

# The influence of soil physical properties on root development of fruit trees

Cornel NEGRUȘIER<sup>1</sup>, Lehel LUKÁCS<sup>2</sup>, Ionuț DASCĂLU<sup>3</sup>, Adelina VENIG<sup>4</sup>, Orsolya BORSAI<sup>5\*</sup>

<sup>1</sup> University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Department of Soil Sciences, e-mail: [cornel.negrusier@usamvcluj.ro](mailto:cornel.negrusier@usamvcluj.ro)

<sup>2</sup> Horticultural Research Station Cluj-Napoca, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, e-mail: [lehel.lukacs@usamvcluj.ro](mailto:lehel.lukacs@usamvcluj.ro)

<sup>3</sup> University of Life Sciences "King Mihai I" from Timisoara, Faculty of Engineering and Applied Technologies, Department of Horticulture, e-mail: [dascalu\\_ionut91@yahoo.com](mailto:dascalu_ionut91@yahoo.com)

<sup>4</sup> University of Oradea, Faculty of Environmental Protection, e-mail: [adelina.venig@uoradea.ro](mailto:adelina.venig@uoradea.ro)

<sup>5</sup> University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Horticultural and Business in Rural Development, Department of Horticulture and Landscape Architecture, e-mail: [orsolya.borsai@usamvcluj.ro](mailto:orsolya.borsai@usamvcluj.ro)

\* Corresponding author: [orsolya.borsai@usamvcluj.ro](mailto:orsolya.borsai@usamvcluj.ro)

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## Abstract

Soil physical properties significantly influence the growth and development of fruit tree roots, which, in turn, affect tree health, productivity, and overall fruit yield. Root systems are critical for water and nutrient uptake, and their efficiency is largely dependent on soil characteristics such as texture, structure, bulk density, porosity, and water-holding capacity. Soils with fine-textured particles, such as clay, often exhibit lower root penetration due to higher compaction and reduced pore space, leading to poor root development. Conversely, coarse-textured soils, like sand, may offer better root penetration but may also present challenges in retaining adequate moisture and nutrients. Optimal root growth typically occurs in soils with a balanced texture, good structure, and appropriate aeration. Soil bulk density plays a crucial role in root growth, with higher bulk densities generally hindering root expansion by reducing pore space and limiting oxygen availability. Furthermore, soil compaction is a major limiting factor, often leading to poor root development and decreased tree stability. Water availability, influenced by soil porosity and field capacity, also governs root growth, with roots favoring well-drained soils that retain enough moisture for nutrient uptake. Additionally, the depth and uniformity of the soil profile are important for root penetration, especially in deep-rooting fruit trees. This review highlights the complex interactions between soil physical properties and root development in fruit trees, underscoring the importance of understanding these factors for optimizing soil management practices. Improving soil structure through practices such as aeration, organic matter incorporation, mycorrhizal fungi and irrigation management can promote healthy root systems, leading to enhanced tree vigor, fruit yield, and long-term orchard sustainability. Further research is necessary to explore the impacts of specific soil modifications on root architecture and fruit tree performance in varying environmental conditions.

**Keywords:** soil texture, porosity, bulk density, mycorrhizal fungi, sustainability

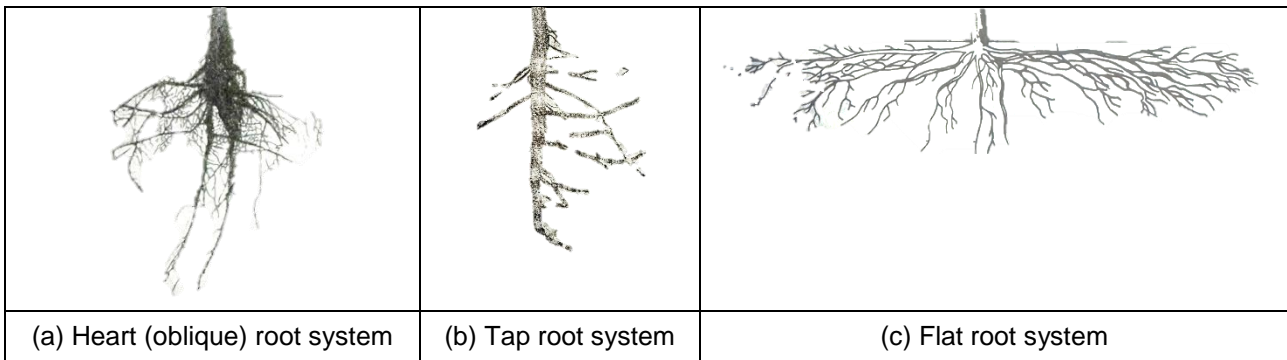
## Introduction

The physical properties of soil significantly influence the development of root systems in fruit trees, affecting their growth, health, and fruit production. The root system is responsible for anchoring the tree, absorbing water and nutrients from the soil, and storing energy as carbohydrates [25]. Understanding the root pattern distribution in fruit trees is critical for improving orchard management, optimizing irrigation systems, and enhancing tree vitality. Root architecture, which includes the depth, spread, and density of roots, varies significantly between species and is influenced by several environmental factors [27].

However, genetic traits can help to define the type of the growing pattern of certain species, several

research results highlighted that environmental factor such as high-water tables, excessive stoniness and compacted soil layers play a decisive role in defining the formation of any plant's root system [28]. The ratio to which all these factors influence root system formation and its functioning is still largely undetermined. The soil volume in which lateral and vertical roots are spread is crucial for root system development. Limited volume of soil available to the root system results in weak anchorage of the tree and poor distribution of the root system. In general, tree roots will grow in that portion of the soil where moisture, aeration, mechanical properties, and fertility are most favorable [32]. Several research results suggest that, in most cases, 80-90% of the total tree root mass is located in the upper 60 cm of soil, where the soil structure is loose, which facilitates the accessibility of water, oxygen and vital nutrients for the tree [39,46]. At deeper levels the soil bulk density increases and aeration decreases leading to a much more limited root mass [51]. Contrary to popular belief, the distribution of the tree root system typically extends significantly beyond the dripline (the area defined by the canopy spread), and in many cases, it may extend up to 2-fold the radius of the trees' canopy, or even beyond [12,44].

Fruit trees exhibit varying root structures that can be broadly categorized into three main types such as heart root, tap root and flat root systems (Figure 1). Although, some trees can combine different types of root systems, depending on plant species and on existing environmental factors.



**Figure 1. The main types of roots of fruit trees  
(Source: authors' own collection)**

Many fruit trees, such as apples, pears, and peaches, develop flat root systems (Figure 1c). These roots are generally shallow, highly branched, and spread horizontally near the soil surface. These roots are particularly efficient in capturing surface water and nutrients. In such systems, the root mass tends to be concentrated in the top 30–60 cm of soil, allowing the tree to access water from precipitation or irrigation efficiently [8,49]. In contrast, trees like walnuts, chestnuts, and almonds tend to develop deeper taproots, particularly in younger trees (Figure 1b). Taproots penetrate deep into the soil in search of water and nutrients, with lateral roots branching off from the main taproot at various depths. Taproot systems allow trees to access deeper soil layers and may contribute to greater drought resistance once the root system is well-established. As long as taproots are generally more vulnerable to mechanical damage, the formation of deep roots is influenced by soil texture and compaction [43,50]. In reality, most of the fruit trees exhibit a combination of these root types, with an initial taproot that gradually transforms into a flat system as the tree matures. This mixed architecture allows the tree to optimize resource acquisition from both surface and deeper soil layers [16,13].

Root pattern distribution in fruit trees is highly influenced by several interrelated factors, including genetic, environmental, and cultural factors. Therefore, the main aim of this review article was to screen and synthesize the existing literature regarding the physical properties of the soil that influences the most root development in fruit trees.

### **Material and Method**

In this review article, we summarized key-research findings existing in the scientific literature on the root pattern distribution of fruit trees, drawing from a wide range of studies across various geographical locations, species, and environmental conditions. The following materials and methods were used to identify, analyze, and integrate the relevant research findings:

#### *Literature search*

A comprehensive literature search was conducted using several academic databases, including Google Scholar, Clarivate Analytics – Web of Science Core Collection, Scopus and PubMed. The search terms included combinations of the following keywords: "root system architecture", "root pattern distribution", "fruit trees", "root depth", "root growth", "irrigation and root development", "fruit tree rootstocks", and "soil conditions and root development". The search was restricted to articles published from 1945 to 2024 to ensure the inclusion of recent studies and advances in the field.

#### *Selection Criteria*

Two criteria were used to include or exclude certain research article results in this study. For inclusion original research articles, reviews and book chapters written in English were considered focusing on root distribution of fruit trees. Similarly, studies investigating root system patterns across diverse fruit tree species (e.g., apples, peaches, cherries, citrus, walnuts etc.) were included. In addition, research results that revealed the impact of environmental conditions (soil texture, water availability, climate) and cultural practices (irrigation, fertilization) on root growth were also included. To be able to synthesize the information obtained from recent and prior knowledge and to create something new, a series of research article results were not included, especially those which focused solely on non-fruit-bearing trees or woody plants that are not typically grown in orchards. Likewise, studies with lack of detailed information on root architecture, soil physical properties and root distribution data were not included in the current review. Research published in languages other than English unless translations were available, were not taken into consideration.

#### *Data Extraction and Analysis*

The selected studies were analyzed to extract key information related to the following parameters:

- Fruit tree species and rootstock: the type of fruit tree and its rootstock (if applicable).
- Root system characteristics: type, depth, spread, and architecture.
- Soil and environmental conditions: soil type, texture, compaction, pH, and moisture content, as well as climate conditions (temperature, rainfall).

The data were systematically recorded in a structured matrix to facilitate comparisons across studies. A focus was placed on studies that used non-destructive imaging methods, as these offer detailed insights into root distribution over time.

#### *Data Synthesis and Statistical Methods*

The data extracted from the studies were synthesized to identify common trends and divergences across species and environmental conditions. Where possible, statistical analyses from the reviewed studies were noted, particularly those that used multivariate analyses (e.g., principal component analysis) to correlate root growth patterns with specific soil or environmental variables. Meta-analytic techniques were not used in this review, as the heterogeneity of the studies (e.g., species differences, study designs, and measurement techniques) prevented direct quantitative comparison. Instead, the review emphasizes qualitative synthesis and narrative analysis, supported by visual diagrams and root distribution models where available.

#### *Review Limitations*

Although every effort was made to identify and include studies across various regions and conditions, certain limitations must be acknowledged:

- Geographic Bias: Most studies were concentrated in temperate regions, particularly in North America and Europe, which may limit the applicability of findings to tropical or arid climates.
- Species Bias: Some fruit tree species, such as apples and citrus, were more extensively studied than others, potentially skewing the results toward these species.
- Variation in Methodology: Differences in experimental design, root sampling techniques, and measurement protocols make it challenging to directly compare findings across studies. Variations in rootstock and cultivar may also affect root development independently of environmental factors.

#### *Ethical Considerations*

All studies included in this review adhered to ethical guidelines for plant research. Specifically, no invasive procedures were conducted by the authors of this review, and all cited studies followed appropriate institutional or national ethical protocols for field and laboratory-based research.

## **Results and Discussion**

Through this comprehensive review process, we aim to provide a thorough understanding of the factors influencing root growth in fruit trees and offer practical insights for orchard management and horticultural practices.

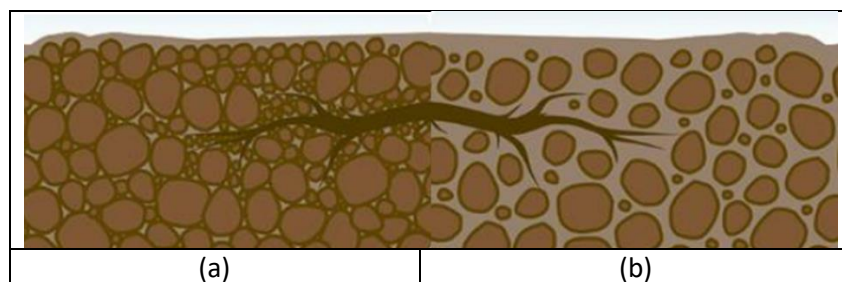
#### *Soil volume and structure*

The first most important conditioning factor for root functionality is the soil volume which is defined by

the distribution capacity of both lateral and vertical roots. When only a limited soil volume is available for the root system of the tree, a weak anchorage of the tree in the soil will be realized. In these circumstances, the mass of the roots and their surface area in contact with the soil are both limited, resulting in a poor distribution of the root system. As the soil volume exploited by the root system increases, the storage capacity of water and nutrients also increase helping thus the tree to develop [20]. According to previous studies, based on the thickness of the soil layer a tree is capable to exploit, soils were classified as deep (thickness over 100 cm), and shallow soils (<50 cm). However, it is generally known that tree fruit cultivation implies the use of a variety of rootstocks and types that are distinguished by particular biological traits like vigor, rooting time, tolerance to varying soil element levels, etc. [34,48]. Tree species can be divided into three categories on soils without limiting factors, according to previous research done on seven different tree species across the whole range of representative soils for the climatic area favourable to tree cultivation. These include combinations of vigorous varieties, or rootstocks with deep rooting, with the depth of the main root mass distribution at 20–60 cm, combinations of medium vigor varieties, or rootstocks with medium rooting, with the depth of root mass distribution at 20–40 cm, and combinations of weak vigor varieties, or rootstocks with superficial rooting, with the depth of the main root mass distribution at 10–30 cm [3,4,33,47].

Soil texture, defined by particle size distribution, affects water retention and nutrient availability, which are vital for root development [21]. A well-structured soil promotes better root penetration and aeration, facilitating root growth and function [38]. Soil texture significantly influences the root systems of fruit trees through various mechanisms, including soil management techniques, root system architecture, and microbial community interactions. Sandy soils, which drain quickly, tend to promote shallow root growth, whereas clay soils, which retain moisture, may encourage deeper root penetration [22]. Soils with high compaction or poor aeration limit root expansion and lead to the development of a more horizontal root pattern [11]. Loamy soils are typically ideal for fruit trees, providing a balance between water retention and drainage, allowing roots to spread evenly [14].

Soil compaction occurs when soil particles are pressed tightly together, which reduces the pore space between them (Figure 2). In heavily compacted soils, there are few large pores. This compaction decreases the rates of water infiltration and drainage, as larger pores are more effective at moving water downward through the soil compared to smaller ones [7,42]. Additionally, gas exchange is slowed in compacted soils, increasing the risk of aeration issues [35]. While compaction does raise soil strength — the soil's ability to resist displacement by external forces — it also forces plant roots to exert more effort to penetrate the compacted layer. Techniques like deep tilling, mulching, or planting cover crops can help improve soil structure and facilitate healthy root development.



**Figure 2. Soil compaction – (a) – compacted and (b) – uncompacted soil (Source: Authors own creation)**

Air and water are both present at the same time in the soil is characteristic of well-structured soils. In unstructured soils, there is either excess water and insufficient aeration or a lack of water accompanied by excessive aeration.

The degree of clay structuring determines the quality of clay soils; trees with cracked and homogeneous structures have better branched and thicker roots than those with continuous compact structures, where the root system is dispersed throughout the superficial horizons [Gucci et al, 2012].

Tree root growth and penetration are facilitated by the aero-hydric regime in soils with textural differentiation, where a fine-textured horizon with well-structured clay is situated above a coarse-textured horizon [31].

In contrast, the existence of a 100 cm soil profile with a continuous, compact clay horizon hinders the root system's natural distribution and exacerbates the aero-hydric regime by allowing waterlogging in this horizon [29].

Even the broken structure of the clay does not always stop the development of a poor form of rooting and root asphyxiation events caused by excessive moisture on clayey soils without textural differentiation, particularly on vertisols. It has been reported that depending on the varying resistance of structural aggregates to the action of water (structural stability), root asphyxiation may occur in clayey soils with a fragmented structure during wet years.

#### *Soil porosity*

Soils' porosity is determined by the percentage of their volume that is not occupied by solid particles. The porosity type that is most expressive and conclusive is aeration porosity. It is one of the most crucial markers of a soil's physical suitability for growing tree species since it is related to both the real aeration and the usable water capacity, both of which affect how well plants assimilate water. Aeration porosity levels are primarily influenced by the structure, clay type, and soil texture. By comparing the growth of trees with varying aeration porosities, it was reported that trees grow poorly when the porosity is low (less than 10%) and when it exceeds specific thresholds (between 25 and 30%) [30].

The impacts of improper soil aeration can be gradual and include irregular root system dispersion, occasional inadequate nutrition, and tree death.

#### *Soil Bulk Density*

Soil bulk density is defined as the mass of soil per unit volume (including pore spaces), is a critical factor influencing tree fruit root development. It reflects soil compaction levels and significantly impacts root growth, water movement, and nutrient availability. High bulk density typically indicates compacted soil with reduced pore space, which hinders root penetration and expansion [20]. Roots in compacted soils must exert greater force to grow, limiting their access to water and nutrients. This restriction can stunt root systems, reduce tree stability, and lower fruit yields. Furthermore, compacted soils prevent water infiltration and drainage, exacerbating drought stress or waterlogging, both detrimental to root health.

Conversely, low bulk density in well-structured soils promotes root proliferation by providing ample pore space for root elongation, water flow, and gas exchange. This environment fosters robust root systems capable of supporting healthy tree growth and fruit production [37].

Managing soil bulk density through practices like organic matter addition, reduced tillage, and avoiding soil compaction during wet conditions is essential for optimizing root development in fruit trees and ensuring sustainable orchard productivity.

#### *Water Availability*

In general, overwatering or underwatering are the two main stressors that affect plant growth. If a specific amount of surplus moisture acts as a restricting factor and has a deadly effect in a short period of time, the effect of a moisture shortage manifests more slowly and is, with the exception of very rare circumstances, non-lethal. This is due to the trees' unique root system, which transfers the absorption function to the skeletal roots that delve deeper into the soil in the event of a prolonged moisture deficit. Additionally, trees have a great capacity to absorb water from the soil up to suction pressures of 16 kg/cm<sup>2</sup> [1].

However, the roots respond by losing weight when the soil moisture content falls below the ideal range, apple plants grafted on M9 and M16 and pear trees grafted on quince have both shown this occurrence, which occurs before noticeable symptoms in the crown, with weight loss as a result of the newly created roots slowing down [24].

In climatic regions where this phenomenon is common, irrigation systems can be installed to ameliorate the soil moisture deficit. However, in recent years, there has been increased focus on excess moisture, whether temporary or permanent, which is often found in fruit plantations.

In water-saturated soils, the plant's water and mineral supply is impacted by inadequate aeration, soil physical, chemical, and biological changes, and the presence of toxic substances. Additionally, the metabolism, particularly the respiratory metabolism, is seriously disrupted.

In certain species that are less resistant to flooding, glycolysis leads to the formation of acetaldehyde, followed by ethanol, which accumulates, causing the blockage of citric acid. In more tolerant species, an increase in malic acid content is generally observed, which is not toxic to the plant, providing a significant advantage in achieving resistance to excess water compared to simple morphological adaptation through the development of lacunar spaces [19].

A series of research studies conducted on wild peach tree have associated high sensitivity of this species to root asphyxiation with a significant content of amygdalin in the roots [36]. In roots, amygdalin and emulsin combine anaerobically to generate hydrocyanic acid [18]. Water saturation led to the hydrolysis of cyanogenic glycosides in roots and the release of hydrogen cyanide, according to greenhouse experiments on plum, peach, and apricot.

The general symptoms of the root system under conditions of excess moisture can be summarized as reduction or inhibition of root growth, necrosis, root mortality, adventitious root formations at the soil surface or at the water layer surface and lenticel proliferation on submerged roots [45].

Trees, in general, are more affected by stagnant water than by flooding with running water, due to the water's content of O<sub>2</sub> and CO<sub>2</sub>. The duration of tree survival under submerged conditions varies depending on the species. For apple trees, significant damage occurs after 4-5 days, while for quince trees, it occurs after 25-30 days during the growing season [5]. It has been found that trees are extremely sensitive to excess soil moisture during the growing season, while this phenomenon had no significant effects during the dormant period [9]. The resistance during the dormant period varies considerably, for example, for apple trees between 12 and 14 days and 100-110 days [10,52]. In fact, the root system is most affected when excess moisture occurs during the summer period [46].

Studies conducted in peach and apricot plantations situated on flat lands (typical chernozems, cambic, and clay illuvial soils) with excess moisture of phreatic origin showed that the minimum critical depth of water depends on the soil texture. The maximum level that the groundwater can reach in the soil profile during the wettest season of the year or when irrigation is applied varies between 80 cm for peach grafted on seedling or almond on sandy soils and 250 cm for apricot grafted on cherry plum on clayey soils [48].

Root development in fruit trees varies throughout the tree's life. In younger trees, the root system is primarily concentrated near the surface to take advantage of nutrient-rich topsoil. As the tree matures, the root system spreads and deepens, especially in species that develop taproots. For young fruit trees, excess water poses significant risks as their root systems are still developing. Prolonged waterlogging depletes oxygen in the root zone, leading to hypoxia (oxygen deficiency), which inhibits root respiration and nutrient uptake. The weakened roots become more susceptible to fungal pathogens, such as *Phytophthora*, causing root rot. Stunted root development during this critical phase can impair the tree's long-term growth and reduce its structural stability. In contrast, it has been found that older trees tolerate excess soil moisture better than nursery-grown or recently planted trees [41]. In mature fruit trees, excess water can compromise flower and fruit development. Limited oxygen in the root zone reduces the tree's energy for flowering, fruit set, and fruit ripening. Poor nutrient uptake leads to smaller, lower-quality fruits and an increased risk of fruit drop. Extended waterlogging during the reproductive stage may reduce yields significantly and impact the tree's productivity in subsequent years. During the vegetative growth stage, excess water disrupts the balance between shoot and root growth. Oxygen-deprived roots are less efficient at absorbing nutrients like nitrogen and potassium, essential for leaf and shoot development. This results in yellowing leaves (chlorosis) and reduced shoot elongation. Additionally, waterlogged conditions can lead to an accumulation of toxic substances like reduced iron or manganese in the soil, further stressing the tree [23].

Repeated episodes of excess water can shorten a fruit tree's productive lifespan. Chronic stress weakens the tree, making it more vulnerable to pests, diseases, and environmental extremes. For some fruit trees, such as citrus, prolonged exposure to waterlogged conditions can result in complete dieback [2].

According to the research fruit trees' tolerance to excessive soil moisture varies significantly. Various studies have confirmed that stone fruit species are more susceptible to this phenomenon than fruits with many seeds [15]. However, previous results reported that in France, apple and pear trees are the most tolerant to excess moisture, plum trees are intermediate, while peach and cherry trees are more sensitive being classified in the following descending order of tolerance to waterlogging: very high tolerance (quince), high tolerance (pear), medium tolerance (apple), low tolerance (plum and lemon), medium sensitivity (cherry), high sensitivity (apricot, peach, almond), and extreme sensitivity (olive) [40,41].

For apple trees a wider range of rootstocks have been developed which allow the selection of the most suitable size for any cultivation system but also the sensitivity of fruit tree rootstocks to excess moisture, with diverse tolerance classes for this phenomenon.

In conclusion, excess water poses a significant threat to fruit trees at all stages of their growth, with young and mature trees being particularly vulnerable. Proper water management is crucial to ensure healthy root systems, sustained growth, and optimal fruit production over the tree's lifespan.

#### *Mycorrhizal Fungi*

Mycorrhizal fungi gained more special attention in recent years. These organisms form symbiotic relationships with the roots of most terrestrial plants, including fruit trees. These fungi colonize the root cortex and extend their hyphae into the surrounding soil, forming an extensive network that increases the effective surface area of the root system. These symbiotic organisms establish mutually beneficial associations with the root systems of fruit trees, enhancing nutrient uptake, water absorption, and overall plant resilience. Two primary types of mycorrhizal associations are relevant to fruit trees including Arbuscular Mycorrhizal Fungi (AMF) and Ectomycorrhizal Fungi (EMF). Arbuscular Mycorrhizal Fungi (AMF) penetrate the root cells of the

host plant, forming structures called arbuscules, which facilitate nutrient exchange. AMF are commonly associated with most fruit trees, such as apple (*Malus domestica* Borck.), cherry (*Prunus avium*), and citrus species [6].

Ectomycorrhizal Fungi (EMF) form mycelium network around root tips and extend their hyphae into the soil but do not penetrate root cells. EMF are more typical in certain nut-producing trees but less prevalent in common fruit trees. Moreover, it is important to mention that arbuscular mycorrhizal fungi (AMF) aid plant colonization in acidic soils, and can have a series of benefits on plant growth and development but high acidity could also restrict fungal growth and diversity. In extreme environments, AM fungi can thrive but the effects of acidic soil on the functionality of AMF and arbuscule formation are not completely understood yet [26]. Blueberries are among the few plant species that form mycorrhizal relationships exclusively with a specific type of mycorrhizal fungi known as Ericoid mycorrhiza. Similarly, cranberries, huckleberries, and lingonberries are also associate solely with Ericoid fungi. Previous research results reveal that *Phialocephala fortinii* inoculation in blueberries increased the contents of nitrogen, phosphorus, and potassium in blueberry plants.

The mycorrhizal relationship is centered on the exchange of nutrients. Fungi benefit by receiving carbohydrates produced through photosynthesis in the host tree. In return, the fungi enhance nutrient uptake for the tree, particularly of immobile nutrients like phosphorus (P), nitrogen (N), and trace minerals such as zinc (Zn) and copper (Cu). The extensive hyphal networks of mycorrhizal fungi can access nutrients in soil microenvironments that tree roots alone cannot reach. For example, phosphorus is often locked in insoluble compounds in the soil, but mycorrhizal fungi secrete enzymes, such as phosphatases, that release this nutrient in a plant-available form [17].

Mycorrhizal fungi contribute significantly to soil structure and fertility as well. Their hyphae bind soil particles together, improving aggregation and reducing erosion. By promoting soil organic matter accumulation, these fungi support a diverse and stable soil microbial community, which further benefits in fruit tree health. The symbiosis also influences the soil's carbon cycle. Mycorrhizal fungi contribute to carbon sequestration by transferring significant amounts of carbon from the tree into the soil ecosystem, where it is stored in fungal biomass and soil organic matter.

Integrating knowledge of mycorrhizal relationships into fruit tree cultivation offers enhanced productivity, reduced fertilizer dosage. By improving nutrient uptake efficiency, mycorrhizal fungi reduce the need for synthetic fertilizers, lowering costs and environmental impact. Incorporating mycorrhizal inoculants during orchard establishment or promoting conditions favorable for natural colonization can align with sustainable agricultural practices.

Despite their benefits, optimizing the use of mycorrhizal fungi in fruit tree cultivation faces challenges. The effectiveness of mycorrhizal associations can vary with tree species, soil conditions, and agricultural practices. Excessive use of agrochemicals, such as fungicides and high-dose fertilizers, can disrupt the fungi-plant relationship. In this context, future research should focus on identifying optimal fungal strains for specific fruit tree species; developing inoculation technologies that are cost-effective and scalable and investigating the role of mycorrhizal fungi under changing climatic conditions.

## Conclusions

Root pattern distribution in fruit trees is a complex and multifaceted process that depends on a variety of genetic, environmental, and management factors. Understanding these factors is crucial for optimizing fruit tree growth, water use efficiency, and overall orchard productivity. By taking into account the soil environment, water availability, tree age, rootstock selection, and other factors, horticulturists can develop more effective strategies for managing fruit tree root systems. As research in this area continues to evolve, it is expected that a more detailed understanding of root architecture will lead to further innovations in sustainable fruit production practices, contributing to healthier trees and higher yields. The symbiotic relationship between fruit tree roots and mycorrhizal fungi exemplifies nature's intricate interdependencies. By facilitating nutrient and water uptake, enhancing stress tolerance, and improving soil health, mycorrhizal fungi are indispensable allies in fruit tree cultivation. Leveraging this symbiosis in agricultural practices offers a pathway to sustainable and productive fruit farming, benefiting both growers and the environment. Continued exploration of this relationship holds promise for advancing horticultural science and addressing global food security challenges.

## References

- [1] Abdelkader, A. B. (2022), *Sap flow rate and transpiration of apple trees as affected by climatic conditions and soil water availability*, Doctoral dissertation, Free University of Bozen-Bolzano.
- [2] Aiyappa, K. M., Srivastva, K. C., & Bojappa, K. M. (1962), *Citrus Decline—a Review*. Indian Journal of Horticulture, 19, pp. 70-79.
- [3] An, H., Dong, H., Wu, T., Wang, Y., Xu, X., Zhang, X., & Han, Z. (2017), *Root growth angle: An important trait that influences the deep rooting of apple rootstocks*, Scientia Horticulturae, 216, pp. 256-263.
- [4] An, H., Luo, F., Wu, T., Wang, Y., Xu, X., Zhang, X., & Han, Z. (2017), *Dwarfing effect of apple rootstocks is intimately associated with low number of fine roots*. HortScience, 52(4), pp. 503-512.
- [5] Andersen, P. C. (1982), *Effects of flooding on peach, apple, quince and several pear species*. HortScience, 17(3), p. 497.
- [6] Bâ, A. M., Plenchette, C., Danthu, P., Duponnois, R., & Guissou, T. (2000), *Functional compatibility of two arbuscular mycorrhizae with thirteen fruit trees in Senegal*, Agroforestry Systems, 50, pp. 95-105.
- [7] Becerra, A. T., Botta, G. F., Bravo, X. L., Tourn, M., Melcon, F. B., Vazquez, J., & Nardon, G. (2010), *Soil compaction distribution under tractor traffic in almond (Prunus amygdalus L.) orchard in Almería España*. Soil and Tillage Research, 107(1), pp. 49-56.
- [8] Böhm, W., (2012), *Methods of studying root systems*. Springer Science & Business Media, (33).
- [9] Bregger, J. T., & Brown, G. F., (1945), *Conserving soil and moisture in orchards and vineyards*. US Government Printing Office (1970).
- [10] Choi, B. H., Bhusal, N., Jeong, W. T., Park, I. H., Han, S. G., & Yoon, T. M. (2020), *Waterlogging tolerance in apple trees grafted on rootstocks from G, CG, and M series*. Horticulture, Environment, and Biotechnology, 61, pp. 685-692.
- [11] Correa, J., Postma, J. A., Watt, M., & Wojciechowski, T. (2019), *Soil compaction and the architectural plasticity of root systems*. Journal of experimental botany, 70(21), pp.6019-6034.
- [12] Crane, J. H., & Balerdi, C. F. (2005), *Guava growing in the Florida home landscape*. Horticultural Sciences Department document HS4, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, pp.1-8.
- [13] Danjon, F., & Reubens, B. (2008), *Assessing and analyzing 3D architecture of woody root systems, a review of methods and applications in tree and soil stability, resource acquisition and allocation*, Plant and soil, 303, pp. 1-34.
- [14] DeJong, T. M. (2021), *Concepts for understanding fruit trees*. CABI.
- [15] Ebert, G. (2009), *Pome and stone fruits of the temperate zone*. International Potash Institute Horgen Switzerland Ipl Bulletin, 19, pp. 1-74.
- [16] Eissenstat, D. M., Wells, C. E., Yanai, R. D., & Whitbeck, J. L. (2000), *Building roots in a changing environment: implications for root longevity*. The New Phytologist, 147(1), pp. 33-42.
- [17] Fall, A. F., Nakabonge, G., Ssekandi, J., Founoune-Mboup, H., Apori, S. O., Ndiaye, A., & Ngom, K. (2022), *Roles of arbuscular mycorrhizal fungi on soil fertility: contribution in the improvement of physical, chemical, and biological properties of the soil*. Frontiers in Fungal Biology, 3, pp.723-892.
- [18] Ferrara, G., Maggio, P., & Pizzigallo, M. D. R. (2010), *Cyanogenic D-amygdalin contents of the kernels of cultivated almonds and wild Amygdalus webbii Spach*. The Journal of Horticultural Science and Biotechnology, 85(5), pp. 410-414.
- [19] Fischer, G., Casierra-Posada, F., & Blanke, M. (2023), *Impact of waterlogging on fruit crops in the era of climate change, with emphasis on tropical and subtropical species: A review*. Agronomía Colombiana, 41(2), pp. 1.
- [20] Gregory, P. J., Atkinson, C. J., Bengough, A. G., Else, M. A., Fernández F., Harrison, R. J., & Schmidt, S. (2013), *Contributions of roots and rootstocks to sustainable, intensified crop production*. Journal of experimental botany, 64(5), pp. 1209-1222.
- [21] Hayes, E., Higgins, S., Mullan, D., & Geris, J. (2023), *High-resolution assessment of riverbank erosion and stabilization techniques with associated water quality implications*. International Journal of River Basin Management, 1 p 15.
- [22] He, Z. L., Calvert, D. V., Alva, A. K., Banks, D. J., & Li, Y. C. (2000), *Nutrient leaching potential of mature grapefruit trees in a sandy soil*. Soil science, 165(9), pp. 748-758.

- [23] Huang, B. (2000), *Waterlogging responses and interaction with temperature, salinity, and nutrients*. In *Plant-environment interactions*, pp. 281-300.
- [24] İkinci, A., Bolat, I., Ercisli, S., & Kodad, O. (2014), *Influence of rootstocks on growth, yield, fruit quality and leaf mineral element contents of pear cv. 'Santa Maria' in semi-arid conditions*. *Biological Research*, 47, pp. 1-8.
- [25] Jackson, R. B., Pockman, W. T., Hoffmann, W. A., Bleby, T. M., & Armas, C. (2007), *Structure and function of root systems*. In *Functional plant ecology*, pp. 151-174.
- [26] Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., & Barea, J. M. (2003), *The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility*. *Biology and fertility of soils*, 37, pp. 1-16.
- [27] Kenis, K., & Keulemans, J. (2007), *Study of tree architecture of apple (*Malus× domestica* Borkh.) by QTL analysis of growth traits*. *Molecular Breeding*, 19, pp. 193-208.
- [28] Lehmann, J. (2003), *Subsoil root activity in tree-based cropping systems*. In *Roots: The Dynamic Interface between Plants and the Earth*. The 6th Symposium of the International Society of Root Research, pp. 319-331.
- [29] Lungu Constantineanu, C. S. (2015), *Holistic Survey of a Degraded Soils cape from Eastern Romania: Hypothesis of Reclamation and Social-Economical Development*. Tesi di dottorato, Università degli Studi di Palermo
- [30] Morales-Olmedo, M. G., Sellés, G., Pinto, M., & Ortiz, M. (2021), *Full-field characterization of sweet cherry rootstocks: responses to soil with different air-filled porosities*. *Plant and Soil*, 469, pp. 457-473.
- [31] Moraru, S. S., Ene, A., & Badila, A. (2020), *Physical and hydro-physical characteristics of soil in the context of climate change. A case study in Danube river basin, SE Romania*. *Sustainability*, 12(21), p. 9174.
- [32] Pallardy, S. G. (2010), *Physiology of woody plants*. Academic Press.
- [33] Paltineanu, C., Nicolae, S., Tanasescu, N., Chitu, E., & Ancu, S. (2017), *Investigating root density of plum and apple trees grafted on low-vigor rootstocks to improve orchard management*. *Erwerbs-Obstbau*, 59(1), pp. 29-37.
- [34] Parandiyal, A. K., Kaushal, R., & Chaturvedi, O. P. (2018), *Forest and fruit trees-based agroforestry systems for productive utilization of ravine lands*. *Ravine lands: greening for livelihood and environmental security*, pp. 361-383.
- [35] Petry, H. B., Mazurana, M., Marodin, G. A. B., Levien, R., Anghinoni, I., Gianello, C., & Schwarz, S. F. (2016), *Root distribution of peach rootstocks affected by soil compaction and acidity*. *Revista Brasileira de Ciência do Solo*, 40.
- [36] Pinochet, J. (2010), *Plum–almond hybrid rootstock for replant situations*. *HortScience*, 45(2), pp. 299-301.
- [37] Priori, S., Pellegrini, S., Vignozzi, N., & Costantini, E. A. (2020), *Soil physical-hydrological degradation in the root-zone of tree crops: problems and solutions*. *Agronomy*, 11(1), p. 68.
- [38] Przybyłko, S., Szpadzik, E., Marszał, J., Kowalczyk, W., & Wrona, D. (2022), *Different floor management systems affect soil properties and initial development of apple tree (*Malus× domestica* Borkh.) in an orchard*. *Agriculture*, 12(12), p. 2070.
- [39] Radha, T., Mathew, L. (2007), *Fruit crops*. New India Publishing, 3.
- [40] Remy, P., Bidabe, B. (1962), *Root asphyxia and collar rot in pome fruit trees. The influence of the rootstock*.
- [41] Rowe, R. N., & Beardsell, D. V. (1973), *Waterlogging of fruit trees*.
- [42] Ruiz-Sánchez, M. C., Plana, V., Ortuño, M. F., Tapia, L. M., & Abrisqueta, J. M. (2005), *Spatial root distribution of apricot trees in different soil tillage practices*. *Plant and soil*, 272, pp. 211-221.
- [43] Saied, A.S., Gebauer, J., Hammer, K., Buerkert, A. (2008), *Ziziphus spina-christi (L.) Willd.: a multipurpose fruit tree*. *Genetic Resources and Crop Evolution*, 55, pp. 929-937.
- [44] Sánchez, E.E., Giayetto, A., Cichón, L., Fernández, D., Aruani, M. C., & Curetti, M. (2007), *Cover crops influence soil properties and tree performance in an organic apple (*Malus domestica* Borkh) orchard in northern Patagonia*. *Plant and Soil*, 292, pp. 193-203.
- [45] Schaffer, B., Davies, F. S., & Crane, J. H. (2006), *Responses of subtropical and tropical fruit trees to flooding in calcareous soil*. *HortScience*, 41(3), pp. 549-555.
- [46] Schenk, H. J., & Jackson, R. B. (2002), *The global biogeography of roots*. *Ecological monographs*, 72(3), pp. 311-328.

- [47] Sharma, D. D., & Chauhan, J. S. (2003), *Effect of different rootstocks on root distribution of apple*. VII International Symposium on Temperate Zone Fruits in the Tropics and Subtropics-Part Two, 696, pp. 167-171.
- [48] Taylor, N. J., & Gush, M. B. (2014), *The water use of selected fruit tree orchards*. Water Research Commission Report, 14.
- [49] Teskey, B. J. (2012), *Tree fruit production*. Springer Science & Business Media.
- [50] Tracy, S. R., Black, C. R., Roberts, J. A., & Mooney, S. J. (2011), *Soil compaction: a review of past and present techniques for investigating effects on root growth*. Journal of the Science of Food and Agriculture, 91(9), pp. 1528-1537.
- [51] Watson, G. W., Hewitt, A. M., Cusic, M., & Lo, M. (2014), *The Management of Tree Root Systems in Urban and Suburban Settings: A Review of Soil Influence on Root Growth*. Arboriculture & Urban Forestry, 40(4).
- [52] Zhou, P., Qian, J., Yuan, W., Yang, X., Di, B., Meng, Y., & Shao, J. (2021), *Effects of interval flooding stress on physiological characteristics of apple leaves*. Horticulturae, 7(10), p. 331.