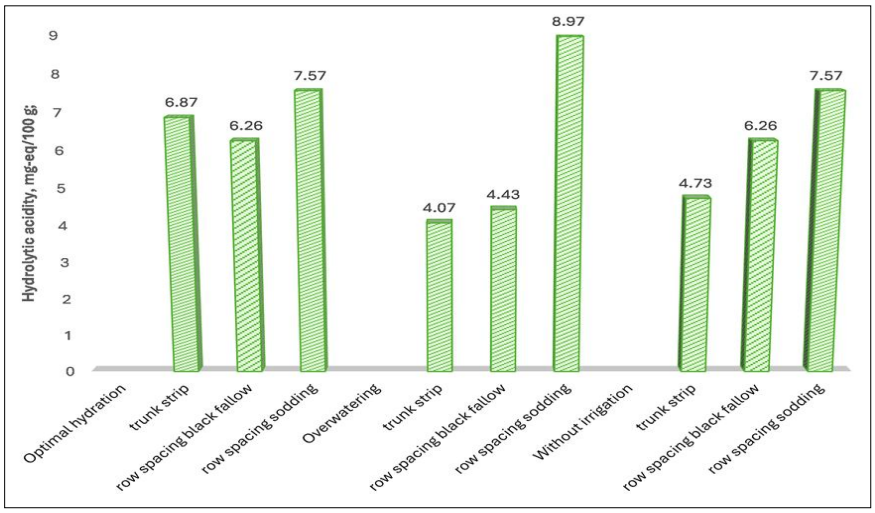


Diagram 3: Hydrolytic acidity of the soil depending on the degree of moisture and soil maintenance system in an intensive apple orchard.

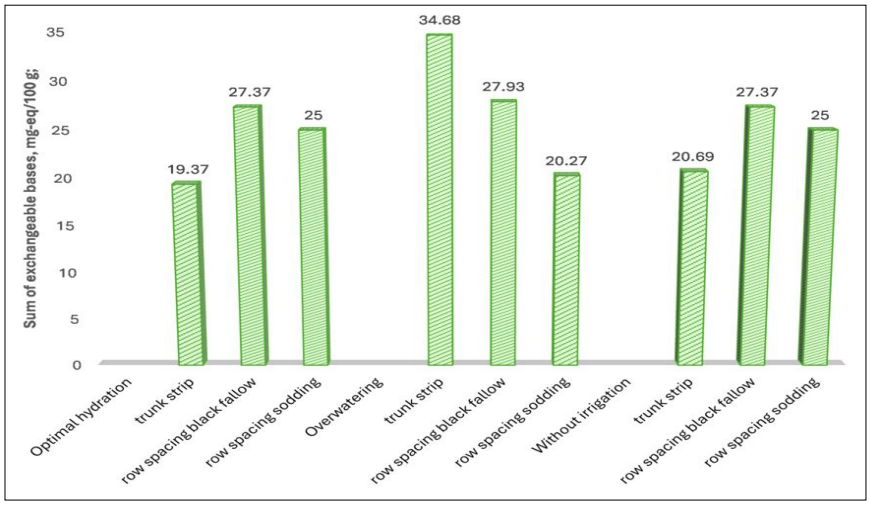


Diagram 4: The sum of the exchange bases of the soil depending on the degree of moisture and the soil maintenance system in an intensive apple orchard.

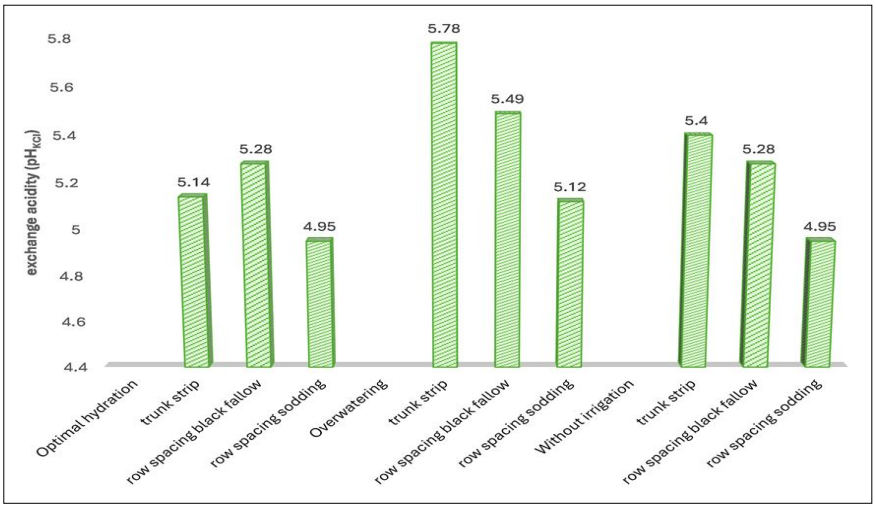


Diagram 5: Exchange acidity of the soil depending on the degree of moisture and soil maintenance system in an intensive apple orchard.

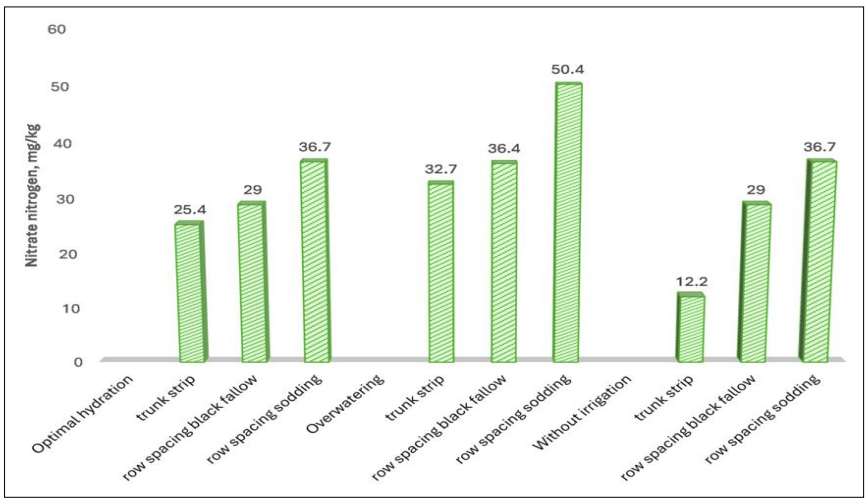


Diagram 6: Nitrate nitrogen content in the soil depending on the degree of moisture and soil maintenance system in an intensive apple orchard.

of the blackening grass mixture. The lowest content of nitrate nitrogen in the soil was noted in the trunk strip in the absence of drip irrigation (Diagram 6).

At the optimal watering level and without watering, the number of yeast cells relative to the soil in the middle of the row spacing was significantly higher in the soil of the trunk strip and in the blackened soil (LSD05= 5800 cells/g). The largest number of yeast colonies was observed in the variant where the aisles were kept under black steam against the background of waterlogging of the soil and the smallest in the soil of the aisles when kept under black steam against the background of moderate irrigation and without irrigation (Diagram 7).

Relative to the middle of the aisles, which were not covered with plants, but were kept under black steam, the number of mold fungi in the soil of the aisles, which were blackened, is always significantly higher (LSD05= 250 cells/g) (Diagram 8).

The greatest number of mold fungi in the soil was observed when the row spacing was blackened with legume and cereal grasses without irrigation or against the background of optimal moisture. The smallest number of mold fungi in the soil was noted in the trunk strips and aisles, which were kept under black steam, especially with moderate drip irrigation or lack thereof. It should be noted that waterlogging in this experiment is not critical, especially when using blackening, where there is practically no loss of trees. Thus, the method of comparing changes in soil parameters in the row spacing, relative to the trunk strip, provides a more visual understanding of changes in soil fertility under the influence of the garden. In addition, this approach has a certain practical industrial application. In the event that the row spacing, according to the analysis results, meets all the parameters of suitability for an apple tree, it is possible to lay a new orchard on this site without maintaining the renovation period of the site, which lasts at least 5 years.

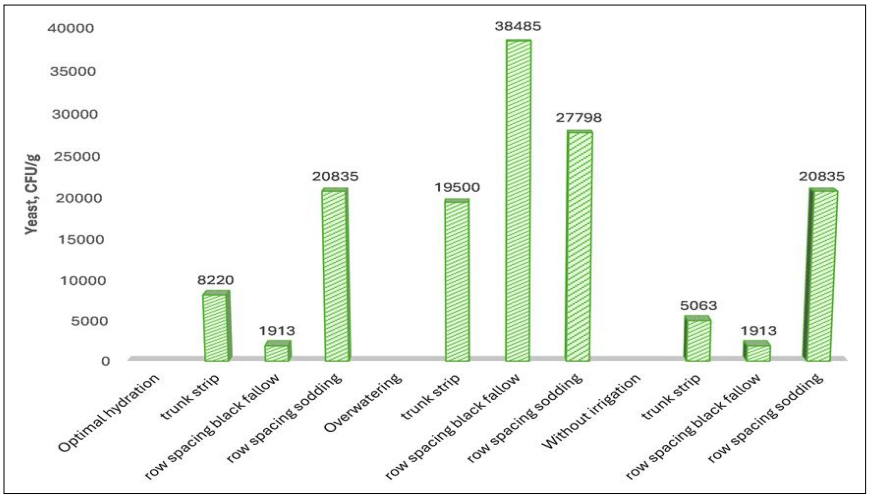


Diagram 7: Yeast content in the soil depending on the degree of its moisture and the maintenance system in an intensive apple orchard.

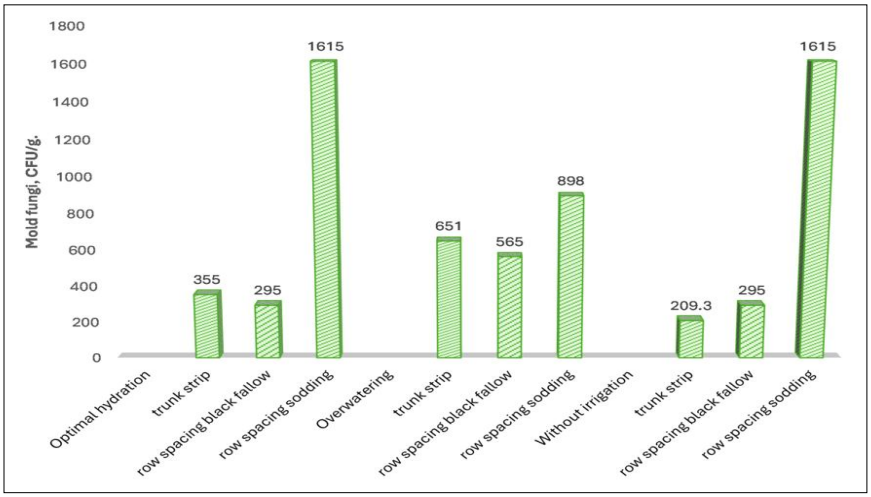


Diagram 8: The content of mold fungi in the soil, depending on the degree of its moisture and the maintenance system in an intensive apple orchard.

This is achieved by replacing the worn-out, depleted, depleted soil of the root zone of the apple tree with new soil from the garden aisles. This technique is the basis for accelerated reconstruction of an intensive apple orchard, as the longest-lasting monoculture in fruit growing.

CONCLUSION

1. Using the middle of the uncovered row spacing as a reference point, it becomes clear that the hygroscopic soil moisture is always significantly higher in the trunk strips and blackened row spacing; at two different irrigation levels (optimal and without irrigation), the maximum field moisture capacity is lower when the soil is blackened; at all three irrigation levels, the hydrolytic acidity of the soil is higher in the soil that was under bean and cereal grasses; at all three levels of irrigation, the amount of exchange bases is lower in blackened soil, the level of nitrates in the soil is always higher in blackened aisles; with an optimal level of irrigation and without irrigation, there are more yeast cells in the soil of the trunk strip and in blackened soil; mold fungi in the soil of aisles that have been blackened are always more; in the absence of drip irrigation or with moderate watering, the physical clay content is the same in all technical areas (row spacing, trunk lane) and does not depend on the row spacing system.
2. When assessing changes in the physical, chemical and biological parameters of the soil, it is important to conduct a comparative analysis of this change in the trunk strip relative to the row spacing.
3. This approach makes it possible, using an extensive database, to make a predictive model of changes in soil fertility in gardens of various types with specific technological parameters.
4. The use of the “comparison method” makes it possible to assess the possibility of accelerated renovation of the site after the end of the production cycle of the plantings.

ACKNOWLEDGEMENT

The research was carried out at the expense of a grant Russian Science Foundation No 25-26-00232, https://rscf.ru/project/25-26-00232/.

Disclaimers

The views and conclusions expressed in this study are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

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

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Balaji, K., Pandiarajan, T. (2022). Performance assessment of soil moisture meter under sandy clay loam soil. *Agricultural Reviews*. **43(2):** 243-248. doi: 10.18805/ag.R-2286.

Cao, Y., Li, X., Qian, X., Gu, H., Li, J., Chen, X. and Shen, G. (2023). Soil health assessment in the Yangtze River Delta of China: Method development and application in orchards. *Agriculture, Ecosystems and Environment*. **341:** 108190.

Chen, M.L., Huang, Y.M., Liu, H.J., Xie, S.W., Abbas, F. (2019). Impact of different nitrogen source on the compost quality and greenhouse gas emissions during composting of garden waste. *Process Safety and Environmental Protection*. **124:** 326-335.

Cheverdyn, Y.I., Bespalov, V.A., Titova, T.V. (2015). Changes in physico-chemical properties of chernozem soils depending on the nature of seasonal water logging. *International Research Journal*. **10(41)**.

Elchininova, O.A., Kuznetsova, O.V., Soyonova, A.N., Chichinova, G.V. (2018). Hydro-physical properties of soils in mid-mountain basins of the altai mountains. *Bulletin of NSAU (Novosibirsk State Agrarian/university)*. **2(47):** 19-29.

Hong, S.B., Geronimo, F.K., Choi, S.H., Kim, L.H. (2018). Impacts of nonpoint source pollutants on microbial community in rain gardens. *Chemosphere*. **209:** 20-27.

Kolos, P. (1973). Instruction manual of the central Institute of petrochemical services of Agriculture for conducting mass soil analyses in zonal agrochemical laboratories. pp. 55.

Kabelka, D., Kincl, D., Janecek, M., Vopravil, J., Vrablik, P. (2019). Reduction in soil organic matter loss caused by water erosion in inter-rows of hop gardens. *Soil and Water Research*. **14(3):** 172-182.

Kuzin, A.I., Pugachev, G.N., Trunov, Yu.,V. (2017). Influence of inter-row sodding on soil physical properties and nitrogen content in intensive apple orchards. *Advances in Science and Technology of AIC*. **31(7):** 36-38.

Lan, T., Guo, S.W., Han, J.W., Yong-Li, Yang, Zhang, K., Zhang, Q., Yang, W., Li, P.F. (2019). Evaluation of physical properties of typical urban green space soils in Binhai area, Tianjin, China. *Urban Frestry and Urban Greening*. **44:** 126430.

Li, H.J., Si, B., Ma, X., Wu, P. (2019). Deep soil water extraction by apple sequesters organic carbon *via* root biomass rather than altering soil organic carbon content. *Science of the Total Environment*. **670:** 662-671.

Mărghitaş, M., Toader, C., Mihai, M., Moldovan, L., Hangan, M. (2012). Pedoagrochemical characteristics of apple tree growing soils from the Reghin region. *Lucrări Ştiinþifice Seria Agronomie*. **55(2):** 99-103.

Mehta, P., Walia, A., Kakkar, N. *et al.* (2014). Tricalcium phosphate solubilisation by new endophyte Bacillus methylotrophicus CKAM isolated from apple root endosphere and its plant growth-promoting activities. *Acta Physiol Plant*. **36:** 2033-2045.

Mertoglu, K., Ileri, O., Altay, Y. (2018). Aqueous leaf extracts effect of some apple cultivars on growth characteristics of the green manure legumes *via* allelopathy. *Fresenius Environmental Bulletin*. **27(6):** 4052-4060.

Min, Y., Shaofei, W., Xining, Z., Xiaodong, G., Shuai, L. (2020). Soil properties of apple orchards on China's Loess Plateau. *Science of The Total Environment*. **723:** 138041.

Neilsen, G.H., Hogue, E.J., Forge, T., Neilsen, D. (2003). Surface application of mulches and biosolids affect orchard soil properties after 7 years. *Canadian Journal of Soil Science*. **83(1):** 131-137.

NiedŸwiecki, E. (1991). Physical and chemical properties of brown earths developed from boulder clay in Western Pomerania under arable farming, apple-tree orchard and deciduous forest, as affected by soil compaction. *Soil and Tillage Research*. **19(2-3):** 237-244.

Paul, R., Singh, R.D., Patra, A.K., Biswas, D.R., Bhattacharyya, R., Arunkumar, K. (2018). Phosphorus dynamics and solubilizing microorganisms in acid soils under different land uses of Lesser Himalayas of India. *Agroforestry Systems*. **92(2):** 449-461.

Rajalakshimi, P., Mahendran, P.P., Mary, P.C.N, Ramachandran J., Kannan, P., Ramessh, C., Selvam S. (2025). Spatial analysis of soil texture using gis based geostatistics models and influence of soil texture on soil hydraulic conductivity in melur block of Madurai district, Tamil Nadu. *Agricultural Science Digest*. **45(1):** 91-96. doi: 10.18805/ag.D-5691.

Ranjna, S., Joginder, P., Mohinder, K. (2017). Isolation of phosphate solubilizing Pseudomonas strains from apple rhizosphere in the Trans Himalayan region of Himachal Pradesh, India 77. *BioRxiv*. **25:** 1-15.

Revut, I.B. (1964). Soil Physics. L. Kolos Publ. pp. 318.

Tamiru Haile, Bussa Bayisa, Geneti Tadele (2023). Assessment of soil and water conservation practices and its implication on soil physicochemical properties, at West Guji Zone, Gelana Woreda, Southern Ethiopia. *Agricultural Science Digest*. **43(3):** 346-350. doi: 10.18805/ag.DF-456.

Unnikrishnan Anagha, M., Rajalekshmi, K., Bindhu, P.S. (2023). Soil degradation vs soil retrogression: A review. *Agricultural Reviews*. **44(4):** 509-515. doi: 10.18805/ag.R-2241.