Orchards 4 Future –

Education about Climate Change and Adaption

Orchards 4 Future – Education about climate change and adaption

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I Introduction

Fruit growing has played an important role in the cultural landscape for centuries. The genetic diversity of orchards is particularly high with over 6.000 fruit varieties (Flachowsky & Höfer, 2010). Orchards characterize the landscape in many regions. In the course of their development, orchards have become increasingly important as a valuable habitat for many animal and plant species. Today, up to 5.000 species of animals, plants and fungi live here.

Many of these are on the Red List and are threatened with extinction. For this reason, orchards are among the most important and valuable cultural landscape biotopes - yet their existence has been under threat for many decades. Growing settlement areas and infrastructure projects, lack of use, lack of care, intensive agriculture and inappropriate compensatory measures are just some of the problems.

For some years now, the consequences of climate change have also been observed in orchards. Late frost, heat and drought, as well as additional pressure from pests and diseases and new pests such as the Japanese beetle (*Popillia japonica*) or the marmorated stink bug (*Halyomorpha halys*), are some of the challenges in this context. Higher temperatures favour some species of insects (faster succession of generations, more growth) and fungi (e.g. black bark scorch (*Diplodia*)) that damage fruit trees. In addition, damage patterns such as sunburn due to high solar radiation and premature fruit drop due to drought stress can be observed, as well as an increase in extreme events such as heavy rain, frost, hail and storms and a longer growing season. Higher temperatures also result in a more frequent and increased need for water. Windfall fruit spoils more quickly and can therefore no longer be used for the production of juices.

These impacts of climate change particularly affect unmanaged orchards, e.g. with high mistletoe infestation and/or nutrient deficiency. The lack of care has led to and continues to lead to the loss of many orchards, while at the same time, the replanting of young trees is becoming much more difficult under increasingly extreme climatic conditions.

Working to protect orchard meadows therefore also means understanding the challenges of climate change for these biotopes. Currently, many courses on the subject of orchards focus on good pruning. However, it is also necessary to look at the entire environment to derive specific recommendations for action. This means reading the landscape in which fruit trees are located or in which they are planted. It also means to see fruit trees as part of an ecosystem. In particular, more attention should be paid to the soil, i.e. a good supply of water and nutrients. Correct pruning remains a central component of fruit tree care and must be adapted to the climatic conditions (e.g. increased risk of sunburn on the trunk and fruit, branch breakage due to heavy storms).

This paper aims to show which topics and approaches will be of greater relevance in future educational programs. The paper incorporates many approaches that are currently being tested by practitioners in orchard cultivation. Scientific research in the future should show even more precisely how approaches described here actually influence tree health.

II Tackling climate change at the roots – roots & rootstocks

1. The root

The root system of mature fruit trees is typically hidden from view. What we observe is the crown and the trunk, which begins its growth at the soil surface where the root collar ends. Below this point lie the roots, which are usually concealed from sight. However, even if you have not seen them, you likely have a vague notion of what they are like. But what exactly is their shape? Are the roots of fruit trees similar? How deep and wide do they extend? Do their shapes mirror the tree crown? How does the root's shape and size influence its function? These and other questions will be addressed in the following chapter.

What is a root and what are its functions?

The root is a vegetative, usually subterranean organ of woody plants. Its growth is temporally unlimited (Lehká, 2021), meaning it continues to grow throughout the life of the plant. As it spatially expands, the zone from which trees absorb moisture and nutrients also shifts outward from the trunk. However, this shift is not uniform. Growth intensity during a single growing season exhibits periods of activity and dormancy. Tree roots grow minimally at soil temperatures of 0–7 °C and more vigorously at 7–20 °C. Root elongation predominates in April, May and June, followed by a dormancy period interrupted by weaker autumnal growth in September and October (Cifranič, 1956, Fruit Growing). During warm autumns, root growth may continue well later into winter, as evidenced by the formation of new roots in young seedlings dug out during autumn and stored in moist substrates at fruit nursery shops. After the second growth wave, a winter dormancy period ensues, induced by the cold season. This highlights the significance and benefits of early autumn planting for bare-rooted seedlings, which can begin to root partially already during autumn.

Root growth is generally positively geotropic, meaning the roots grow in the direction of gravitational force. However, this does not apply to all roots. Negative geotropic growth (growth against gravitational force) is observed primarily in finer roots responsible for nutrient uptake, which often grow near the soil surface as they search for resources. For instance, in forest ecosystems, roots penetrate the humus layer, and in grassland biotopes, they come into contact with the root systems of grasses and herbs, competing for resources. Roots grow opportunistically, expanding where conditions are favourable. Another characteristic of roots is their hydrotropism, i.e., growth toward more humid soil areas, and hydrotropism, i.e., growth towards water.

When observing often highly idealised illustrations depicting root growth, one might assume that roots develop evenly in the subsurface layer, systematically filling the space beneath the crown. However, it should be recognised that just as the aerial parts of trees exhibit varied crown characteristics, root systems are both species-specific and heavily influenced by the soil properties of the particular location. Factors limiting root system development include soil depth, humus content, the availability of nutrients, the depth of the subsurface water table, and impermeable subsoil layers, which constrain root growth. Additionally, the availability of soil air, which decreases with depth, plays a crucial role. A common misconception is that the root system mirrors the crown.

So, what do roots typically look like? In reality, tree root systems are surprisingly shallow, with long lateral roots spreading close to the soil surface. It is uncommon for trees to develop many deep roots exceeding a depth of 2–3 metres, although some species and specific conditions (e.g. arid regions) can result in roots reaching significantly greater depths (several dozens of metres) (Slavíková, 1989). Most roots grow near the soil surface: 90 % of the number of roots grow only to a depth of 60 cm, and up to 99 % of all roots occupy soil to a maximum depth of 1 metre (Coile, 1937).

While the length of roots growing vertically (downwards) is often overestimated, the horizontal spread of roots is frequently underestimated. The lateral extent of roots typically far exceeds the area covered by the crown's vertical projection (Fig. 1). The area occupied by roots can be 4–7 times larger than the area projected by the crown. Thus, tree root systems in the soil commonly overlap. The root system of a healthy tree can extend 2–3 times beyond the crown's projection, also known as the eaves area, and the total root area of roots may exceed the area of the tree's leaves.

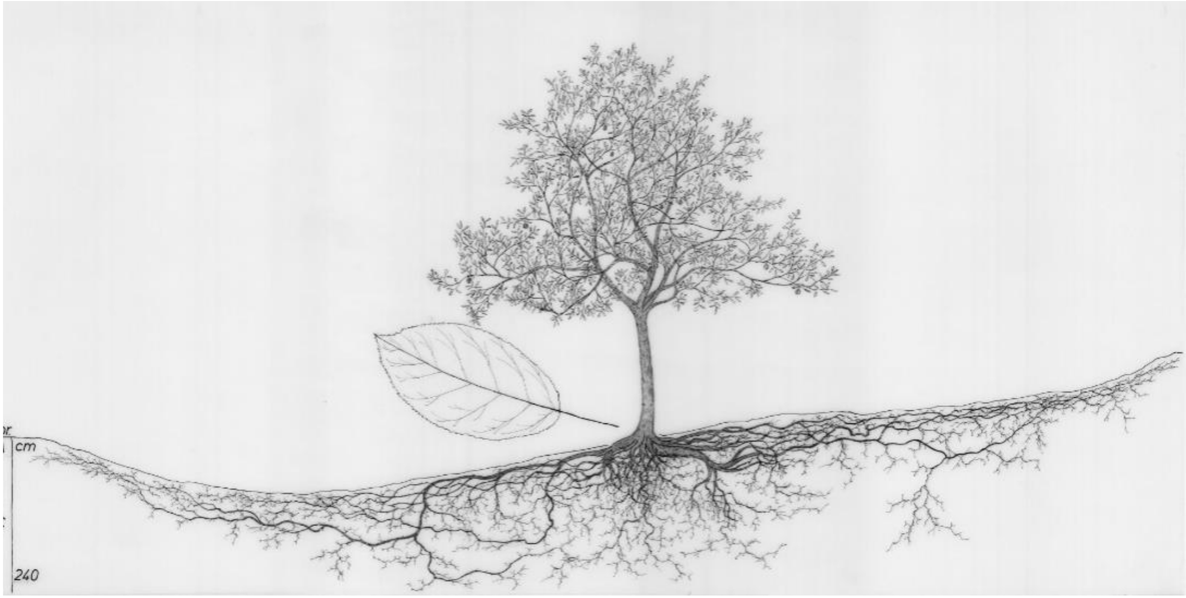


Figure 1 – Root distribution in Malus sylvestris according to Kutcher/Lichenegger (2002)

Similarly, the notion of a taproot may not always align with the reality of the soil environment. The taproot, which naturally develops during the early stages of a tree's life, gradually slows its growth over time. Horizontal lateral roots increasingly take on the role of a structural support for trees. Mechanical damage, diseases, pests (vertebrates, invertebrates, microorganisms), or soil impermeability often result in the absence of a distinguishable taproot within the root system. However, there are significant differences in the root systems of various tree species. Some species have a stronger natural tendency to maintain a prominent taproot or a system of several downward-growing roots. Deeper root systems tend to develop in walnuts, service trees (*Sorbus domestica*), pears, and occasionally cherries. Shallow roots are typical of most other species, including commonly cultivated ones such as apples and plums.

The growth of the taproot typically ceases under unfavourable conditions, such as the aforementioned lack of soil air. Furthermore, it rapidly decreases in thickness as radial and horizontal roots emerge from it. This diminishes the necessity of prioritising direct-seeding of orchards, where trees are grown directly from seed at a permanent site, over nursery-grown seedlings.

Lateral roots, which are formed by branching of the main root, thicken significantly with age. The number of lateral roots in the upper section of the main root is usually low, ranging from four to eleven, and their bases may be visible on the trunk. Near the trunk, these roots can reach diameters of several tens of centimetres. However, their thickness diminishes rapidly with distance; at 2–4 metres from the trunk, they typically measure only 2–5 cm in diameter. At this thickness, they lose most of their rigidity and strength, making them more prone to breaking under strong winds. Nonetheless, in species with vigorous growth, thicker roots may still be observed farther from the trunk than the typical diameters mentioned above.

Beyond the zone of rapid tapering, lateral roots spread outward over many metres, maintaining diameters of 1–2 cm without further significant narrowing. In some species, these roots grow at depths of 10 cm, while in others, they descend diagonally to depths of 20–50 cm before continuing their horizontal growth.

A further layer consists of fine, short-lived roots, which branch out from lateral roots. These are referred to as root hairs, absorption roots, active roots, or feeder roots. Their growth is highly directional, responding to the availability of nutrients and moisture. They thrive in soil that is well-aerated, sufficiently moist, and nutrient-rich. These roots branch profusely, forming dense networks or fans composed of thousands of short (3–4 mm) and thin (0.2–1 mm) non-woody, white rootlets (Dekánek Š., Chlebník, Š., 1969). Their primary function is the uptake of water and nutrients from the soil. The absorption capacity of roots varies across species, resulting in differences in the competitiveness of various tree species.

Surface soil layers often dry out, are exposed to extreme summer heat, and freeze during winter months. These temperature fluctuations frequently damage or destroy fine, non-woody roots. Biotic factors, such as rhizophagous pests, also contribute to root damage, as these organisms feed on the juicy, non-woody roots of trees (Lyford, 1975). Root damage and dieback are therefore common and caused by numerous factors. However, new roots regenerate quickly following damage, with their growth dynamics matching or even exceeding that of leaf formation in the tree's crown.

Roots are also closely associated with the hyphae of mycorrhizal fungi. Mycorrhizal fungi are symbiotic organisms, and two types are distinguished: endomycorrhiza and ectomycorrhiza. In endomycorrhiza, fungal hyphae penetrate the interior of plant cells, whereas in ectomycorrhiza, they remain in the intercellular spaces, often forming a complex network of hyphae. Ectomycorrhizal fungi are notable for producing fruiting bodies – mushrooms – which we consume.

In fruit trees, the association is primarily with endomycorrhiza. This symbiosis is mutually beneficial: the fine fungal hyphae significantly expand the area through which the tree can absorb water and dissolved nutrients from its surroundings. Fungi are more efficient at nutrient uptake than plants, which in return supply the fungi with organic compounds rich in sugars and lipids derived from photosynthesis. According to Sheldrake (2020), more than 90 % of all plant species depend on these relationships.

Moreover, fungi can connect multiple trees, facilitating the transport of nutrients within a complex network of relationships. As noted by Jemrič, Škrlec, Skendrovic, and Blazinkov (2018), fungi can increase fruit tree yields by up to 50 %. Nutrient sharing is also possible due to the naturally occurring „grafting“ of roots among trees of the same species (Perry, 1982).

The practical aspects of mycorrhizal research involve evaluating the relationship between plant nutrition provided by fertilisers and the presence and activity of fungi. Additionally, there is ongoing debate regarding the necessity of applying mycorrhizal preparations (containing only a narrow selection of mycorrhizal species) during the planting of young trees. Equally pertinent is the role of fungi in supporting tree growth under changing climatic and soil conditions, where fungi can mitigate stress caused by waterlogging as well as by water deficits.

In summary, the root system of a tree consists of three primary types of roots.

Close to the trunk, there are thick anchoring roots main function of which is to provide **mechanical stability** by securing the tree in the soil. At a greater distance from the trunk, these roots change into and branch out as transport roots. These are long and provide a structural framework for the **transport of nutrients and water**. From the transport roots arise thin, non-woody absorption roots, the primary role of which is to **take up water and nutrients** from the soil environment.

The root system also performs several additional functions, including:

• **Metabolic function**: The chemical processing of mineral substances and the synthesis of growth regulators occur here.

• **Storage function**: The creation and storage of reserve substances intended to help the tree endure various adverse conditions.

• **Reproductive function** – In some species, root suckers are a significant means of spreading the original plant. New individuals remain part of the life continuum of the parent plant, as they are connected to it via the root system. Among common fruit trees, this phenomenon can be observed in species such as plums, sour cherries, and sweet cherries. If an individual is separated from the parent tree, it can be considered a clone with identical genetic information.

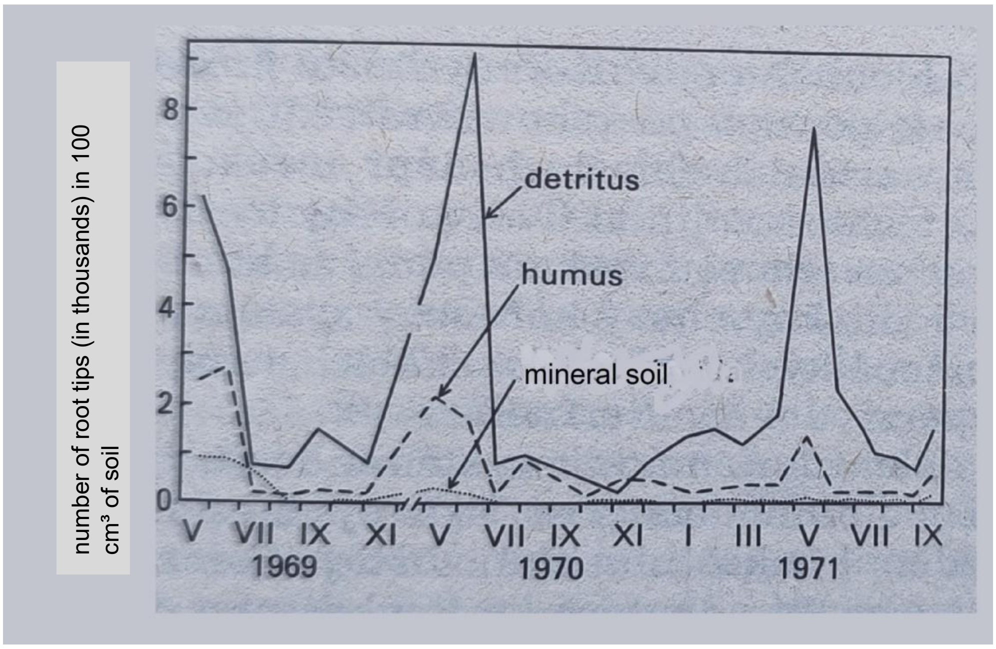


Figure 2- Changes in root density (number of living root tips) over three years across three soil horizons in a forest habitat of acidophilous beech forests (Luzulo–Fagetum) highlight the relationship between nutrient availability and the concentration of roots responsible for nutrient uptake from the soil (Slavíková, 1986)

From the perspective of plant ecology, the roots of fruit trees form an extensive root system, characterized by one or several main anchoring roots growing positively geotropically, as well as long lateral roots that permeate a relatively large volume of soil in comparison to the small surface area and volume of active roots.

As previously mentioned, root growth is opportunistic and dependent on favourable environmental conditions. Thus, the highest root concentration occurs near the surface, where the soil is less compacted and more aerated, and where water and nutrient sources are more accessible (Fig. 2). There is also a relationship between soil fertility and the shape of the root system. In nutrient-rich soils, roots tend to branch extensively, while in nutrient-poor soils, the root systems are characterized by long, slender, poorly branched surface roots.

The groundwater table also affects root growth. Due to the lack of oxygen, roots do not penetrate waterlogged environments but branch out above them, in the zone of capillary rise. However, in most locations, groundwater does not reach levels that would threaten the growth of fruit trees. During drier periods, trees rely on rainwater retained within the soil profile (Dobson, 1995).

The relationship between roots and the crown is also significant (Perry, 1982). The root system is connected to the crown through vascular bundles. This means that if this connection is disrupted, such as when a large portion of roots is removed or dies, it may damage the crown, leading to the death of corresponding parts of leaves and branches or to stress within the whole tree, proportional to the severity of the damage. Similarly, if a tree is repeatedly defoliated, some roots may die.

The above-mentioned can support the hypothesis that the removal of a large portion of branches (particularly the structural ones), such as during rejuvenation pruning, may lead to the death of some of the roots that nourished them. This can subsequently cause further root damage and ultimately reduce the tree's vitality. Whether this occurs depends on the species-specific physiological response of the tree.

The method of nutrient transport between roots and the above-ground part of the plant varies among species. In species with ring-porous wood, such as oak, a specific root is directly connected to a corresponding set of branches, typically on the same side of the tree as the root. The death or damage of roots in trees with such restricted, unilateral vascular systems usually leads to the death of corresponding branches. Other species have different anatomy, where nutrients travel in curved and spiral patterns, indicating that the tree's roots supply all branches and leaves evenly. The death or damage of roots in such trees does not result in the unilateral death of parts of the crown.

Tree anatomy can vary even within species, and the mechanism of connection between the root and above-ground parts of the plant is not well-known for most species. However, root death always impacts tree vitality, observable in its above-ground parts.

In older trees, where rejuvenation pruning is considered as part of care, two unrelated but combinable phenomena commonly occur. The first is drying of the crown in its lower parts. Large structural branches dry out, leaving wounds several centimetres wide after removal, which the tree cannot heal during its lifetime. This drying of branches is unrelated to root vitality loss but is caused mainly by shading of the lower parts of the crown. Simply put, the tree no longer needs these branches for nutrition. Preventive measures include quality formative and carefully planned, timely maintenance pruning.

A different situation occurs when branches at the top of the tree dry out. This signals poor physiological health of the tree, leading to the gradual dying of the root system, making the tree unable to nourish the higher branches. Over time, individual branches and eventually the entire tree dies. This can be delayed by creating favourable growing conditions for the tree.

For fruit trees, another categorization of root systems is worth mentioning. Although simple, it is crucial for tree growth, size, and survival potential. It relates to the way how the individual tree originated.

The first way is the generative form, where the tree grows from a seed. In this case, the root system is larger, less dense, and forms a main taproot. It could be said that it has a more natural character with tree development. These roots typically tolerate less favourable natural conditions, anchor the tree well in the soil, and support long life spans.

The second method is vegetative reproduction. This typically includes using a part of the plant, such as a stem, containing areas with meristematic (dividing) cells. These cells, such as buds, can create new structures and specialize in new functions, such as root formation. These roots are called adventitious roots and have a different growth hierarchy than those from generative reproduction. For example, the taproot is absent. Adventitious roots have specific characteristics. They usually grow weaker than the roots of trees propagated generatively. However, these trees often have earlier and higher fruit production.

When discussing roots and parts of the stem in fruit trees, we often refer to rootstocks. Therefore, the following section will focus on them in more detail.

2. Fruit tree rootstocks

The propagation of fruit trees is a complex issue that involves various methods and techniques in practice. The natural mode of tree propagation is sexual, or generative reproduction, in which a new individual grows from the seed of the parent tree. However, plants also commonly use asexual, or vegetative, propagation methods, which can also be described as expansion. In nature, both types of reproduction occur, sometimes even within the same species or individual (for example, in plums, sour cherries, sweet cherries, and sea buckthorn). Generative reproduction is more commonly utilized for several reasons, with one of the key advantages being the genetic diversity in offspring, which may lead to improved traits compared to the parent plants. This genetic variation serves as an essential mechanism for evolution. Vegetative propagation, which occurs naturally in the form of root suckers, results in new individuals with identical genetic information to the parent tree, typically growing in its vicinity. This can be limiting in the long term.

In human-managed fruit tree propagation and cultivation, both generative and vegetative methods are used, often in combination.

Generative propagation is used when:

- The goal is to breed a genotype with new desirable traits. If successful, further propagation of this plant may result in the development of a new cultivar.
- Variability in offspring is not a concern because the species reliably retains key characteristics, including fruit quality, from the parent tree. This is the case for certain fruit trees and shrubs such as peaches, chokeberries, serviceberries, chestnuts, almonds, and service trees. However, in most cases, offspring do not reliably inherit the characteristics of parent trees.
- The primary purpose of the fruits is not for food consumption but for seed production, with seedlings grown as rootstocks. The traits of such seedlings are largely empirically predictable. The objective is typically to cultivate long-lived trees and maximize the adaptability and resilience of the root system. These seedlings are later grafted with a selected cultivated variety.
- Local, well-adapted ecotypes of wild fruit trees are preserved and expanded to establish viable, deliberately planted populations.

Vegetative propagation is used when:

- The goal is to maintain a specific cultivated variety and to ensure that its traits are consistently passed on to new individuals.
- The species can be easily propagated from vegetative parts that root readily, such as cuttings, layers, or suckers. This is common for many shrubs, including hazelnuts, currants, jostaberries and gooseberries. Such plants are made up of a single organism and are therefore referred to as own-rooted plants.
- Some species are not propagated by seed due to their very small seeds and the delicate nature of seedlings, which require specialized agronomic techniques. Examples include raspberries, strawberries, currants, chokeberries, gooseberries and sea buckthorn. In such cases, propagation via cuttings is a simpler approach.

- Specific traits of a plant are desired for use in rootstock propagation. Although the selected individual may not produce high-quality fruit, other characteristics — such as growth vigour, fertility, or resistance to biotic and abiotic factors — are of greater importance.
- Certain species do not reliably produce viable seeds under local conditions (such as subtropical species or black mulberry, medlars), or waiting for generative offspring is not feasible.

2.1 Characteristics and Role of Rootstock

A rootstock is a plant specifically selected to be grafted with another plant. Once joined with the second component, the rootstock forms the root system and a portion of the stem (trunk) of the resulting plant. The second component represents the cultivated variety, which constitutes the remaining above-ground parts of the final tree — specifically, the upper stem and the crown. The technique used to combine these two components is called grafting.

Plants created through grafting are not own-rooted because their roots originate from a different plant than their crown. The ability of plants to form a strong graft union is commonly observed at the root level in nature but is relatively rare in the crown, where frequent movement occurs. However, natural graft formations may have inspired humans to experiment with grafting techniques. While some evidence suggests even earlier origins, the first verifiable written record of grafting comes from Greece and is found in a treatise by Hippocrates, dated around 424 BCE (Mudge et al., 2009).

2.2 The Function of the Rootstock

According to Bílek and Hanuš (1984), the primary function of the rootstock is to anchor the tree in the soil with its roots and to supply nutrients and water to the plant. However, the influence of the rootstock extends beyond these fundamental roles, affecting various aspects of tree growth and fruit production, including:

- the vigour of the tree and its ultimate size;
- the lifespan of the individual tree;
- the onset of fruiting and overall yield;
- the characteristics of the fruit, such as size, colouration, storability, and biochemical composition;
- the tree's resistance to biotic and abiotic factors, including its ability to thrive in different soil conditions and efficiently absorb water and nutrients.

The grafted cultivar possesses distinct characteristics that influence the overall tree morphology, or habitus. These characteristics include the tree's overall appearance, crown shape, branching pattern, and the specific traits of leaves, flowers, buds, and, of course, fruits. Additionally, the cultivar determines phenological phases and resistance to both biotic and abiotic factors. The cultivar also affects the rootstock, either stimulating or suppressing its growth, which in turn influences the final size of the entire tree. The influence of various factors on the fertility of a tree is shown in Table 1.

Factor	Influence (%)
Cultivar	27
Rootstock	20
Precipitation	19
Temperature	8
Management	7
Soil type	3
Other factors (pruning, nutrition)	16

Table 1– Influence of selected factors on tree fertility (source: Vachůn, 1996/ Nečas, 2013)

2.3 Types of Rootstocks

The fundamental classification of rootstocks is based on their method of origin, dividing them into **generative (seedling)** and **vegetative (clonal)** rootstocks.

Generative rootstocks originate from seeds. According to Nečas et al. (2016), seedling rootstocks exhibit strong affinity (the ability to successfully graft and form a solid union with the scion), higher frost resistance, and greater resistance to pathogens. A key characteristic of seedling rootstocks is their variability, though they generally demonstrate vigorous growth and high vitality. Mature trees grafted onto seedling rootstocks tend to be large and well-suited for marginal locations and suboptimal growing conditions, including adverse climatic changes.

These trees develop not only a large above-ground structure but also an extensive root system. Their robust root architecture provides superior anchorage, greater tolerance to varying soil conditions, and enhanced water and nutrient uptake from a larger soil volume. Cultivating seedling rootstocks at home orchards is relatively straightforward for most species. Even today, large, long-lived apple, pear, and cherry trees can be found in the countryside. These are almost certainly grafted onto wild-type seedling rootstocks derived from original botanical species. Naturally occurring young seedlings were often selected and utilized for this purpose in agricultural landscapes.

However, according to Nečas et al. (2016), one disadvantage of seedling rootstocks, particularly of those derived from specific cultivated varieties, is their unpredictable and variable susceptibility to pathogens, as well as the genetic heterogeneity of the resulting seedlings. This variability can sometimes be advantageous. Currently, a large proportion of European fruit trees are propagated using only a few rootstock types, which poses a risk if diseases, pests, or other environmental stressors emerge that specifically target these widely used rootstocks. Nevertheless, many key characteristics of individual seedlings and their quality can be assessed early during nursery cultivation. In Table 2 we present selected fruit trees and seed rootstocks suitable for self-help nursery:

Seedling rootstocks for selected fruit tree species, also suitable for home nursery cultivation

apple tree	Seedling of a selected variety (*Malus domestica*), e.g., Jadernička moravská / Kuhländer Gulderling, Antonovka, Strýmka/Bohnapfel – diverse growth, usually good affinity with cultivated varieties
	Seedling (*Malus domestica* × *Malus sylvestris*) – diverse but predominantly vigorous growth, good anchorage in soil, high resistance to frost and drought, later onset of fruiting, longevity, suitable for larger cultivation forms and trees in large gardens, alleys, and orchards
	Wild apple (*Malus sylvestris*) – variable but often vigorous growth, good soil anchorage, high resistance to frost, drought, and asphyxia, good affinity with cultivated varieties, later onset of fruiting, longevity, suitable for larger cultivation forms and trees in large gardens, alleys and orchards
pear tree	Seedling of a cultivated variety (*Pyrus communis*), e.g., Solnohradka / Salzburger Birne pear, Špinka / Gute Graue, Muškatelka šedá / Graue Muskattelerbirne / Gray Muscatel, Boscova fľaša / Boscs Flaschenbirne / Bosc's bottle pear, Pastornica / Pastorenbirne – variable but often vigorous growth
	Seedlings of a semi-cultivated variety (*Pyrus communis*) – vital, long-lived, vigorous seedlings of local and regional varieties
	Wild pear (*Pyrus pyraster*) – variable but predominantly vigorous growth, thorns, tolerates calcareous soils, highly frost-resistant, requires regular root pruning to develop a strong and branched root system, good affinity, suitable for marginal growing areas (poorer soils, higher altitudes), later fruiting onset, longevity, suitable for larger cultivation forms and trees in large gardens, alleys, and orchards
	Birch-leaved pear seedling (*Pyrus betulaefolia*) – variable growth, tolerates alkaline soils with high lime content, resistant to woolly pear aphid and septoria leaf spot
Asian pear	Seedling of a semi-cultivated variety (*Pyrus communis*)
	Wild pear (*Pyrus pyraster*)
cherry, sour cherry	Wild cherry seedling (*Cerasus avium*) – vigorous growth, strong root system, suitable even for heavier soils, frost-resistant, more resistant to gummosis, long lifespan, suitable for larger cultivation forms (half-standard, standard trees)
	mahaleb cherry seedling (*Cerasus mahaleb*) – medium to vigorous growth, shorter lifespan, suitable for harsher conditions and dry, rocky soils, tolerates high lime content, does not tolerate waterlogging, moderately frost-resistant, accelerates fruiting onset
mulberry	white mulberry seedling (*Morus alba*) – used for Morus alba or Morus nigra if propagated to create an own-rooting tree; grafting should be done as low as possible with deep planting (the grafting point at least 15 cm below soil surface), white-fruited forms preferred for better germination and growth
	black mulberry seedling (*Morus nigra*) – very difficult to obtain in local conditions of most central European countries as seeds do not mature enough to be viable

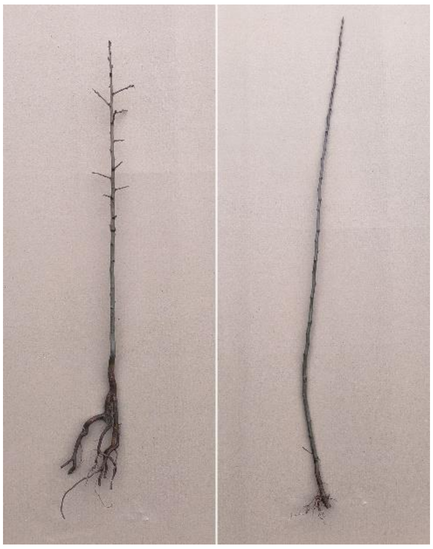
plums, greengages, mirabelles	Myrobalan seedling (*Prunus cerasifera*) – variable but usually vigorous growth, strong root system, suckering tendency, delays fruiting and reduces specific yield (crop relative to canopy volume), highly adaptable – suitable for dry and gravelly soils, as well as heavy and wet soils and marginal locations, unsuitable for apricots and late varieties in fertile, wet soils, as the wood of grafted varieties may not ripen properly, variable susceptibility to plum pox virus, prolonged sap flow period
	MY-BO-1 (*Prunus cerasifera*) – selected myrobalan with more uniform progeny, good frost resistance, fewer suckers, good bud acceptance, tolerant to plum pox virus, suitable for drier areas, trees end vegetation later, it is rarely used due to lack of seed sources
	Plum seedling (*Prunus domestica*) of variety Belica/Gelber Spilling – very variable growth, suitable for heavier and wetter soils
	Plum seedling (*Prunus domestica*) of variety Duranzia – medium growth, suitable for wetter soils, adaptable to both warm and cold regions, broad affinity, suitable for heavier soils (also for apricots), early sap loss
	Plum seedling (*Prunus domestica*) of variety Greengage / Große Grüne Reneklode – very variable, predominantly medium growth, earlier fruiting compared to myrobalan and standard seedlings, suitable for medium-heavy, heavy, and wetter soils, also suitable for apricots
	Plum seedling (*Prunus domestica*) of variety Wangenheim – very variable growth, generally 30–40 % weaker than myrobalan, does not form root suckers, accelerates fruiting, good yield, requires fertile and wetter soils, intolerant to drought, frost-resistant, also suitable for apricots
	Blackthorn (*Prunus spinosa*) – weak growth
apricot	apricot seedling (*Prunus armeniaca*) – suitable for quality, well-aerated, lighter soils, intolerant to heavy soils, high carbonate content, has a strong root system
	myrobalan (*Prunus cerasifera*) – suitable for dry and light soils, unsuitable for late and vigorously growing apricot varieties, as well as for fertile, wet soils in marginal areas, where the wood of grafted varieties may not ripen properly
	plum seedling (*Prunus domestica*) of variety Wangenheim and Green Greengage – suitable for wetter and heavier soils in marginal areas
	plum seedling (*Prunus domestica*) of variety Duranzia – suitable for wetter and heavier soils in warmer regions
medlar	medlar seedling (*Mespilus germanica*) – vigorous growth, strong root system, difficult to obtain locally due to immature seeds
	hawthorn seedling (*Crataegus monogyna*) – on this rootstock the fruits of the medlar are the most flavorful, medium-growth, drought-resistant
	pear seedling (*Pyrus communis, Pyrus pyraster*) – the most vigorous growth

peach	peach seedling (*Prunus persica*) – vigorous growth, intolerant to calcareous soils, suitable for heavy clay soils but not overly wet ones, long lifespan
	Montclar® (selected peach seedling – *Prunus persica*) – medium vigorous growth (70–75 % of standard seedlings), frost-resistant, long-lived, partially sensitive to plum pox virus, phytophthora, nematodes, partially resistant to bacterial canker and verticillium wilt
	GF-305 (selected peach seedling – *Prunus persica*) – medium vigorous growth (70–75 % of standard seedlings), suitable for heavy, wet soils, intolerant to calcareous soils, less frost-resistant, highly susceptible to plum pox virus, partially sensitive to phytophthora and nematodes, partially resistant to bacterial canker and verticillium wilt
	Rubira (selected peach seedling – *Prunus persica*) – vigorous growth (90 % of standard seedlings), increases fruit yield, less frost-resistant, intolerant to calcareous soils, partially sensitive to phytophthora and nematodes, partially resistant to bacterial canker and verticillium wilt
	almond seedling (*Amygdalus communis*) – medium growth, suitable for dry soils and high lime content of soils, long-lived, poor transplant tolerance, high risk of drying out in winter after transplanting
rowan (mountain ash)	Rowan seedling (*Sorbus aucuparia*)
almond	seedling (*Amygdalus communis*) – strong growth, for drier soils and soils with a higher lime content, longevity, poorly tolerates transplanting, high risk of winter drying out when transplanting
walnut	common walnut seedling (*Juglans regia*)
	black walnut seedling (*Juglans nigra*)
hazelnut	Turkish hazel (*Corylus colurna*) – used for standard-shaped hazelnut trees, initially slow growth, variable growth
elder-berry	elderberry seedling (*Sambucus nigra*)
Rowan -pear hybrid (sorbo pyrus)	seedling of a semi-cultivated variety (*Pyrus domestica*)
	wild pear (*Pyrus pyraster*)

Table 2– Seedling rootstocks for selected fruit tree species, also suitable for home nursery cultivation.

Vegetative Rootstocks. This group of rootstocks is not derived from seeds. They are obtained by separating specific parts from the mother plant before or after rooting. There are several techniques, depending on the different abilities of the woody plants to root from vegetative parts. For trees, these parts are mainly rooted shoots (in the propagation technique of offsets or mound layering) and cuttings (in the technique of propagation by cuttings). Other well-known techniques, such as clump division and layering, are used mainly for shrubs. A relatively new form of vegetative propagation of rootstocks is the in vitro method, where plants are cultured on a nutrient medium under sterile laboratory conditions. This form of plant propagation uses shoot tips, buds, or cells from meristematic tissues. An overview of the types of vegetatively propagated rootstocks is presented in Table 3.

Vegetatively propagated rootstocks also have their specific features. A major advantage in terms of use is their great variety, particularly concerning growth strength. For most species, it is possible to grow trees with weak, medium, or strong growth by selecting an appropriate rootstock. In other words, trees can be bred to be low, medium-sized, or large at maturity. Vegetatively propagated rootstocks also have uniform and predictable properties consistent with the mother plant. Another advantage is high fertility and a faster onset of fruiting. According to Nečas et al. (2016), less favourable characteristics include problematic affinity (in some types), weaker root systems, even in strongly growing rootstocks, lower adaptability to various soil conditions, and associated higher care requirements. From an ecosystem perspective, unlike large trees, they provide ecological functions to a lesser extent and quality.



In practice, customer dissatisfaction with the development and growth of young fruit trees grafted onto weak-growing rootstocks is a common phenomenon. This is mainly due to a lack of knowledge regarding proper care, which includes mechanical support for the trees, regular irrigation, fertilization, root competition management, and more frequent pruning. In simplified terms, weak-growing rootstocks are not suitable for more demanding cultivation conditions typical of extensive orchard systems or less suitable growing areas.

Figure 3 - Comparison of the root system of generatively and vegetatively propagated rootstocks. On the left side of the picture is a one-year old pear seedling (Pyrus pyraster), on the right is a one-year-old offset from the mother plant of the type rootstock MM106. Photo: B. Jakubek.

By combining rootstock and variety, four growth combinations can occur according to Peiker et al. (1965):

1. Strong-growing rootstock – strong-growing variety: This combination leads to long-lived and large trees with late fruiting, suitable for poorer cultivation conditions.
2. Strong-growing rootstock – weak-growing variety: The rootstock ensures good tree anchorage in the soil and supports the growth and longevity of weak-growing varieties, enabling the use of more demanding varieties in marginal areas with lower care.
3. Weak-growing rootstock – strong-growing variety: This combination is used in intensive fruit growing to maintain high-quality but strongly growing varieties on low trunk forms.
4. Weak-growing rootstock – weak-growing variety: The trees have weak growth, are short-lived, and quickly age, are poorly anchored in the soil, but have high fertility. They are suitable for intensive plantings with adequate care.

In the above combinations of rootstock and variety, we find guidance on how to select a tree for planting. If the requirement is vitality and the ability to survive in the open field without intensive care, it is necessary to choose strong-growing, generatively propagated rootstocks and also to choose suitable varieties that are characterized by more robust growth and slower onset of fruiting. If we have good soil, a smaller plot, and expect adequate care for the planted trees, more demanding trees can be chosen. A good compromise for gardens is medium-growth trees that do not require support or supplemental irrigation, bear fruit earlier and are easier to maintain with pruning.

Before selecting the right rootstock, let us ask the following questions:

- Will the rootstock handle the soil and climatic conditions of the location?
- Does it have a good affinity with the grafted variety?
- Will the necessary maintenance be provided (support, pruning, irrigation, soil cultivation, fertilization, etc.)?
- When can we expect the onset of fruiting?
- What is the intended use of the fruit — for direct consumption or processing?
- What planting density (spacing) of the trees do we plan?
- What is the maximum acceptable height of the trees?

Vegetative rootstocks for selected fruit tree species

apple tree	**M9** – weak growth (25-30 % of the apple seedling), small root system, shallow rooting, the tree requires irrigation but does not tolerate waterlogging well, requires cultivation without grassing and lifelong support, frost-resistant, partially susceptible to woolly aphids, very susceptible to fire blight and crown gall (*Agrobacterium tumefaciens*), partially resistant to powdery mildew and to root collar rot, partially resistant to crown rot, produces fruit abundantly, accelerates the onset of fruiting and increases yield, also increases fruit size, suitable for low forms – bush trees
	M26 – cross between M16 x M9, weak growth (40-55 of apple seedling), but stronger than M9, dependent on location, small root system, but larger than M9, requires irrigation, does not require lifelong support, frost-resistant, accelerates the onset of fruiting and increases yield, but less than M9, highly susceptible to fire blight, partially susceptible to viruses, moderately resistant to root collar rot, partially susceptible to crown gall, (*Agrobacterium tumefaciens*), moderately resistant to crown rot, poorly tolerates transplantation, produces few suckers, suitable for low forms – bush trees and quarter standard tree
	M7 – moderately strong growth (60-70 % of apple seedlings), root system richer than M9, suitable for poorer and drier soils than M9, does not require lifelong support, frost-resistant, does not accelerate the onset of fruiting, partially tolerant to viruses, partially susceptible to woolly aphids, partially resistant to fire blight, partially resistant to root collar rot, partially susceptible to crown gall (*Agrobacterium tumefaciens*) and crown rot, tolerates transplantation well, produces more suckers, suitable for all areas, suitable for quarter standards and half standards
	MM106 – cross between M1 x Northern Spy, moderately strong growth (65-80 % seedling), suitable for slopes, accelerates the onset of fruiting and increases yield, suitable for all areas, frost-resistant, (partially) resistant to woolly aphids, partially susceptible to fire blight, partially susceptible to powdery mildew, very susceptible to crown gall (*Agrobacterium tumefaciens*), partially susceptible to crown rot, produces few suckers, suitable for quarter standards, half standards, feathered, and freely growing bush trees
	A2 – strong growth similar to the seedling, very frost-resistant, multiplies well by suckers, does not form suckers, but loses sap early, making it more suitable for Forkert grafting, accelerates the onset of fruiting compared to seedlings and increases yield, partially sensitive to fire blight, phytophthora, woolly aphids and root collar rot.
pear tree	**Quince BA-29**: derived from the Provençal quince, this rootstock has medium growth (50-70 % of a pear seedling) and is moderately frost-resistant (down to -18 °C). It has a shallow root system and requires irrigation. It accelerates the onset of fruiting and increases yield but is somewhat susceptible to fire blight, less resistant to high groundwater levels and is not compatible with all pear varieties
	Fox 11: A medium-strength rootstock (60-70 % of a pear seedling), slightly stronger than Quince BA-29, it has deeper roots, making it more drought-resistant, doesn't need permanent support and is more tolerant of calcareous soils, also accelerates the onset of fruiting and increases yield

	Fox 16: similar to Fox 11, but slightly less tolerant of calcareous soils, has deep roots and is drought-resistant, accelerates the onset of fruiting and increases yield
	Fox 9: similar to Fox 11, with medium growth and deep roots, making it drought-resistant, accelerates the onset of fruiting slightly more than Quince BA-29 and creates minimum suckers
	OHxF (Old Home x Farmingdale): hybrid rootstock, resistant to fire blight and has deep roots, it is frost-resistant and compatible with most pear varieties, generally improves fruiting and accelerates the onset of fruiting
	OHxF 333: moderately vigorous rootstock (50-70 % of a pear seedling), moderately to highly frost-resistant (down to -23 °C), and somewhat resistant to pests like aphids and diseases like fire blight, it is more tolerant of calcareous soils than Quince BA-29, although less than Fox 11, it may reduce fruit size but is considered comparable or even superior to Quince BA-29
cherry, sour cherry	**GiSelA 3®** – an interspecific hybrid of *Prunus cerasus* Schattenmorelle x *Prunus canescens*, strong growth during the first two years, which significantly slows down with the onset of fruiting (30-50 % of cherry seedlings), accelerates the onset of fruiting and promotes balanced fruit production, requires permanent support, well compatible with cherries and sour cherries, does not create suckera, frost-resistant, encourages horizontal branching.
	GiSelA 5® – an interspecific hybrid of *Prunus cerasus* Schattenmorelle x *Prunus canescens*, weak to moderately vigorous growth (45-50 % of cherry seedling), accelerates onset of fruiting and promotes balanced fruit production, does not require permanent support, well compatible with cherries and sour cherries, does not create suckers or only slightly, frost-resistant, encourages horizontal branching, partially susceptible to Phytophthora, crown gall (*Agrobacterium tumefaciens*), and bacterial canker, tolerates transplantation moderately
	GiSelA 6® – an interspecific hybrid of *Prunus cerasus* Schattenmorelle x *Prunus canescens*, moderately vigorous growth (approx. 60 % of cherry seedling), accelerates onset of fruiting and promotes balanced fruit production, does not require permanent support, well compatible with cherries and sour cherries, does not create suckers or only slightly, frost-resistant, encourages horizontal branching, less demanding on soil than GiSelA 5, tolerates heavier soils but not high groundwater levels, partially susceptible to Phytophthora, bacterial canker, and partially resistant to crown gall (*Agrobacterium tumefaciens*), tolerates transplantation moderately
	GiSelA 12® – interspecific hybrid of *Prunus cerasus* Schattenmorelle x *Prunus canescens*, moderately vigorous growth (55-75 % of cherry seedling), accelerates the onset of fruiting and promotes balanced fruit production, does not require permanent support, well compatible with cherries and sour cherries, does not create suckers, frost-resistant, encourages horizontal branching, less demanding on soil than GiSelA 5 and 6, tolerates heavier soils, even slightly waterlogged, but prefers sandy, lighter soils, better tolerates dry and hot summer positions than GiSelA 6, but is the most demanding rootstock in the nursery, combines well with very fertile and self-pollinating varieties, is more wind-resistant than GiSelA 6, partially susceptible to Phytophthora, bacterial canker, and

	partially resistant to crown gall (*Agrobacterium tumefaciens*).
	GiSelA 13® – an interspecific hybrid of Prunus cerasus Schattenmorelle x Prunus canescens, accelerates the onset of fruiting and promotes balanced fruit production, does not require permanent support, well compatible with cherries and sour cherries, does not create suckers, frost-resistant, encourages horizontal branching, suitable for self-pollinating varieties prone to over-fruiting, suitable for poorer soils and areas, accelerates spring bud burst, more drought-resistant compared to GiSelA 5 (requires about 30-35 % of the water compared to GiSelA 5)
	Colt – interspecific hybrid of *Prunus avium* F299/2 x *Prunus pseudocerasus*, moderately strong to strong growth (75-90 % of cherry seedling), does not accelerate onset of fruiting, less frost-resistant, does not require permanent support, well compatible with cherries and sour cherries, partially resistant to Phytophthora and bacterial canker, very susceptible to nematode damage, partially susceptible to crown gall (*Agrobacterium tumefaciens*), tolerates transplantation moderately, does not create suckers
plums, gages, mirabelle plums	**Wavit®** – clonal selection of the Wangenheim variety, moderately strong growth (approx. 60 % compared to seedling), compatible with all plums, gages, mirabelle plums, frost-resistant, does not require permanent support, does not create suckers, handles autumn transplanting well.
	Ishtara® – multiple hybrid (*Prunus cerasifera x Prunus salicina*) x (*Prunus cerasifera x Prunus persica*), moderately strong growth (approx. 70 % compared to seedling), compatible with all plums, gages, mirabelle plums, accelerates the onset of fruiting, does not require permanent support, requires soil sufficiently supplied with moisture, partially resistant to Phytophthora and nematodes, very susceptible to bacterial canker, partially susceptible to PTSL and verticillium wilt, creates few suckers, handles autumn transplanting well
	St. Julien A – moderately strong growth (approx. 75 % compared to seedling), compatible with all plums, gages, mirabelle plums, frost-resistant, does not require permanent support, partially resistant to Phytophthora and bacterial canker, highly susceptible to nematode damage, highly susceptible to PTSL, partially resistant to crown gall (*Agrobacterium tumefaciens*), creates few suckers, less than myrobalan, handles autumn transplanting well.
apricot	**Wavit®** – clonal selection of the Wangenheim variety, moderately vigorous growth (approx. 60 % of seedling), compatible with all plums, greengages and mirabelles, frost-resistant, does not require permanent support, does not sucker, tolerates transplantation well in autumn.
	St. Julien A – moderately vigorous growth (approx. 75% of seedling), compatible with most apricot varieties, frost-resistant, does not require permanent support, partially resistant to Phytophthora and bacterial necrosis, very susceptible to nematode damage, very susceptible to PTSL, partially resistant to crown gall (*Agrobacterium tumefaciens*), partially suckers, less than myrobalan, tolerates transplantation well in autumn

peach	**Wavit®** – clonal selection of the Wangenheim variety, moderately vigorous growth (approx. 60% of seedlings), compatible with all plums, gages, and mirabelles, frost-resistant, does not require permanent support, does not create suckers, tolerates transplantation in autumn well, grafted varieties on it do not suffer from chlorosis in calcareous soils
	Ishtara® – multiple hybrid (*Prunus cerasifera x Prunus salicina*) x (*Prunus cerasifera x Prunus persica*), moderately vigorous growth (approx. 70 % of seedling), compatible with all peaches and nectarines, accelerates the onset of fruiting, does not require permanent support, requires soil sufficiently supplied with moisture, partially resistant to Phytophthora and nematodes, very susceptible to bacterial canker, partially susceptible to PTSL and verticillium wilt, does not create many suckers, tolerates transplantation in autumn well, grafted varieties on it do not suffer from chlorosis in calcareous soils
	St. Julien A – moderately vigorous growth (approx. 75 % of seedlings), compatible with all peaches and nectarines, frost-resistant, does not require permanent support, partially resistant to Phytophthora and bacterial canker, very susceptible to nematode damage, very susceptible to PTSL, partially resistant to crown gall (*Agrobacterium tumefaciens*), creates few suckers, less than myrobalan, tolerates transplantation in autumn well, grafted varieties on it do not suffer from chlorosis in calcareous soils
	GF-677 – interspecific hybrid of peach and almond, strong growth, does not weaken growth compared to seedling or only slightly, does not require permanent support, very susceptible to Phytophthora, crown gall and bacterial canker, moderately resistant to nematodes, very resistant to plum pox, partially susceptible to verticillium wilt, suitable for dry and calcareous soils, tolerates transplantation and autumn planting well, does not like heavy soils with stagnant water
medlar	**Quince BA-29** – rootstock derived from the Provençal quince (*Cydonia oblonga*), with moderately strong growth (50-70 % compared to pear seedlings), it is moderately frost-resistant (down to -18 °C), has a shallow root system, and requires irrigation, does not need lifelong support, accelerates the onset of fruiting, and increases fruit yield. It is very resistant to root-knot nematodes, somewhat susceptible to bacterial fire blight, partially resistant to woolly aphids, and very resistant to crown gall (*Agrobacterium tumefaciens*), it is more tolerant to calcareous soil compared to other quince rootstocks like Quince A or Sydo, tends to create suckers, and it is less resistant to high groundwater levels
almond	**Ishtara®** – A multiple hybrid (*Prunus cerasifera* x *Prunus salicina*) x (*Prunus cerasifera* x *Prunus persica*), with a moderately strong growth (approx. 70 % compared to seedling rootstocks). It is compatible with all almond varieties, accelerates the onset of fruiting, and does not require lifelong support. It prefers soil that is adequately moist, is partially resistant to *Phytophthora* and nematodes, highly susceptible to bacterial canker, somewhat prone to PTSL and verticillium wilt, and produces few suckers.
	GF-677 – an interspecific hybrid of peach and almond, with strong growth, comparable to or only slightly weaker than a seedling rootstock, does not require lifelong support and is highly susceptible to *Phytophthora*, crown gall and bacterial canker, it is moderately resistant to nematodes, highly resistant to plum pox virus, and somewhat prone to verticillium wilt, suitable for dry and calcareous soils, it handles transplanting well, including autumn planting but does not thrive in heavy soils with stagnant water

Table 3– Vegetative rootstocks for selected fruit tree species

However, we usually do not find such a wide selection of rootstocks in fruit nurseries. In the following table, the types of available rootstocks for selected fruit tree species are listed, along with the expected canopy projection in maturity. The data on canopy projection at maturity is approximate and is the result of five key factors in practice. These are environmental conditions, the type of fruit tree, the variety, the rootstock, and, of course, the care provided.

Rootstock type and approximate canopy projection at maturity for selected fruit tree species

apple tree	growth/rootstock		
	weak/M9, M26	moderate /MM106	robust/A2, apple seedling
	approximate crown diameter (m)		
	3	6	8 - 11

pear tree	growth/rootstock		
	weak/Quince BA-29	weak to moderate/ Fox 11	robust/pear seedling
	approximate crown diameter (m)		
	3	3 – 5	8 – 11

cherry	growth/rootstock		
	weak/GiSelA 3,5	moderate /colt, mahaleb cherry seedling, GiSelA 6, 12, 13, GiSelA 17 (between moderate and robust)	robust/wild cherry seedling
	approximate crown diameter (m)		
	3	6 – 7	11 – 12

sour cherry	growth/rootstock		
	weak/GiSelA 3, 5	moderate /colt, mahaleb cherry seedling, GiSelA 6, 12, 13, GiSelA 17 (between moderate and robust)	robust/wild cherry seedling
	approximate crown diameter (m)		
	3	4	6 – 7

plum	growth/rootstock		
	weak/Pixy, Wavit	moderate /St. Julien, Adesoto, selected myrobalan 29C, Montclar	robust/myrobalan seedling
	approximate crown diameter (m)		
	3	4	6

apricot	growth/rootstock		
	weak/ Wavit, Torinel	moderate /St. Julien A, GF-677, selected myrobalan 29C, Montclar, Rubira	robust/apricot seedling, myrobalan seedling, BSB-1
	approximate crown diameter (m)		
	4	5	6

peach	growth/rootstock		
	weak/Wavit	moderate /St. Julien A, GF-677, Adesoto, Ishtara, Montclar, GF-305	robust/peach seedling, BSB-1
	approximate crown diameter (m)		
	3,5	5	6

walnut	growth/rootstock		
	weak/x	moderate/selected walnut seedling and vegetative types (napr. Vlach)	robust/ common walnut seedling (also J. cinerea a J.nigra)
	approximate crown diameter (m)		
	X	8 – 10	12 – 14

morus alba, morus nigra	growth/rootstock		
	weak/x	moderate/x	robust/white mulberry seedling, black mulberry seedling
	approximate crown diameter (m)		
	X	X	10

service tree	growth/rootstock		
	weak/x	moderate/ hawthorn seedling, quince (bad affinity)	robust/service tree seedling
	approximate crown diameter (m)		
	X	?	15 – 20

chestnut	growth/rootstock		
	weak/x	moderate/hybrid C. sativa x C. crenata, C. sativa x C. molissima	robust/ chestnut seedling
	approximate crown diameter (m)		
	X	X	12 – 20

rowan-pear hybrid (sorbopyrus)	growth/rootstock		
	weak/x	moderate/x	robust/ pear seedling
	approximate crown diameter (m)		
	x	X	9 – 11

Table 4– Rootstock type and approximate canopy projection at maturity for selected fruit tree species.

We have been planting trees for a long time. Let's therefore take care when choosing suitable trees. Let's give them sufficient space and appropriate care on our land. They will reward us not only with a harvest. We can observe how they grow, develop and change. Also, they do not bloom just for us. They are a home and source of life for a large number of other organisms.

III The right location

Unfortunately, it is a bitter reality that not all locations are suitable for planting fruit trees anymore. A lack of water and nutrients in particular are limiting factors. On the other hand, due to climatic changes, some locations are now more suitable for growing fruit trees. The importance of good site selection has increased once again due to climatic challenges. Anyone planning to plant a meadow orchard or maintain an existing meadow orchard should first be able to read the respective location to derive the right measures. To be able to evaluate a location, abiotic factors (e.g. climate data, soil samples) must be obtained in advance. Additionally, the location must be examined on-site.

1. Plant dressing and plant spacing

The classic planting systems include the rectangular, square or triangular formation. In the past, fast-growing fruit varieties were planted at least 10 m apart from each other. However, the planting distance should always be adapted to the conditions. For example, the site conditions may require or allow a smaller spacing, as the growth of the trees is not (or no longer) as strong as it used to be. Increasingly, greater consideration should be given to mutual shading during establishment or the possible positive influence of different woody plants. The site conditions under which orchards with high-stemmed varieties on fast-growing rootstocks can survive in the long term under the already changed climatic conditions also depend on the flexibility of the farmer. The tree population to be established or maintained is mostly located on grassland which is managed by mowing and/or grazing.

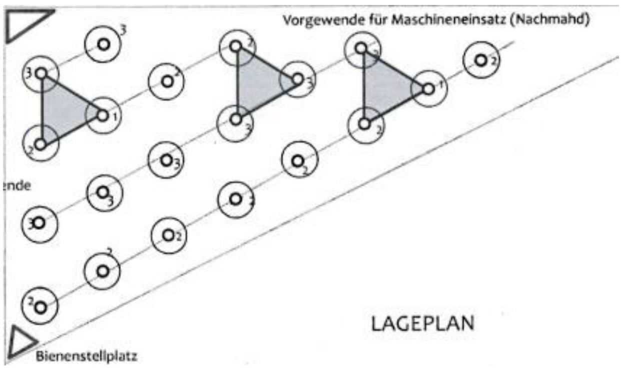


Figure 4- Planting trees in a triangle

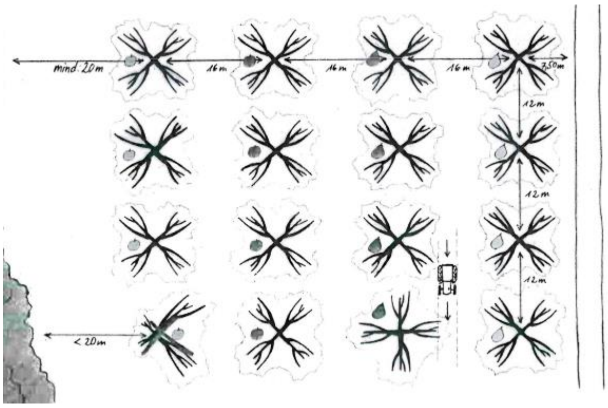


Figure 5 - Planting trees in a square

2. Annual average precipitation

One of the most important site factors is precipitation. Growers need to know the annual total distribution and extremes.

In Poland, a long-term study (1989-2020) determines the average water consumption of different fruit varieties. According to the study, this is 560 mm for apples, 530 mm for pears, 510 mm for sweet cherries and 550 mm for plums during the growing season from April to September (Stachowski et al., 2021). These amounts of precipitation are a prerequisite for optimal tree growth, high yields and high fruit quality.

In dry locations in Central Europe, annual precipitation regularly falls below these values. In commercial fruit growing, this regularly leads to lower vegetative growth and slightly lower yields in areas without supplementary irrigation. If the annual precipitation is below 400 mm, newly planted trees can die. If rainfall is so low for several consecutive years (as it was recently the case in 2018 and 2019), the water reserves in the topsoil layer are not completely replenished in winter. This means that the currently predominant fruit tree species such as apples, pears, plums and cherries at this location may have problems without additional irrigation.

It has not yet been sufficiently investigated whether more warmth-loving fruit species such as mulberries, almonds, walnuts or quinces cope better with decreasing rainfall at these locations. Late frosts are particularly challenging for these species.

An annual precipitation of more than 600 mm is optimal for the establishment of an orchard meadow. Attention must also be paid to the distribution of precipitation. The months from the end of March to July are particularly important for the growth of the plant. During this time, the necessary nutrients must be available through sufficient soil moisture. If there is severe drought during this period, this leads to reduced vitality, even if the total annual precipitation is high.

Too much rain is also challenging for fruit trees. From a precipitation level of 1200 mm, new pests such as Marssonia can endanger fruit trees.

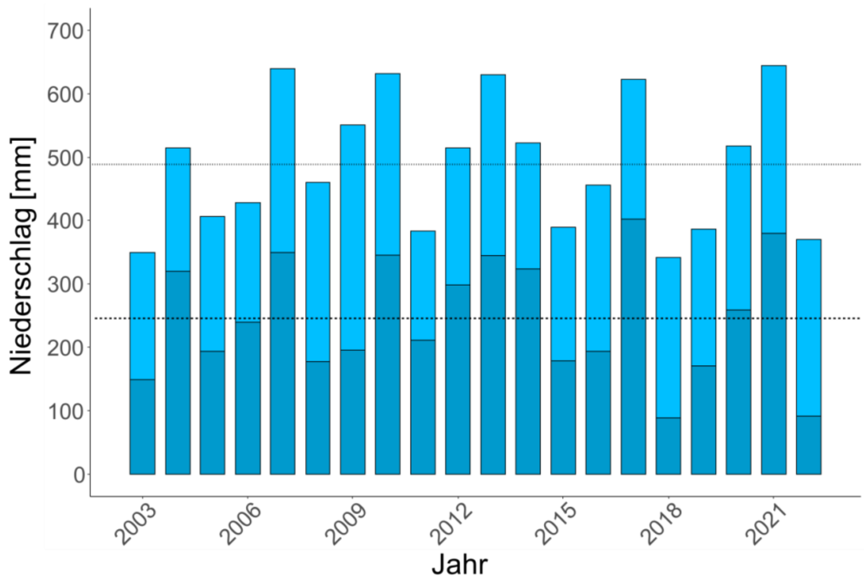


Figure 6- - Annual precipitation and precipitation totals in the months of May to August in Erfurt (Germany), 2003 - 2022

The graph shows the annual precipitation (total bar) and the precipitation sum in the months of May to August (dark blue bar) at the location of the education and research centre for gardening in Erfurt (Germany) in the years 2003 - 2022. The dotted line marks the average annual precipitation in the period 2003 - 2022, and the dashed line is the average precipitation sum in the months of May to August in the same period.

3. Altitude

In some regions of Europe, low altitudes are only suitable for orchards to a limited extent. Here, the pressure from sunburn, drought and pests such as mites, aphids and mildew has increased significantly.

On the other hand, changing climatic conditions mean that high altitudes can be planted with orchards where it was previously not possible. Normally, the temperature decreases by an average of 0.6 degrees per 100 meters of altitude (Bundesamt für Meteorologie und Klimatologie MeteoSchweiz, 2025.) This means that this effect is noticeable from 600 m above sea level. Sometimes the choice of varieties is now crucial to be able to harvest ripe fruits during the growing season. For these locations, summer apple varieties and those with an overall early ripening date in the season are preferable. From an altitude of 600 m above sea level to 1.000 m above sea level, further site parameters must be taken into account. For example, in exposed and wind-prone locations there may be an increased risk of failure.

In a range between 1.000 m above sea level and 1,200 m above sea level, it is difficult to establish a classic orchard meadow in Germany. Preference should be given to favourable locations with appropriate exposure and cold air drainage, or these should be ensured by structural changes.

From a site altitude of 1.200 m above sea level, it is not possible to establish a meadow orchard with tall fruit trees under current climatic conditions, or only in special locations (sheltered from the wind, good soil, etc.).

4. Soil

The soil properties are largely determined by the pore space and the pore size distribution. The pore space is filled with water and/or gas. The size and distribution of the pores depend on the soil texture, the soil structure and the arrangement or storage of the soil particles. Soil texture or particle size distribution, describes the distribution of particle sizes in the soil. Soil texture is divided into sand (coarse particles), silt (medium-sized particles) and clay (fine particles). The soil texture influences the physical properties of the soil.

Fruit trees require a rootable soil horizon of at least 60 cm. For this reason, an analysis of the fractions present and their proportions should be carried out down to this depth.

Figure 7 – The root system of a sweet cherry tree

The illustration shows the root system of a 12-year-old sweet cherry tree on the low-growth-induced rootstock Gisela 5. The majority of the fine roots are above a depth of 40 cm. However, the roots penetrate up to 1 m deep into the soil (Photo: Martin Penzel)

When looking at the soil, it is important to determine whether the soil is sandy, silty or clayey.

Sand has a low water retention capacity and therefore low nutrient availability. A site with low rainfall can therefore quickly become a marginal site for fruit trees. Improving the soil by adding suitable mineral and organic substances is recommended in this case.

Soil improvement measures are also helpful in very clayey soils. Clayey soils are vulnerable to soil compaction. This means an insufficient pore structure with a low soil air content and therefore poor water availability. Heavy soils warm up more slowly. The proportion of dead water, which is not available to plants, is high here. The silty soil has many positive properties of the clay and sand fraction and is therefore less problematic.

However, the most favourable soil textural class for establishing an orchard is loam. Loamy soil provides a fertile basis for a sufficiently good supply of plant-available water and nutrients.

Consequently, if the site has loamy soil, there will be the least restrictions on establishing or maintaining an orchard. This type of soil is very suitable for orchards and buffers any less suitable parameters at the site.

The importance of soil-improving measures has increased due to more frequent water shortages. The soil properties (soil type) should therefore be determined by soil analysis. Test kits can be used for soil analysis. They are carried out by soil laboratories, specialist gardening companies and various providers on the internet.

The results of the soil analysis provide information on which parameters need to be improved. An overview of soil-improving measures for planting, in the eaves area and grassland is given in chapterIII.

Additionally, to determine the soil texture, other parameters should be examined. These include the humus content, total nitrogen, the C/N ratio, phosphate, iron, potassium, molybdenum, zinc, manganese, copper and boron (Schliebner et al., 2023).

The pH value is another important indicator that can be used to derive information about the location and any necessary measures for soil improvement. Whether the soil is more acidic, neutral or alkaline influences nutrient availability, soil life activity, crumb structure and thus plant growth (Planatura, 2025).

For most fruit trees, a pH value between 6 and 7 is optimal (Cornell College of Agriculture and Life Science, 2025). If the pH value is low, a galvanized vole basket can be used, as corrosion progresses quickly enough (see page42)

5. Cardinal direction (slope length & position within the slope)

If the site is inclined, the direction of the slope plays a decisive role due to the sunshine duration and intensity.

Facing north has the advantage that water does not evaporate as quickly, as there is usually no direct sunlight. Due to climate change, the phenological calendar starts earlier in many places. This is another reason why a northern location is now advantageous. This is because the lower sunshine duration delays the start of the vegetation phase and frost-vulnerable flowers open later.

The orientation of the slope towards the east means that in wind-exposed locations, drying and very cold winds can hit the fruit trees unhindered and cause damage.

The south can meanwhile be alimiting location factor. High temperatures and increased risk of sunburn on the surfaces of the plants can thwart the plan to establish an orchard. In the case of very long and elongated slopes, the drainage of water from orchards can play an important role. The slowing down of water runoff and its storage should be encouraged.

In Germany, the main wind direction is west. Aligning the sloping orchard area to this wind and weather side may require adjustments to the surrounding area. So-called nurse planting and hedges can be beneficial here (see page 37).

6. Slope

In addition to the alignment of the slope, the degree of inclination is also important.

A slope of up to 5 % can be classified as problem-free or of little influence. In the range between 5 % and 10 %, the significance of surface runoff increases. In the case of pre-compacted or already very dry soils, heavy precipitation events can result in the water not remaining in the area and being available to the plants. This water runs off unhindered and may even cause erosion damage to the plant. Appropriate terracing of the terrain can help here. Surface compaction should also be avoided.

From a slope of 10 %, the water must be collected, stored and made available to the plants at the appropriate time.

Despite these measures, the establishment of an orchard can fail in unfavourable southern exposure and unfavourable soil conditions. Not all sites that were suitable for planting 20 to 30 years ago are still suitable today.

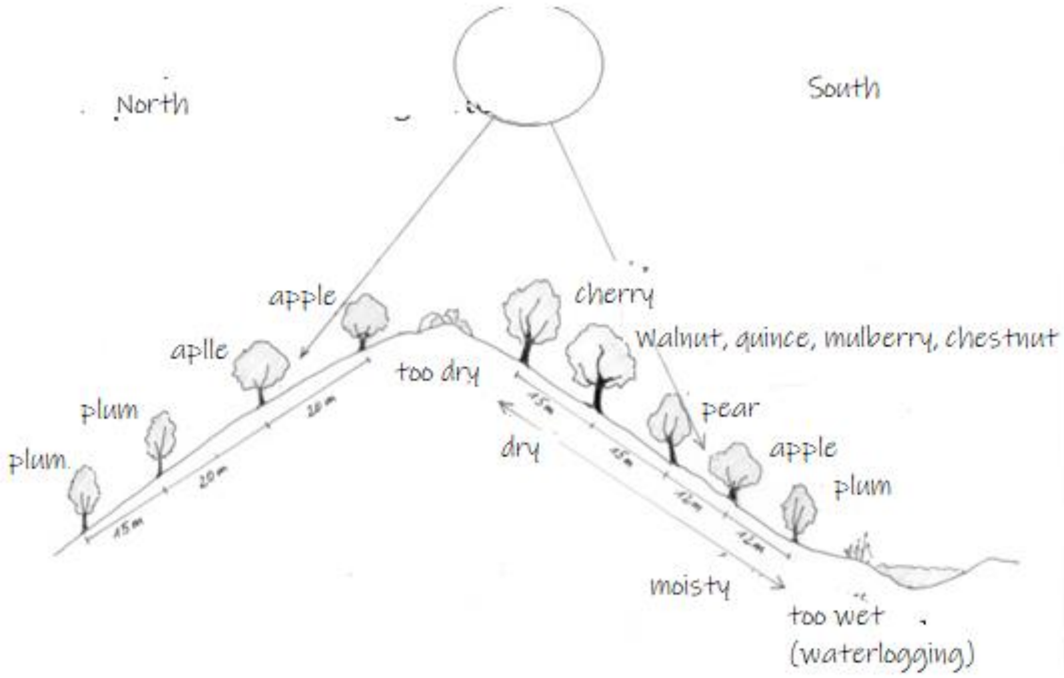


Figure 8- Direction, slope and choice of fruit species

7. Worksheet: How to approach a location

This sheet is a guide to help you consider the necessary parameters when approaching a meadow orchard. It can be used to

a) plan the creation of a new orchard meadow or

b) to plan maintenance measures on an existing orchard (including new plantings).

Such an approach includes obtaining abiotic factors in advance (e.g. climate data, soil samples) and approaching the orchard on site. Measures can be derived from the collected data. These measures are primarily described in the following chapters.

Filled in by:				Date:		
Abiotic factors/character of the site						
Communal district:	Area size (ha):		Height above sea level (m):	Land-parcel-nr.:		
Soil texture (proportions of sand, loam, clay, silt) and, if known, other soil quality parameters:						
Homogeneous distribution of this soil properties at the site: *See site plan for additional information				☐yes*		☐ no
Main precipitation period (months, mm):			Dry periods (months, mm):			
Soil horizon thickness (cm):	pH – value:		Peak precipitation event (mm in 24h):			
Annual precipitation total (mm):			Easements (e.g. underground lines, overhead lines) *See site plan		☐yes*	☐ no
Occurrence of special types of precipitation (hail, snow), damage to vegetation:			Special areas of conservation, special protection areas:			
Main wind direction	Open position towards the main wind direction :				☐yes*	☐ no
Biotic Factors						
Beekeeping *See site plan	☐ yes*	☐ no	Flowering period - start and end (also consider food plants for insects):			
Pollinating fruit varieties:			Other pollinating animals:			
Number of trees:			Composition of tree fruit species (number of trees):			
Arrangement of trees (e.g. square, triangle):			Distance between trees (m):	Gaps to fill with young trees (number):		
Number of young fruit trees (up to the age of 15)	Number of trees in yield phase:			Number of trees in maturity:		

General condition of trees (vitality assessment, pests like mistletoes):	Alien growth (e.g. seedlings, root suckers):
Main use of the orchard (e.g. self-sufficiency, part-time farming)	Grassland use (e.g. nature conservation habitat, grazing, mowing)
Surrounding use (e.g. distance to forest, field, road):	Slope > 5 %: *See site plan ☐yes* ☐ no
Main slope direction (exposition):	Slope length:
Machine suitability (embankment, clearance profile, headland):	Cold air formation (obstacles to runoff):
Interviewing the farmer (history of the site, experiences):	
Measures to improve the location in terms of climate resilience	
Unsuitable fruit tree species:	Suitable fruit tree species:
Soil improvement measures (e.g. mulching, fertilization, planting of shrubs):	
Creation of habitats (structures for beneficial animals):	
Wind protection measures (e.g. hedges)):	Use of nurse planting (e.g. support plants such as oleaster):
Soil modelling such as terracing and ditches (retention and drainage):	
Special plant qualities (e.g. annual heisters):	Use of seedlings (e.g. on-site grafting of seedlings):
Evaporation protection measures (e.g. mulching tree pits, planting hedges):	Use of bark additives (e.g. painting the trunk)
Special pruning measures (e.g. preservation of shading structures on the tops of strong branches):	

III Water management & nutrient management

Water is the key to vital trees. A tree can only grow tall and grow old if sufficient water is available. To remain healthy, a tree must be supplied with enough nutrients, which it absorbs through its roots.

The German scientists Monika Möhler and Martin Penzel describe the effects of reduced water availability in a research report on the irrigation of sweet cherries:

"With decreasing soil water content down to 30% of the usable field capacity, the transpiration rate of herbaceous plants and trees changes only slightly (Ritchie, 1981; Sinclair et al., 2005). With a further decrease in soil water content, the transpiration rate of the leaves of deciduous trees decreases linearly due to the closing of stomata (Sinclair et al., 2005). This reduces the exchange of water vapour between the tree and the atmosphere, which, however, is also accompanied by a reduction in the assimilation rate of the leaves (Rieger et al., 2003).

In various Prunus species, a reduced assimilation rate of the leaves, triggered by a reduced soil water content, led to a decrease in shoot growth after 14 - 22 days (Jiménez et al., 2013). A low water supply of cherry trees also limits the water transport via the phloem into the fruit, which has an influence on their daily growth rate and consequently the fruit mass at harvest (Morandi et al., 2018)." (cited in Penzel & Möhler, 2023).

The research report of Penzel and Möhler looks at the water requirements of fruit trees from the perspective of commercial fruit growing.

Irrigation is easier to implement here than in orchards. The impact of water shortages on the vitality of trees in orchards, which in contrast to trees in plantations reach an advanced age, is often much more fatal.

Forecasts assume that the average annual rainfall in Central Europe will remain the same, but that the seasonal distribution will change. In the first half of apple fruit development, the amount of precipitation has already decreased somewhat, while it has increased in the second half, albeit with fewer but heavier precipitation events.

1. Soil preparation: healthy soil is the basis for healthy trees

When you think of water management, you might immediately think of a water tank and the number of watering cans needed to get a tree through dry spells. However, good water management does not start with collecting and making water available, but with maintaining or restoring water-storing soils.

In recent years, there has been a growing realization in fruit tree care that it is necessary to focus not only on the treetop but also more on the soil. This is because the right supply of water and thus nutrients is the basis for healthy root and leaf growth and therefore also for disease resistance (Decker, 2024). In combination with a drought, a lack of nutrients can even be life-threatening for a tree (Schliebner et al., 2023).[1]

[1] Water is also crucial for controlling black bark blight (*Diplodia*), one of the most serious fruit tree diseases that have taken hold in many places as a result of climate change. The German pomologist Hans-Joachim Bannier assumes that healthy trees will not be attacked by bark blight (Bannier, 2024).

Humus-rich soils are therefore key to the long-term preservation of orchard meadows: Humus can store three to five times its weight in water. Humus increases the pore volume in the soil. As the humus content increases, so does the proportion of water available to the plants (Grundler, 2023). Healthy soils also resist erosion, which minimizes the risk of nutrients being washed out (Schliebner et al., 2023).

Measures can be applied at three levels:

- At the planting stage,
- below the crown, i.e. below the drip line,
- on the entire grassland area.

1.1 Promotion of nutrient-rich soil while planting

a) Compost soil and other organic material

The soil can be improved by adding organic material to the planting hole.

This increases the tree's ability to absorb water and store nutrients and makes it easier to grow roots after planting. It is important to note that organic material, mixed with the soil from the planting hole, should be placed a maximum of 15 cm deep into the soil (Pomologen-Verein, 2023).

Other arborists recommend (instead of compost) adding effective microorganisms, horn shavings, hair meal or molasses pellets to the top layer of soil. A dried mushroom substrate is also suitable both as a planting hole addition and as a covering material for the trees. The mushroom substrate, also known as “Champost”, not only serves as a nutrient supplier but also as a food source for soil organisms (Bund Deutscher Champignon- und Kulturpilzbauer e.V., 2021; European Commission 2021).

b) Biochar

Terra Preta is a concept that originated in the Amazon. Indigenous people enriched the soil with a composted or fermented mixture consisting of plant residues, dung and human faeces and containing (vegetable) charcoal from the hearths. Through centuries of cultivation, black earth soils developed, sometimes over a meter deep.

Modern vegetable charcoal is produced by pyrolytic carbonization of vegetable raw materials at high temperatures (400 - 750 °C). A traditionally very common form is charcoal.

Biochar is an ideal habitat for microorganisms. It can be used to increase nutrient and water retention in the soil. Soil aeration is improved, greenhouse gas emissions are reduced, pollutants are bound and humus formation is promoted.

However, despite the benefits that the application of biochar can bring, negative effects on environmental media such as soil, soil organisms and water are still difficult to predict. This is because the biomass used to produce biochar is dependent on the production conditions, in particular the pyrolysis temperature. As there are no uniform or fully researched standards for the production of biochar, success cannot be guaranteed when it is applied (Xiang et al., 2021). There is still a need for research (as with other innovative ideas for adapting to climate change as well).

c) Mycorrhiza

The symbiosis with mycorrhizal fungi is of enormous benefit to the tree. Mycorrhization generally increases drought resistance. Nutrient uptake is also increased, as the fungal threads increase the plant's root network. By storing antibiotics and tannins in the fungal mycelium and the plant, the trees are also better protected against diseases and pests. As the fungal threads hold the soil particles together, the soil structure is also improved and erosion resistance is increased.

Mostly, young plants from tree nurseries have already formed symbioses with mycorrhizal fungi, as these have already become established there as a result of many years of cultivation. If you want to be on the safe side when growing plants of unknown origin, you can add mycorrhizal granules directly into the planting hole or sprinkle them under the root ball.

1.2 Support of the tree pit

In traditional fruit tree care, the focus on the tree pit ends after the juvenile stage. A tree pit is recommended until the 4th to 7th year of growth (Pomologen-Verein, 2023). Permaculture, in particular, is the origin of concepts in which long-term plant communities are promoted on a tree pit. Unfortunately, there are no scientific studies on how these plant communities affect tree health. However, these concepts show one way in which tree pits or the crown eaves area can be promoted even after the trees have reached the juvenile stage.

a) The traditional way: A chopped and mulched tree pit

The grass is a competitor for nutrients and water for the tree. Therefore, the turf around a young tree should be removed to a depth of 5-8 cm. This simple measure can significantly increase the vitality of the young tree. This is particularly important in very dry conditions: the denser the turf, the more rainwater adheres to it (evapotranspiration). In addition, the grass has shallower roots than the tree itself. If there is only a little rain, water may not reach the tree itself and is immediately absorbed by the grassroots. This also immediately limits the supply of nutrients.

The standards of fruit tree care (developed by the German Association of Pomologists) advocate that the size of the tree pit should be oriented towards the size of the drip line. The depth of the tree pit should be limited to 5 cm to avoid root damage (Pomologen-Verein, 2023). When removing the turf and loosening the soil around the trunk with a sharp hoe, care must be taken not to damage it. A watering ring should then be created around the tree pit. This can be easily achieved by placing the turf upside down as a small wall around the tree pit. The Thuringia Orchard Action Plan recommends a diameter of 60 - 70 cm and a capacity of approx. 20 liters (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022). Due to intensive evaporation, some practitioners assume that a tree pit should hold at least 40 litres per watering cycle.

The tree pit can now be supported in a variety of ways so that water and nutrients are optimally made available to the tree. The German standards of fruit tree care recommend adding compost to the tree pit to support young trees with moderate vitality. If young trees have not yet reached an average annual growth of over 60 cm after three years of growth, the tree pit should be covered with a layer of compost approx. 5 cm high (about one wheelbarrow per tree) (Pomologen-Verein, 2023). Lime can also be used to fertilize the tree pit (Golde, 2023). At high pH values, gypsum can be used as a fertilizer instead of lime. This promotes the tree's calcium supply and improves the soil structure without additionally increasing the pH value in alkaline locations.

It is also beneficial to cover the tree pit with mulch. Mulching not only provides nutrients but also keeps the soil moist, reduces evaporation and makes watering much more effective. Soil temperature and temperature fluctuations are lower under a mulch cover of the tree strip than in uncovered soil. This can further reduce the irrigation requirements of fruit trees (Penzel & Möhler, 2023).

Mulching the tree pit can not only increase the vitality of the trees but also their yield. This is shown by a German multi-year trial on the yield of sweet cherries. The results of the research project showed that the use of mulch covers on the tree strip increased the yield by an average of 2.4 kg per tree compared to a control variant without mulch cover and irrigation. The highest tree yields were achieved with grass cuttings as mulch cover (ib.).

When selecting the mulch material, care should be taken to ensure that it does not bind too much nitrogen (e.g. bark mulch). If nitrogen-absorbing wood chippings are used, a handful of horn shavings should be added (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022).

Leaves, hay or grass cuttings are more suitable. Grass that has been mown early in the year is particularly suitable. The C/N ratio is particularly favourable here. If the grass was mown late in the year or straw was used, rock flour should be added to the mulch material (Schliebner et al., 2023). Rock flour enriches the soil with minerals and trace elements. In comparison, horn shavings are an organic slow-release fertilizer for the addition of nitrogen.

A mulch combination of horse manure (low salt content) and a cover of wood chips is also possible, which allows fertilization/mineralization and soil cover to be combined well.

b) If vole pressure is high: the chopped and open tree pit

A well-mulched tree pit not only replaces several cans of water. A loose, vegetation-free soil is also extremely unattractive to the vole. However, when deciding if to mulch or not to mulch a tree pit, it is important to weigh up which is the lesser evil: the root damage caused by the vole or the increased drought stress of a tree pit that is not mulched. If the tree pit remains free of vegetation, it is all the more important that it has a watering trough so that water runs towards the trunk and not simply away from it.

c) The alternative way: Planting of the tree pit a la permaculture

The planting of tree pits is a measure that has rarely been used in orchards so far. However, there are numerous examples of this in permaculture literature.

One example is "Alte Mühle Gomnigk". The forest garden project south of Berlin (Germany) brought the thinned-out meadow orchard back to life example with the help of planted tree pits. Traditional planting methods have failed due to the very dry and sandy site. Therefore the gardeners applied permaculture. Strong-smelling perennial rings of mint, radish, Rhine fern and oregano were planted on the tree pit to scare voles away. At the same time, the trunks were naturally shaded in the hot summer months, making a coat of white paint up to the height of the perennials unnecessary.

A completely different location is the Austrian "Krameterhof" at an altitude of over 1.100m. At that farm, the agronomist and permaculture teacher Sepp Holzer recommends lupine, honey clover, alfalfa clover and broom to be planted together with his fruit trees (Holzer et al., 2012)

Planted tree pits appear to have great potential, which is why their practicability in the management of extensive orchards should be tested.

A study carried out in Poland also confirms the positive effect that a living mulch cover of peppermint (*Mentha × piperita*) or lady's mantle (*Alchemilla mollis*) can have on the trees. The study indicates that the biodiversity in the area could be significantly increased compared to mowed control areas. The positive influence of the planted tree pits on root growth was significant in the trial (Mia et al. 2021).

A planted tree pit can also prevent voles. Strongly scented perennials (e.g. crown imperial (*Fritillaria imperialis*), garlic (*Allium sativum*) or sweet clover (*Melilotus sp.*) (NABU 2024)) or daffodil (*Narcissus sp*.) and onions (*Allium cepa*) (Curtis et al., 2002) can scare voles away. Research is also currently being conducted into whether common ground ivy (*Glechoma hederacea*) can deter voles (Bodenseestiftung, 2024).

Figure 9 - Planting tree pits and mulching

In the City Orchard in Bratislava, the soil was significantly improved by applying bark mulch and compost. Previously, the soil at this location was heavily compacted. The mulch also ensures better water retention. Care must be taken to ensure that the tree pit in the immediate area of the trunk is kept free of vegetation. Herbaceous plants can grow as ground cover next to the tree at a distance of one meter. As long as they are not strong nitrogen consumers, they will not compete with the tree. Photo: M. Penzel

However, it should be noted that other plants can also become competitors for nutrients and water for the trees. In some cases, these effects on the trees have not yet been sufficiently scientifically studied. If the tree pit is planted as soon as possible after planting the tree, both root systems can adapt better to the competitive situation. If perennials are planted too late, their establishment is made more difficult/impeded as the tree roots have already spread everywhere.

d) Mineral soil improvement through rock flour

Based on soil analysis, the right rock flour can be applied to the tree pit or dripline area. Due to their fine grain size, rock powders bind a lot of moisture and existing organic nutrients. Rock flour contains many mineral salts and trace elements.
The guide “Orchard Meadows in a changing climate” (Schliebner et al., 2023) provides an overview of which rock flour is the right one, based on a soil analysis.

e) Mycorrhiza

When the soil is subsequently inoculated, the root zone is inoculated with mycorrhiza granules via boreholes, similar to the application of biochar. In this case, however, the boreholes must be much narrower. The application of mycorrhiza is mainly practised in areas with frequent soil exchange (e.g. urban trees) and is recommended for poor, depleted soils and weakened trees. In combination with the pore-rich biochar, the habitat for mycorrhizal fungi can be positively influenced. Phosphorus in particular can be made available to the trees this way.

1.3 Nutrient and Water management on the entire grassland

a) Avoiding soil compaction

The soil must not be compacted so that it can store water. Driving on grassland with heavy machinery must be avoided, especially when it is very wet. Nevertheless, even in the name of tree care, we sometimes see unprofessional practices: Orchard meadows where excavators are used for planting in very wet conditions or the removal of cuttings with chippers and heavy machinery on muddy ground. In some places, tree care is also becoming more challenging due to climate change: where just a few years ago the ground was almost completely frozen in winter, today it is mainly damp and impassable in the winter months.

b) Mulching the grassland

It would be appropriate to state that mulching is a new management measure used in traditional orchards and was not part of traditional management practices. When mulching, the mown material is left on the meadow and not removed. As a result, the grass cut serves as a natural fertilizer. Therefore, from the perspective of a tree, mulching is beneficial as it supplies the tree with nutrients.

However, from the perspective of species diversity of grassland vegetation, attention must be paid to the frequency of mulching. According to Gaisler et al. (2019), mulching once a year inhibits the establishment of woody plants but does not prevent the spread of weedy species. Mulching once a year is considered the least suitable frequency of this measure, as it has a similar impact on grassland vegetation as ceasing management altogether. Mulching 2–3 times a year has a more favourable effect on the species richness of grasslands (Pavlů et al., 2016; Gaisler et al., 2019).

Therefore, there is a kind of conflict of interest, between the grassland and the tree, that needs nutrients. If you look from the perspective of species-rich grassland, it is necessary to understand that in the long term, mulching does not replace traditional management, such as mowing with removal of phytomass (typically two mowings) or extensive grazing (Römermann et al., 2009). Hence, alternatively, mulching can be used only along rows of trees or under the tops of trees only (Schliebner et al., 2023: 17).

c) Mowing

Hay meadows were traditionally mowed twice a year, while drier types (with lower phytomass production) were mowed once a year. After mowing, cattle grazing typically followed (Žarnovičan et al., 2020). This type of management ensured species-rich grassland. A healthy biotope, in which beneficial insects were encouraged, also minimized the pest infestation of the trees. Vole pressure was also lower on mown meadows.

However, how orchard meadows are managed has changed considerably in recent decades. The industrialization and intensification of agriculture have led to orchard meadows often being mowed and grazed insufficiently or not at all.

It is therefore in the interests of trees and grassland to promote traditional rural management of orchards. The time of mowing, mowing intensity (gradually moving smaller areas with a time interval) and technique of moving depends on the respective site conditions and vegetation. These points also determine the biodiversity of the meadow.

d) Grazing

Grazing can have many positive effects on orchards. The trampling of the animals reduces vole pressure and bush encroachment can be prevented.

The exact effect of grazing on the respective location depends on the feeding behaviour of the respective grazing animal and the type of grazing (e.g. standing pasture, rotational grazing, portion grazing) as well as any additional mechanical pasture maintenance management.

Mob grazing is particularly promising in terms of soil and climate protection. This form of grazing involves many animals grazing a small area for a short period. The grassland afterwards enjoys a long rest period. In this way, mob grazing serves to build up the soil in dry areas with the help of animals. They are supposed to trample down large grazing residues of more than half of the vegetation. Mixed with manure, the resulting mulch layer protects the soil from drying out and erosion and can be a valuable source of carbon (Netzwerk Mob Grazing, 2024).

e) Planting of hedges (and other groves)

Local adaptation through tree and shrub hedges (e.g. fruit polyculture) reduces the damage potential of strongly drying winds or slows down the effects of extreme weather events (intensive precipitation in combination with storms). Hedges should preferably be planted on the east and west sides of the orchard. These must maintain an air permeability of 40 - 60%, as otherwise, the fungal pressure on the site could increase (Schober & Fleckstein, 2024).

Hedges that improve the quality of the soil can also be planted. Planting shrubs such as *Elaeagnus* and black karagana (*Caragana arborescens*), for example, can help to build up humus. This is because the nodule bacteria on the roots of these plants bind the nitrogen in the air. In this way, they ensure their nitrogen balance and at the same time make nitrogen available to other plants if the bushes get pruned. At the same time, both oleaster and pea bushes are valuable sources of food for pollinators (Stattwerke e.V., 2024a; Stattwerke e.V., 2024b).

2. Further measures to keep water

a) Reduction of the space between plants

The standard spacing between fruit trees is 10 – 12 m. This means that the tall trunks do not get in each other's way either underground with the roots or above ground with the branches. Mechanical cultivation of the area is easily possible. To create more shade and therefore less evaporation, some practitioners now advise closer plant spacing. The spacing varies depending on the type of fruit. However, one disadvantage of smaller plant spacing is the associated greater susceptibility to scab (Schober & Fleckenstein, 2024) and more difficult mechanical processing.

b) Nursing trees/ supporting trees

Nurse trees are a temporary support planting for the establishment of new orchards. Poplars (*Populus sp.*), rowan trees (*Sorbus aucuparia*), alders (*Alnus sp.*) or even birches (*Betula sp.*) can be planted directly next to young fruit trees. If they become too large and compete too strongly with the fruit tree, they must be removed from the location. Otherwise, the effect can be reversed and both trees will compete for water.

A research project is currently conducted in Baden-Württemberg (Germany) to investigate the effect of nurse trees on climate-resilient orchards. The project assumes that nurse trees can have a positive effect on fruit trees by fixing nitrogen and making it available to the target tree. This effect can be explained by the fact that fine roots are constantly renewed. The dead roots are decomposed and serve as a source of nitrogen for the tree. The dense planting also leads to the formation of fungal networks in the soil, which in turn is important for the carbohydrate and water supply (Schütze, 2024).

Practitioners in the fields of agroforestry and permaculture attribute further positive effects to nurse trees. For example, the foliage can create a microclimate that has a positive effect on the growth of the fruit tree. The nurse tree also helps to prevent sunburn on the surface of young plant parts. At the same time, habitat structures are developed that encourage beneficial insects and thus promote natural plant protection and pollination.

c) Terracing

There are numerous examples of terracing in permaculture farming and agroforestry. Sepp Holzer writes about this in his permaculture standard work: “Terracing the terrain counteracts soil erosion on slopes. Valuable humus is not washed away but retained on the slope. Terraces store and retain moisture: precipitation and melt water is available to the plants much longer.” (cit. Holzer, 2012).

When planning plantings, key line design is a particularly good way to keep rainwater available to the fruit trees in the best possible way. Small ditches can be created along the key lines to slow down the rainwater. Heavy rainfall thus seeps into the ground more slowly and is not washed directly into the valley (Skala & Skala, 2023). There are also other ways of soil modelling, such as backfilling, that can enhance the effects of water drainage or storage as well.

d) Water reservoirs and irrigation systems

Young trees in particular need additional water to develop healthily. With increasing drought, this may mean that it is not enough to let the rain do all the work. Water either needs to be trucked to the meadow in tanks, drip irrigation needs to be installed or water reservoirs should be created on-site. Whether underground cisterns can be installed or wells drilled depends not only on the natural conditions on site but also, at least in Germany, on building and nature conservation laws. Rainwater barrels and the abstraction of drinking water are still common options in allotment gardens but are difficult to implement on orchard meadows with increasing size or distance to developed infrastructure. The same applies to drawing water from natural bodies of water (rivers, lakes). Whether this is permitted and compatible with water protection laws must be clarified in advance. This is because not only trees but also rivers and lakes are under stress during drought and high temperatures.

Automatic irrigation of an orchard remains the last resort due to the financial outlay, legal hurdles and competition for the scarce resource of water. First of all, it is important to plan the orchards well and to ensure water-retaining soils through good nutrient and grassland management.

IV Planting of fruit trees

1. Planting a fruit tree – Step by step

The increasing drought stress has an impact on how, when and where planting can take place. In many places, springs and summers in particular are drier (European Environment Agency b). The planting shock is therefore much greater. The following recommendations can therefore be derived for climate-adapted planting:

1. **Approach the location first, plant afterwards:** Unfortunately, it is a bitter reality that not all locations are suitable for planting fruit trees anymore. The right location must be chosen carefully, paying particular attention to the quality of the soil and the direction of the slope. Planting correctly does not simply mean digging a hole somewhere, but understanding the location where you want to plant a tree and deriving the right measures from the conditions found (see chapter .... Site planning)

2. **Choose the right rootstocks, varieties and types:** Variety, species and rootstock must suit the location. Research projects are currently in progress in various regions of Europe to renew a variety of recommendations for specific regions under changing climatic conditions. The results should be considered when choosing the right trees.

3. **Pick a good quality:** Above all, good quality means that the tree is healthy and undamaged. The fine root network should be well developed and the leading branches well attached. The trunk must be straight and have a small size at the time of planting. This is because the “planting shock” resulting from root loss and changed site conditions is significantly greater for young trees in larger classifications than 8-10/2x transplanted (8-10 cm at 1 m trunk height and 2 x transplanted). These trees grow less well and require more intensive care (Pomologen-Verein, 2023). A good root system should also be present.
   The “Handlungskonzept Streuobst Thüringen” (Thuringia orchard action plan) specifies further points on the quality of planting material for standard trees on orchard meadows (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022):
   - Bare-root stock should be used instead of root balls or potted stock. These trees grow faster.
   - The grafting point should be relatively high (about a hand's breadth away from the root collar) and must be well-grown.
   - The tree should not have been grafted more than twice in the nursery and should have a trunk size of a maximum of 8-10 cm at a height of one meter.
   - Fertilization during cultivation should be low. This can encourage the trunk to grow thicker and reduce planting shock.
   - The trunk height up to the crown base should be at least 1.8 m, preferably 2 m.
     The angle of inclination of the leading branches to the trunk should be more than 35 and less than 45 degrees.

4. **Choose the right time:** In most European regions, planting should only take place in the fall. This can significantly reduce the planting shock. This is because planting is usually followed by a period with more rainfall and the roots can initially be well nourished. At the same time, the soil temperature is still high enough to allow root growth. This allows new roots to form before the start of the dry period. If a later planting is unavoidable, we recommend a strong pruning in March/April.

5. **Water the tree before planting:** To give the tree a good start, it should be placed in the soil as moist as possible. Before planting, it can stand for up to 24 hours in a bucket filled with water. Under no circumstances should the roots lie naked in the sun. It should always be covered with soil or at least damp cloths.

6. **Dig the planting hole:** The depth of the planting hole must be adapted to the soil and precipitation conditions. Planting holes should be planned larger rather than too shallow to ensure a soil volume that can be rooted through quickly (Golde, 2023). It is also advisable to loosen the bottom and edges of the planting hole to avoid a "flowerpot effect" (ibid.).
   A deeper and wider planting hole (at least 1-1,5 m in diameter and 60 to 80 cm deep) is better loosened and aerated. If a vole basket is used or planted in a gravel ring, the hole must be correspondingly larger (see page 42).

7. **Insert the plant pole:** The planting pole is inserted into the planting hole against the main wind direction. Robinia stakes or posts made of oak heartwood or larch have proven themselves due to their particular robustness. The distance between the trunk of the tree to be planted and the post should be around 10 cm (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022).

8. **Prune roots and branches**: Injured and torn roots must be cut smoothly before planting. This stimulates growth and the formation of fine roots. Rotten roots are cut back to the healthy tissue so that the white root interior is visible. Cuts must point downwards (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022).
   The branches are also pruned as this is the only way to achieve a balanced crown-root ratio. If necessary, pruning can be carried out at a later date in the same season. This may be particularly necessary for very frost-sensitive shrubs such as almonds, mulberries or peaches, as the young branches could freeze back.
   In most cases, the crown must be shortened considerably when pruning, otherwise the excessive leaf mass volume cannot be adequately supplied by the roots. We recommend 1-2 shear lengths.

9. **Insert the tree in the hole:** Care must be taken not to place the tree too deep in the planting hole. After planting, the tree can be pulled slightly upwards so that the root neck is at ground level.

10. **Fill the planting hole:** When digging the planting hole, care should be taken not to mix the soil layers. The excavated soil should be sorted into 3 piles at the edge of the planting hole and after planting, the turf, topsoil and subsoil should be filled back into the hole in the

correct order. Already during planting, the soil can now be improved by adding organic material (see page 31).

11. **Protect the trunk from frost and sun:** Bark can freeze during frosty nights and crack on the north side if the opposite side is exposed to the low winter sun during the day. Whitewashing young trees is a proven measure to prevent this problem. Lime, clay paint or special trunk protection paint can be used as a base. The effect of all paints should be checked annually and reworked if necessary. Alternatively, bast mats, reed mats or plastic sleeves (Anti-Knabb) are available as trunk protection.

    Meanwhile, such a white coating is not only recommended in winter but all year round. This is because, in addition to frost cracks, sunburn and thus black bark burn (*Diplodia*), which is caused by the penetration of fungi on the damaged bark, is a serious problem for fruit trees. This means that more frequent painting up to the crown is recommended.

    Better shading of the trees can also be achieved by planting tall perennials in the tree disc or, in the case of older trees, with shrubs. Also, special pruning measures (see page 50) can support better shading of the trees.

12. **Tie the tree to the pole:** A good connection with the young tree is also important because storms are on the increase. The trunk is tied open with thick natural rope (e.g. coconut, sisal, jute). The rope should also be attached to the planting pole with a nail to prevent it from slipping (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022). The rope must also run up the trunk from the stake, as the tree is still settling.

13. **Protect the trunk from game browsing:** Bite protection must protect the trunk and branches. The trunk protection must be adapted to whether grazing animals or wild animals have access to the trees.
    It should also be taken into account that the tree can be still managed. Watering, chopping and pruning must be possible despite the trunk protection.

14. **Create and maintain the tree pit:** Unfortunately, this step is often forgotten when planting, although it can make a decisive contribution to the vitality and longevity of fruit trees. The care of tree pits is central to the water and nutrient management of fruit trees. On page 32 ff you will find a detailed description of various measures for tree pit care.

15. **Water the tree and above all continue watering:** Immediately after planting, a tree must be watered to sponge the fine roots and achieve a good connection to soil particles. The guide “Streuobstwiesen im Klimawandel” recommends 40, preferably 50 litres of water for this purpose (Schliebner et al., 2023).
    It is just as important that young trees are watered continuously, depending on the weather and the annual shoot. If this step is forgotten, in many places young trees have no chance of growing into vital old trees as the drought increases. It should therefore be clear before planting how (e.g. water tank, water reservoir on site) and by whom (e.g. tree sponsorships, municipal employees, tree care companies) watering can be realized and financed. The Thuringian action plan for orchards recommends 20 litres per tree every two weeks from the end of April to the end of August in the first year. From the second year onwards, watering should take place every 3 weeks, and every 2 weeks in dry weather (Thüringer Ministerium für Umwelt, Energie und Naturschutz, 2022). The guide also summarizes that the experiences

of the particularly dry summer of 2022 have shown that the volume of watering water must be increased to up to 60 litres per watering cycle during extremely long droughts (ibid.).The standards of fruit tree care advocate up to 80 litres of water every 3 weeks during drought (Pomologen-Verein, 2023).

2. The vole – a rising issue

Voles love the roots of young fruit trees and can damage them so badly that they do not survive the first few years of their life. If young trees are planted in meadows with high vole pressure, preventative measures should be taken to protect the roots. Various options can be considered before, during and after the planting of young trees:

a) Metal basket

A vole basket is a wire mesh protection that is placed around the roots when planting. It can be made yourself from close-meshed wire or bought ready-made. Both galvanized and non-galvanized baskets are available from specialist retailers. Both come with different advantages and disadvantages. The ungalvanized basket rots faster. It is therefore not a barrier for the spreading roots, but also offers the voles quicker access to the roots. Galvanized vole baskets last longer but can also damage roots.

The German organization "Hochstamm e.V." has compiled experiences with both galvanized and non-galvanized baskets. In a paper, the association summarizes that ungalvanized vole baskets do not offer sufficient protection. Even worse, galvanized baskets can damage root and trunk growth if they rot too slowly. This is particularly the case in sandy soils. The more humus-rich and acidic the soil, the greater the likelihood that a galvanized vole basket will decompose in time (Hochstamm Deutschland e.V., 2023). The compendium of the Hochstamm e.V. therefore recommends checking the pH value and humus content of the soil before deciding for or against a vole basket (ibd.).The basket should not be used in sandy-dry soils.

If you do not want to do without a basket due to high vole pressure on sandy soils, you must ensure that the planting hole and vole basket have a particularly large volume. As an alternative to planting in a basket, a type of wire tunnel can also be run around the roots. In this case, the wire tunnel must be inserted particularly deep (at least 60 cm) into the soil so that voles cannot reach the roots from below. This construction, which is open at the bottom, has the advantage that the taproots can grow undamaged.

b) Gravel bed

An alternative to the vole basket is a gravel bed or bed of mussel shells placed around the tree. Orchardist Kai Bergengrün recommends the following procedure (Hochstamm Deutschland e.V., 2023):

- Make the planting hole 20 cm deeper and wider than necessary.
- Fill in 10 cm of drainage gravel (16/32) mixed with crumbly soil (for soil sealing) at the bottom.

- Insert a template and secure it with staples, leaving 10 cm of space all around. Fill with gravel outside the template.
- Plant the tree inside the template. Then top up with another 10 cm of gravel at the root base.
- Fill the gravel with compost and use the remaining excavated soil to form a nice watering ring.
- Push the tree trunk protection through to the gravel so that no field mice can slip through.

c) Care of tree pit
The way the tree pit is maintained can encourage or deter voles. Various methods and the associated advantages and disadvantages are presented on page 32 ff.

d) Mowing and grazing

Many orchard managers have had good experiences with grazing and have seen a significant reduction in vole pressure after the area has been regularly grazed.

The constant trampling of the corridors scare voles away. Frequent mowing is also a problem for voles, which feel much more comfortable in an opaque grass cover.

There must be no retreats for the voles in the immediate area around the trees. This means that it must be possible for cattle to access up to 0,5 - 1 m of the trunk and that grass can therefore also be eaten around the trunk. Sufficient trunk protection must also be ensured (Pomologen-Verein, 2023). Alternatively, the vole holes can be stepped on (ibid. 50).

e) Natural enemies

In addition to domestic cats, the vole's predators include many wild animals: weasels, martens, foxes and birds of prey. These animals can be welcomed to the orchard, e.g. by setting up perches for birds, the creation of artificial fox dens or by encouraging natural hiding places such as rock piles and hollow tree trunks for weasels. The website https://wieselnetz.ch/de/ shows how small carnivores can be encouraged.

f) Noises and traps

Voles can be scared away by noise. This can be achieved by sticking open pipes into the ground and placing freely swinging bottles on top of them. Vole scarecrows, which produce underground sound waves when the wind blows, can also be bought ready-made.

Traps can also be set up. These must be checked regularly.

g) Selection of fruit variety

The choice of fruit species can also be decisive when vole pressure is high. For example, voles disdain the roots of walnuts or mulberries.

V Pruning

1. Tree assessment according to the revitalization model

The aim of “climate-robust” fruit tree care is to weaken the tree as little as possible through pruning. At the same time, the vitality and regenerative capacity of the fruit tree should be promoted. A large-crowned fruit tree is in a complex relationship with interactions with its location, vitality, stability, damage characteristics and usability. Recognizing this relationship as well as the situation and needs of an individual high-stem fruit tree and deriving vitality-promoting measures requires a high level of competence on the part of the orchardist.

The German Pomologists' Association has published “Standards of Fruit Tree Care - recommendations for the professional care of large-crowned fruit trees”. This publication is a set of rules that describes good professional practice for the care and pruning of high-stem young and old trees. The central point is the tree assessment (how to approach a tree?) based on the following parameters:

1. **Analyse the conditions of the fruit tree** using clear criteria and features regarding
    - vitality
    - stability, damage and injuries
    - productivity
2. **Identify management objectives, e.g.**
    - renewal of vitality
    - maintaining tree stability
3. **Define pruning intensity concerning**
    - foliage loss, or
    - branch diameter
4. **Selection of measures, e.g.**
    - thinning of crown
    - cutting back of the crown
    - minimum clearance profile e.g. for traffic

When assessing the impairment, the aspects of damage, stability and usability are generally subordinate to the vitality of the tree. The prominent position of vitality is particularly important concerning climate change: high vitality means good regeneration capacity and high tree health. In practical terms, this means, that statically endangered branches with low vitality are pruned very little or not at all. The main reason for the major role played by vitality is that pruning a fruit tree that is clearly or significantly impaired removes potential leaf mass. The tree lacks this leaf mass to form assimilates for revitalization. The leaf mass removed cannot be replaced in subsequent years, which accelerates the weakening of the tree.

The revitalization potential of a fruit tree can be determined by the budding development of the last one to three years. With the help of budding development (shoot growth), it can be divided into regeneration stages. The classification ranges from:

- high vitality
- normal vitality (no damage)
- low damage (ageing)
- considerable damage (aged)
- substantial damage

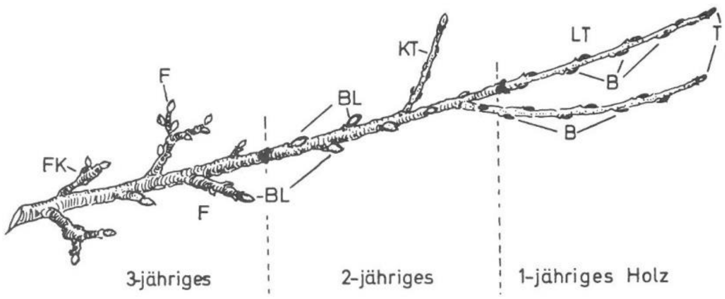


Figure 10- Budding development

source: Riess/ Späth 2001

LT	= Long shoot	F	= Fruit spur	B	= Leaf bud
KT	= Short shoot	FK	= Fruit bourse	BL	= Flower/fruit bud
		T	= Terminal bud		

The table on the next page shows a way of classifying the vitality of mature old trees. The regeneration stage model can also be used with other qualitative characteristics for trees in the crown development phase (young trees).

Regeneration capacity phase	RS -2	RS -1	RS 0	RS 1	RS 2
Assessment of vitality	substantial damage	considerable damage (aged)	low damage (ageing)	Normal vitality (no damage)	high vitality
Regeneration capacity	no longer given or secondary crown formation	uncertain (unlikely)	uncertain (likely)	given	given
Budding development in the last 3-5 years*	predominantly short spur buds almost no long spur buds no shorter long shoots no long shoots dying branches in crown periphery possible local long shoots possible (reaction to crown dieback)	mostly short spur buds rarely long spur buds almost no shorter long shoots no long shoots	many short spur buds moderate long spur buds rarely shorter long shoots almost no long shoots	moderate short spur buds many long spur buds moderate shorter long shoots moderate long shoots	occasional short spur buds moderate long spur buds many shorter long shoots many long shoots
Crown development	static / declining	static	static	rhythmically expanding / static	rapidly expanding

Table 5– Assessment of vitality (Source: POMOLOGEN VEREIN, 2023)

Taking into account other factors affecting stability (including tree fungi or the risk of branches breaking) and usability (including crown structure and overbuilding), a maintenance objective can then be derived.

In the case of young trees there are 2 maintenance objectives:

- Crown development prune
- Crown conversion.

For old trees, there are three maintenance objectives:

- Preservation as a habitat tree for dying or already dead trees (always focuses on the impairment of the crown function)
- Renewal (e.g. crown reduction with allocation of pruning intensity)
- Maintenance of the crown (e.g. thinning of the crown)

Measures for young trees include creating tree pits, watering or fertilizing (as described in the previous chapters.)

For old trees in the yield phase, crown shortening/shortening parts of the crown or thinning out the entire crown are suitable measures (taking into account the vitality and the form of the impairment). In the case of dying trees, the focus is on promoting species diversity on dead wood. Here, crown protection cuts to preserve habitat wood or habitat trees are suitable measures.

When determining the intensity of intervention, the corresponding regeneration stage plays a decisive role for old trees. If this is significantly impaired (RS-2), pruning cannot be carried out as the tree will no longer regenerate on its own and will be further weakened by the removal of potential leaf mass. If the vitality is significantly impaired (RS-1), the removal should not exceed 10 to 15 % of the leaf mass volume, which means that only very fine or fine branches (< 1 cm or 1-3 cm branch diameter) should be removed. If the tree shows positive revitalization in the year following the pruning, more intensive pruning may be carried out in a further pruning pass. If the vitality is slightly impaired (RS0) or vital (RS1), the pruning intensity can be between 15 and 30 % of the leaf mass volume. In the case of very vital trees, more than 30 % of the leaf mass volume can be removed.

This differentiated classification of vitality and the derivation of the intensity of intervention shows how central a profound tree approach is and how carefully a pruning measure must be implemented to strengthen the tree in its vitality and thus also in its resilience to the challenges of climate change.

2. Practical measures

a) choose the right pruning measures

The following pruning techniques are available for professional fruit tree care on old trees:

- Thinning of the crown via slender-pruning of a branch, via thinning of a branch, fruit wood rotation

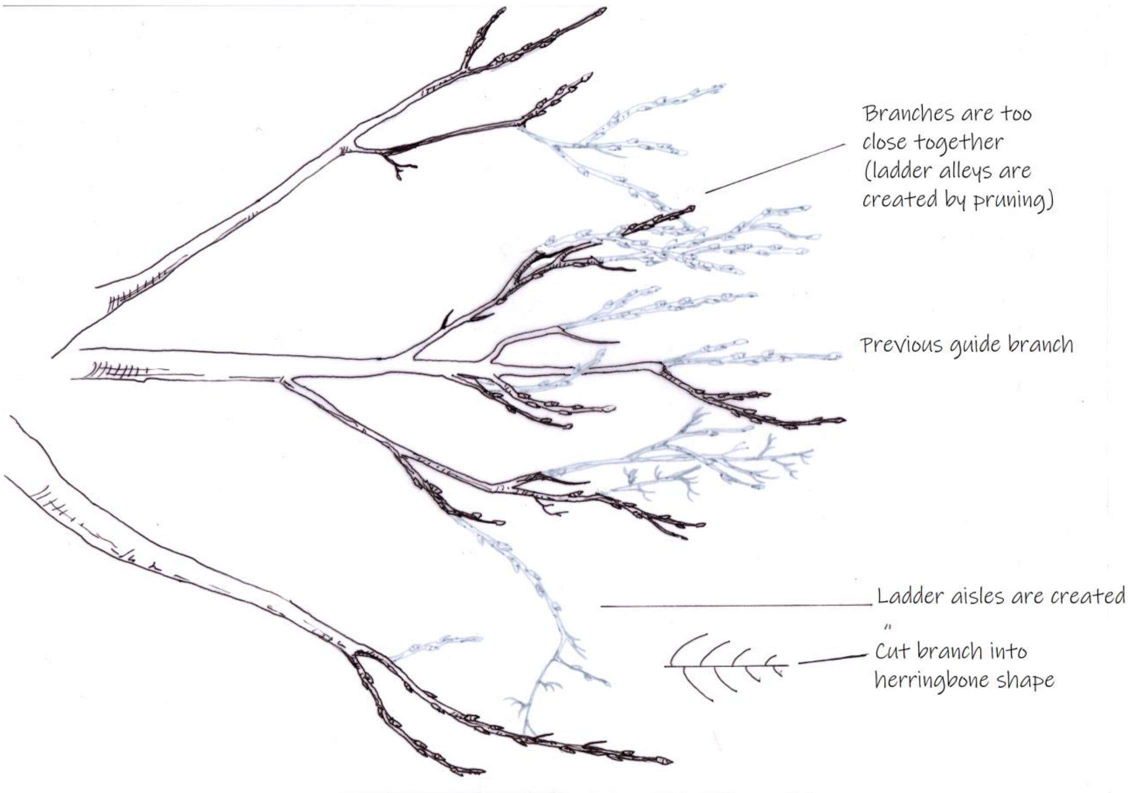


Figure 11 – Thinning of a side branch (Drawing: M. Heller)

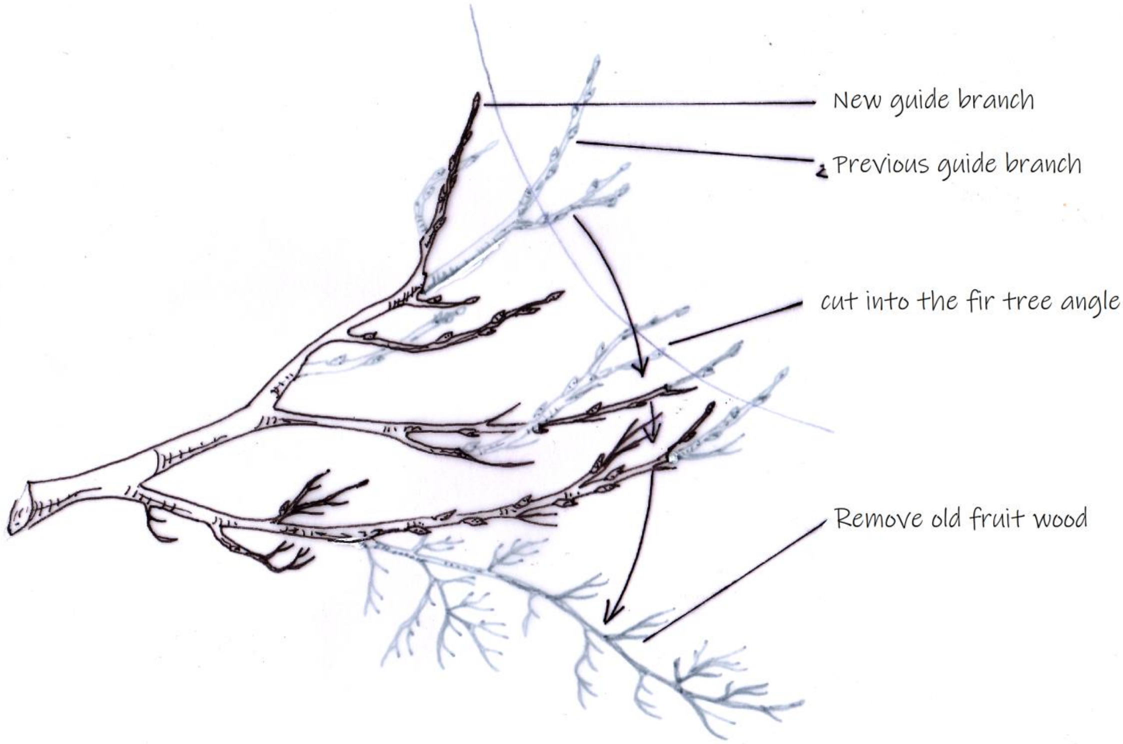


Figure 12- Fruit wood rotation (drawing: M. Heller)

- Crown reduction via diversion of branches,
- Mistletoe removal,

Figure 13- Mistletoe removal

The picture shows an apple tree with heavy mistletoe infestation, before pruning, immediately afterwards and two years later. Even with low vitality, strong pruning is better for the tree than allowing the mistletoe to spread further. Photo: M. Luft

- Deadwood removal for traffic safety or
- Pruning on one-year-old shoots.

If the young tree is sufficiently vital, pruning measures should be based on the chosen crown model (e.g. Oeschberg, spindle, tiered crown). Pruning must be carried out annually over the entire youth period up to the 15th year. Pruning is intended to prevent undesirable development. The crown elements are defined and the crown is built up in a statically sensible way. The branch rank order within and between the individual crown elements must be established or maintained. The shoots at the end of a branch are pruned on outward-facing buds.

b) Reduce pruning wounds

Every pruning wound is an entry point for wood-decaying fungi and other pathogens that weaken the tree. In addition, fruit trees are extremely bad wound healers. Wounds seal off and overgrow slowly. Larger cuts overgrow hardly or not at all.

The absolute wound diameter must not exceed 6 to 8 cm. The relative wound size at the base of the branch must not exceed 1/3 of the size of the branch below. If it is necessary to exceed the relative and absolute wound size, the cut must be made using a sufficient supply branch. The supply branch can be removed in subsequent years if the size ratio changes.

When pruning upwards or downwards, it is also important to ensure that the remaining branch is sufficiently strong so that it can develop properly and there is no supply shadow on the remaining branch. As a guideline, the diameter of the branch at the base of the branch should be at least 1/3 of the wound area of the remaining branch.

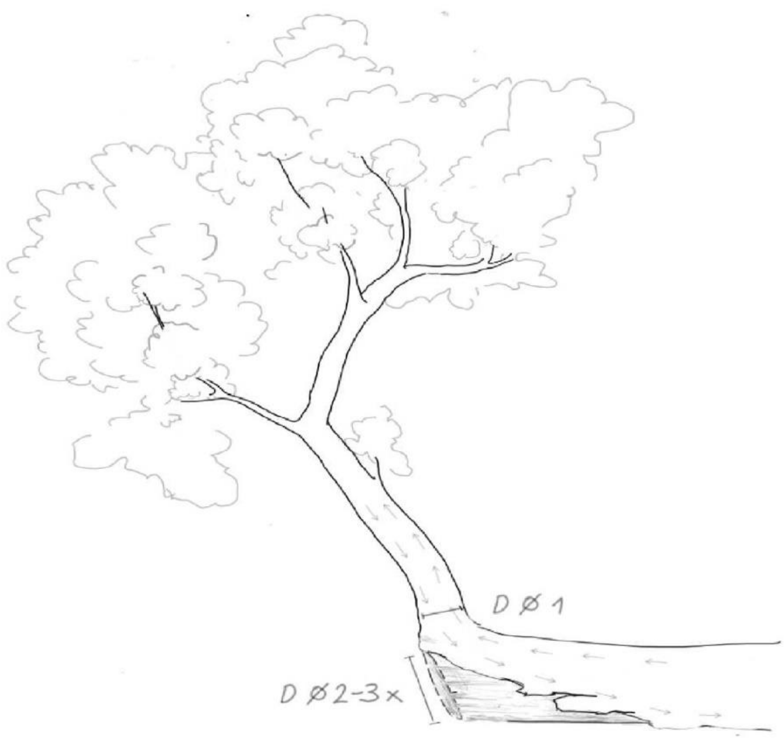


Figure 14- Supply shadow (drawing by M. Heller)

c) Shadowing key branches with leaves

Sufficient leaf mass is important for the formation of assimilates. Leaf mass is also important for good shading of structural branches (trunk centre, leading branches and permanently attached side branches) with leaves. This helps to prevent sunburn.

Even at moderate temperatures, temperatures of up to 50°C can develop in exposed areas, depending on the type of tree and the intensity of the sunlight. In young trees or trees with relatively thin bark, the underlying cambium, which is responsible for cell division, can quickly become damaged. The consequences are necroses, which are gateways for wood-decaying fungi or other pathogens. Pruning should therefore be carried out in such a way that no strong-sized and medium-sized branches in the upper third of the crown are permanently exposed to the sun. Topping is therefore not professional! Pruning should be carried out using slender or fruit wood rotation cuts in the periphery so that there are no large gaps in the sun. In addition, short shoots on side branches and other structural branches should be preserved as far as possible, as they provide direct shade.

d) Trunk protection

It is necessary to protect the still quite thin bark on the trunk of a young tree or the branch sections in the crown of an old tree that is spontaneously exposed due to pruning or branch breakage from sunlight and overheating. The German pomologist Hans-Joachim Bannier recommends self-greening the trunk by not removing short shoots (Bannier, 2024). At the same time, these short shoots act as a water pump and energy source that strengthens the tree. It is also possible for the tree to shade itself if the lowest side branches are not cut back too much (ibid.).

In addition to pruning, other measures are useful. This can be done by painting the trunk or protecting it with reed mats.

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